Developmental differences in the vulnerability to auditory distraction: children vs. adults

by

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Abstract

The thesis addressed whether there are developmental differences in the effects of auditory distraction on short-term memory among children and adults. The theoretical accounts and research addressed in the thesis highlight how rehearsal and attentional control play a role in the observed developmental differences. Rehearsal and attention do not work in isolation but rather interact with one another to enable successful execution of many different tasks (Elliott et al., 2016). One such instance of the interaction between rehearsal and attentional control is when short-term memory tasks are performed in the presence of auditory distraction (Hughes et al., 2007). Developmental research within the irrelevant sound paradigm has shown how rehearsal and attention can be affected by task-irrelevant sounds in different ways, how the efficiency of the two can determine distraction effects, and that the study of distraction is a window into the development of rehearsal and attentional control in children. Although there are different perspectives on the effects of auditory distraction, two accounts have dominated recent understanding. The duplex-mechanism account suggests there may be at least two functionally different types of distraction, one that is the result of interference with rehearsal and the other that is the result of attentional capture (Hughes et al., 2007). This account leads to predictions about the nature of the sounds and the characteristics of tasks that exhibit the most disruption (Hughes, 2014). The unitary account proposes that distraction is only the result of attentional capture and thus attributes less significance to the type of distracting material and task used (Elliott, 2002; Cowan, 1995). The weight of evidence so far is in favour of a duplex account of distraction (Jones, 1994; Jones & Macken, 1993; Jones, Hughes, Marsh, & Macken, 2008; cf. Bell et al., 2012; Körner et al., 2017). Rehearsal supports verbal serial short-term memory and is more vulnerable to auditory distraction wherein each token is different to the one preceding it (changing-state sounds such as *A*-*B*-*A*-*B*-*A*) than a steady-state sequence where the tokens are the same (e.g., *A*-*A*-*A*-*A*). This type of distraction is called the changing-state effect and manifests only when rehearsal is involved (Jones et al., 1992). Attention is needed for the maintenance of items in memory and can be captured by sounds that are unexpected (deviant sounds such as *A*-*A*-*A*-***B***-*A*-*A*-*A*; e.g., Hughes et al., 2013; Vachon et al., 2016). This is the deviation effect and it occurs regardless of processes involved in the task (Vachon et al., 2016; Hughes et al., 2007). The present empirical studies make use of changing-state and deviant sounds to investigate how distraction effects vary among children and adults. The experiments herein are the first to assess the deviation effect, ‘token set-size effect’ and ‘dose effect’ among children — token set-size and dose effects are findings that disruption to rehearsal increases when the number of irrelevant auditory tokens and rate of transition between tokens increase (Bridges & Jones, 1996; Tremblay & Jones, 1998). Results from each of the three empirical studies (and from a joint analysis of data from all three studies) suggest that overall, children and adults are especially vulnerable to distraction stemming from the interference of rehearsal as evidenced by the changing-state effect in serial and probed recall tasks but there was no difference in the magnitude of disruption between age groups. The results also suggest that the deviation effect may manifest more frequently for children than adults and this could be attributed to their poorer attentional control relative to adults. In addition, the combined analyses revealed a greater deviation effect for children compared to adults in serial recall. Taken together, the results suggest that developmental differences are more likely to emerge as a function of differences in attentional control rather than the efficiency of rehearsal. Implications of these results for theories of short-term memory, attention, and distraction are discussed. Practical applications of these findings for learning environments such as schools are also addressed.

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CHAPTER I

INTRODUCTION

What determines the susceptibility to auditory distraction? By capitalizing on differences in cognitive abilities between children and adults, this thesis will explore the factors that make one’s task performance susceptible to auditory distraction. More specifically, the focus will be on how auditory distraction affects memory among children and adults; and, how rehearsal and attentional control, processes that assist memory maintenance, can also determine vulnerability to distraction (Elliott, 2002; Elliott, Bhagat, & Lynn, 2007; Elliott, Hughes, Briganti, Joseph, Marsh, & Macken, 2016; Klatte, Lachmann, Schlittmeier, & Hellbrück, 2010).

The focus on rehearsal and attentional control in memory is well suited for the study of distraction for three main reasons. First, there is ample research to show that auditory distraction affects task performance in two functionally distinct ways – through disruption of the rehearsal process that is being directed to task performance and through the capture of attention away from the focal memory task by so-called ‘deviant’ events in the task-irrelevant sound sequence (Hughes, Vachon, & Jones, 2007; Jones, Hughes, & Macken, 2010; Jones, Hughes, Marsh & Macken, 2008). Second, these processes undergo changes across the lifespan – children’s attentional control increase from childhood into adolescence (Cowan, Fristoe, Elliott, Brunner, & Saults, 2006; Davidson, Amso, Anderson, & Diamond, 2006; Konrad et al., 2005) while their rehearsal abilities change from labelling to a cumulative style of rehearsal in later childhood and adulthood (Jarrold & Hall, 2013; Lehmann & Hasselhorn, 2012; Tam, Jarrold, Baddeley, & Sabatos-DeVito, 2010; Tucker-Drob, 2009). Third, there is evidence to show that auditory scene analysis or auditory streaming – the pre-attentive or automatic perceptual organization of incoming auditory information into subsets based on their environmental origin to form an accurate description of the auditory environment (Bregman, 2001) – functions in a similar manner among school-aged children (7-10 years of age) and adults (Sussman, Ceponiene, Shestakova, Näätänen, & Winkler, 2001; cf. Sussman, Wong, Horváth, Winkler, & Wang, 2007). In addition, Macken, Phelps, & Jones (2009) have shown that the magnitude of disruption by irrelevant sounds increases with an individual's ability to sequentially organize incoming auditory information – therefore, it would follow that children and adults should not show a difference in disruption if their auditory sequence processing abilities (like their auditory streaming abilities) are similar. Taken together, there is an expectation that vulnerability to auditory distraction will vary with age as a function of differences in rehearsal and attentional control rather than auditory perception (Elliott et al, 2016; Andrés, Parmentier, & Escera, 2006; but see Bell & Buchner, 2007; Klatte et al., 2010; Röer, Bell, Marsh, & Buchner, 2015; Rouleau & Belleville, 1996; Schwarz, Schlittmeier, Otto, Persike, Klatte, Imhof, & Meinhardt-Injac, 2015).

Given the changes that take place across the lifespan, it seems reasonable to expect that distraction effects would manifest differently for individuals with poorer attentional control and rehearsal compared to those with superior rehearsal and attentional abilities. Research testing adults has shown that individuals with lower working memory capacity (considered as a measure of attentional control; Engle & Kane, 2004; Hiebel & Zimmer, 2015; Unsworth & Spillers, 2010) are more likely to be disrupted by auditory distraction (e.g., Conway, Cowan, & Bunting, 2001; Hughes, Hurlstone, Marsh, Vachon, & Jones, 2013; Sörqvist, 2010a). Studies comparing children and adults have also found that distraction increases as a negative function of rehearsal efficiency with children experiencing greater levels of disruption compared to adults because of their underdeveloped rehearsal (Elliott et al., 2016). The present experimental series compares distraction effects in children aged five to eleven with young adults aged 18 to 22 years old, with the objective of understanding how the developmental differences (specifically, in rehearsal and attentional control) between these groups (and within the group of children) influences their susceptibility to distraction effects. For example, would children who are considered to have poorer rehearsal and attentional control be more vulnerable than adults to both forms of distraction? Klatte et al. (2010) suggested an equivalence between adults and children in the magnitude of disruption caused by interference to rehearsal. However, a recent study by Elliott et al. (2016) suggested that children were more susceptible to auditory distraction in a short-term memory task because of a greater likelihood of attentional capture. The authors suggested that children's poorer rehearsal abilities were exacerbated by their limited attentional control, and, made them more susceptible to distraction. This discordance within the literature is one factor motivating the present research.

The study of auditory distraction effects on memory has mainly focused on the effects with adults (e.g., Colle & Welsh, 1976; Hughes, Chamberland, Tremblay, & Jones, 2016; Jones & Macken, 1993; Salamé & Baddeley, 1982). However, studies considering the effects among children are scarce (but see, Hygge, 2003; Klatte, Meis, Sukowski, & Schick, 2007; Lercher, Evans, & Meis, 2003; Meinhardt-Injac, Schlittmerier, Klatte, Otto, Persike, & Imhof, 2015). Similarly, the developmental differences approach to auditory distraction has considered the differences between young and old adults (Bell & Buchner, 2007; Röer et al., 2015; Rouleau & Belleville, 1996) with the differences between children and adults only recently being explored (Elliott, 2002; Elliott et al., 2016; Klatte et al, 2010). While developmental work with young and old adults has generally shown an age equivalence in distraction effects driven by attentional capture (Bell & Buchner, 2007; Röer et al., 2015) the results are less clear when comparing adults and children (Elliott, 2002; Elliott et al., 2016; cf.

Klatte et al, 2010). Therefore, the relative scarcity of research with children and the lack of clear-cut developmental findings for adults versus children has motivated the present work.

There are three empirical studies in this thesis, each addressing the potential differences in distraction effects on memory between children and adults. Study I is the first to examine distraction by attentional capture among children. In this study, the link between working memory capacity and attentional capture was explored to identify if working memory modulated developmental differences in the distraction effects. Study II built upon the work from Study I and incorporated a larger age range of children in the analysis to extend the understanding of distraction effects across children aged five to 11 years old. In addition to being the first study to assess children's attentional capture by 'deviants', another original contribution to research is the study of the token-set size and dose effects (Bridges & Jones, 1996) with children. Token-set size and dose effects refer to the finding that as the number of different tokens in a sequence and the number of tokens heard per unit time in an irrelevant auditory sequence increases, so too does the disruption to recall (Bridges & Jones, 1996; Tremblay & Jones, 1998). It is hoped through these studies, the understanding of children's susceptibility to distraction and the developmental differences between children and adults will become clearer.

1.1 The development of rehearsal and attentional control.

The maintenance of information in memory relies on subvocal rehearsal of to-be-remembered (TBR) items to strengthen their traces in memory (Baddeley, 1986). This speech-based process may be overt or covert but both forms of rehearsal rely upon the articulatory processes intended for overt speech production. However, the presence (or indeed absence) of rehearsal has been assessed somewhat indirectly. Among adults, the word-length effect (short words take less time to articulate than long words and are more easily recalled in verbal short-term memory tests; Baddeley, Thomson, & Buchanan, 1975) and the positive correlation between articulation rates and memory spans (individuals who speak faster have larger spans; Schweickert & Boruff, 1986) are taken as evidence for the presence of rehearsal.

For children, however, the picture is much more complex with some research suggesting that as articulation rates increase, rehearsal improves quantitatively (e.g., Hulme, Thomson, Muir, & Lawrence, 1984) while others suggest that a qualitative change takes place and rehearsal in children emerges around 6 or 7 years of age (Flavell et al., 1966; Gathercole, 1998; Henry, Messer, Luger-Klein, & Crane, 2012). However, the weight of evidence is in favour of a qualitative account of rehearsal development. The evidence that children under the age of seven do not experience the phonological similarity effect (better recall of dissimilar items than similar items) and word length effect (better recall of short than long words) on recall suggests they are not rehearsing as these effects would be expected to manifest if verbal rehearsal was being utilised to maintain items in memory (e.g., Halliday, Hitch, Lennon, & Petipher, 1990; Henry, 1991; Henry et al., 2012; Hitch, Halliday, Schaafstal, & Heffernan, 1991). According to the Working Memory model, incoming visual items are converted into phonemic codes for storage within the phonological store through rehearsal (Baddeley, 2002). Therefore, similar sounding items will have similar phonemic codes that are harder to discriminate during recall than codes that are dissimilar and lead to the phonological similarity effect reflected in poorer recall of phonologically similar items compared to dissimilar items (e.g., Baddeley, 1968; Conrad & Hull, 1964; Elvevåg, Weinberger, & Goldberg, 2002). The word length effect is also dependent on rehearsal, as evidenced by the finding that when rehearsal is prevented, the word length effect disappears for visually presented lists but not when list presentation is auditory (Baddeley et al., 1975). Therefore, in the absence of rehearsal, the phonological similarity effect and word length effect would not occur. In addition, some researchers have observed that children under the age of seven do not show lip movements that are characteristic of a primitive form of rehearsal and the positive correlation that is observed among adults between rate of articulation and memory span has not been found among children below seven years old (Ferguson, Bowey, & Tilley, 2002; Flavell et al., 1966; Gathercole, Adams, & Hitch, 1994).

The qualitative argument was also suggested by Vygotsky, wherein covert rehearsal is akin to inner speech – self-directed speech that around six years of age becomes more internalized and increasingly quiet before it turns into inner speech and "goes underground" around eight years of age or middle childhood (Vygotsky, 1934 / 1987; as cited in Crain, 2011). This developmental change is important because of its far-reaching influences on aspects of cognition – according to Vygotsky (1934) goal-directed cognitive activities such as perception, thinking, memory, and attention are dependent on the development of inner speech, and consequently, on the effective use of verbal strategies (Al-Namlah, Fernyhough, & Meins, 2006). This perspective fits well with research showing that inner speech allows children to plan their actions and solve problems (Behrend, Rosengren, & Perlmutter, 1992; Mahy, Mohun, Müller, & Moses, 2016); and its use has been observed when children are faced with difficult tasks and is associated with greater success on a variety of tasks as well (Fernyhough & Fradley, 2005). Studies have also shown how inner speech mediates executive functions (e.g., task switching; Emerson & Miyake, 2003) and short-term memory (e.g., digit span; Mahy et al., 2016) – on the one hand, children use inner speech to remind themselves of task rules and guide their action in task switching settings; on the other hand, inner speech can be used to remember lists of items in serial order through covert speech production (Emerson & Miyake, 2003; Mahy et al., 2016).

Given the verbal nature of rehearsal, it would be reasonable to expect that there would be a relationship between rehearsal and language. In line with this expectation, research shows that language proficiency mediates the relationship between age and rehearsal (Bebko, McMorris, Metcalfe, Ricciuiti, & Goldstein, 2014). This is an important finding which challenges the dominant view that age is the variable which sparks the onset and improvement in rehearsal (e.g., Flavell et al., 1966). However, as Bebko et al. (2014) suggest, age may simply be an umbrella concept to account for the different underlying factors that are responsible for the development of rehearsal. It is argued that as language develops, so does the child’s vocabulary enabling them to describe and retain information in a more detailed manner (Bebko, 1984; Cherney, 2003). Studies comparing language development between deaf and hearing children and adults provide an avenue for understanding the link between rehearsal and language because the performance of deaf individuals in verbal tasks especially those requiring serial processing is poorer than that of hearing individuals (e.g., Okada et al., 2015), and as will become clear, this has been linked to the differential levels of language proficiency. Bebko (1984) and Bebko and McKinnon (1990) found that although both groups of children used rehearsal to recode visual material into linguistic code (verbal labels or manual signs), deaf children were slower in their development and consistent use of rehearsal. When the children’s language development was considered, a clear relationship emerged: children with better language skills were more likely to use rehearsal. In addition, when delays in language acquisition among deaf children were removed, the differences with regards to the emergence of rehearsal were eliminated (Bebko & McKinnon, 1990).

That differences between deaf and hearing children in their use of rehearsal is guided by language proficiency can also be extended to understand differences in rehearsal efficiency among between children and adults. This in turn would be useful for predicting and assessing the effects that auditory distraction may have on rehearsal processes (e.g., Jones et al., 2010). Existing research is in agreement that children begin to use rehearsal around the age of seven and its use is especially prominent when information must be remembered in sequential order (e.g., Bebko, 1984; Bjorklund, Coyle, & Gaultney, 1992; Flavell et al., 1966). When rehearsal emerges, however, is not completely developed and as with any new skill it requires practice in order to improve and become more automatized (Clerc, Miller, & Cosnefroy, 2014). This notion coheres with findings regarding strategy utilization deficiencies among children (e.g., Lange & Pierce, 1992; Miller & Seir, 1994). Therefore, even though rehearsal emerges during middle childhood, younger children do not always adopt a rehearsal strategy to remember information. Young children tend to utilize labelling more than rehearsal with a gradual decline in labelling and increased preference for rehearsal appearing only around the age of ten (Lehmann & Hasselhorn, 2012). Clerc et al. (2014) suggest that this may happen because when rehearsal first emerges, it places a great demand on children's limited cognitive resources as they are required to specifically choose this strategy, devise a motor plan for action, and monitor their usage of the strategy. All of these concurrent activities are assumed to leave very little (or no) resources available for memory-related activities (for example, a free recall task; Lehmann & Hasselhorn, 2007, 2012). However, with consistent and repeated use, rehearsal becomes automatized to a level wherein it enhances rather than prevents recall performance (Clerc et al., 2014; Coyle & Bjorklund, 1997). The eventual automatization of rehearsal has been linked to language development as well; and, Bebko (1984), Bebko and McKinnon (1990), and Bebko et al. (2014) have shown that the improvement in language skills corresponds with a decrease in processing demands of strategies that are language-based. As mentioned above, rehearsal is an inherently speech and language-based process, therefore, it follows that the improvement in language skills leads to the automatization of rehearsal as a strategy to support memory.

In contrast to rehearsal, which emerges in middle childhood, attentional control emerges towards the end of the first year of life as the neural connections that support it begin to mature (Deoni, Mercure, Blasi, Gasston, Thomson, & Johnson, 2011) and then continue to develop through the lifespan (Davidson et al., 2006). Around seven years of age, children’s attentional control is still developing (Cowan et al., 2006; Guttentag, 1997; Lane & Pearson, 1982) and the ability to exert top-down control in order to inhibit irrelevant information is less efficient than in adults (Hwang, Velanova, & Luna, 2010). One role of attentional control is to actively maintain goal-oriented information in the mind and to prevent attentional capture by distractors or irrelevant information (Engle & Kane, 2004; Gazzaley & Nobre, 2012). The act of maintaining information whilst concurrently inhibiting irrelevant information is said to be a function of working memory, of which attentional control is a primary component (Engle & Kane, 2004; Kane, Conway, Hambrick, & Engle, 2008; cf. Cowan, Elliott, Saults, Morey, Mattox, Hismjatullina, & Conway, 2005). Some researchers also suggest individual differences in working memory capacity (WMC) are the result of individual differences in attentional control and that individuals with high WMC are able to resist distraction better than those with lower WMC due to superior attentional control (Conway et al., 2001; Hughes et al., 2013; Sörqvist, 2010a).

1.2 The Link between Rehearsal, Attentional Control, and Distraction.

Most studies consider the effects of distraction on short-term memory tasks that require rehearsal and attentional control for task completion. In most laboratory studies of distraction, a list of TBR items (e.g., letters, digits, words) is shown to participants and they are asked to recall them in any order (free recall; Salamé & Baddeley, 1990) or in their order of presentation (serial recall; Colle & Welsh, 1976). Recall is usually immediately after list presentation or followed by a short retention phase (e.g., 10 sec retention interval; Macken, Mosdell, & Jones, 1999). Participants might also be requested to identify the missing item from a list, or recall which item followed another in the list (missing-item and probed recall tasks; Beaman & Jones, 1997). The defining feature of tasks in such studies is the use of task-irrelevant speech or sounds while the task is underway; and, explicitly instructing participants to ignore the noise because it is irrelevant to the task (e.g., Jones & Macken, 1993). Within this task-setting, rehearsal is often used to remember items (whether in probed or serial recall) while attentional control helps individuals remain focused on the task and ignore the irrelevant sounds. Therefore, it may be that the extent to which distraction effects are observed in these studies is determined by the efficiency of rehearsal and attentional control of the participants.

1.2.1 The Irrelevant Sound Effect.

Irrelevant speech is especially disruptive of serial recall performance (e.g., Colle & Welsh, 1976; Jones & Macken, 1993; Hughes et al., 2005, 2007) and this impairment has been termed the Irrelevant Speech Effect (Salamé & Baddeley, 1982), or more generally, the Irrelevant Sound Effect (ISE; Beaman & Jones, 1997) to encompass disruption by irrelevant speech and non-speech. The ISE is a robust finding that in a study of individual differences in susceptibility to the effect among adults aged 19 to 44 years showed that serial recall accuracy declined by 30% to 50% in the presence of narrative speech compared to quiet (Ellermeier & Zimmer, 1997). Similarly, children have also shown individual differences in susceptibility to distraction by irrelevant tones and speech (Elliott & Cowan, 2005). The prevalence of the ISE among children and adults sparks questions about the underlying mechanisms responsible for the disruption.

The ISE observed in the study by Colle and Welsh (1976) was initially thought to be the result of irrelevant speech masking primary memory traces of the visual items which according to Sperling's (1963, 1967) model of memory suggested that incoming auditory and visual information (once converted to verbal code through rehearsal) would enter the auditory information storage (AIS; Sperling 1963). Irrelevant speech entering the AIS was thought to mask the primary memory traces of the visual items that were also in the AIS. Salamé and Baddeley (1982, 1989) expanded the masking explanation by considering the way auditory input was processed compared to visual items. As incoming speech was encoded as a series of phonemes, it would already be in the phonological code and gain direct access to the phonological store – a storage system within working memory wherein acoustic and speech-based information are held for 2-3 seconds unless rehearsed subvocally to be maintained for longer (Baddeley, 1996). Incoming visual items, however, needed a conversion from graphemes into phonemes to be maintained in the store. According to the working memory model, this grapheme-to-phoneme conversion of visual items is achieved by subvocalization (a process akin to rehearsal; Baddeley, 2002) and subsequently this process serves to maintain the visual and auditory material in the phonological store. In this instance, a conflict was said to arise between the visual and auditory sources of information as a function of its phonological similarity and since speech was processed automatically it would obscure or mask the traces of the items entering from the visual modality and diminish recall accuracy (Salamé & Baddeley, 1982).

An alternative perspective on the ISE proposed by Neath (2000) extended the assumptions of the Feature Model of Nairne (1990). According to Neath (2000), task relevant and irrelevant items are represented in memory in terms of two kinds of features: modality-dependent (e.g., sensory nature of an input depending on whether it originates from the visual or auditory modality) and modality-independent features (e.g., semantic category or phonological identity of an item). The model assumes that irrelevant speech impairs recall through a process called *feature adoption* whereby modality-independent features of irrelevant speech interfere with the modality-independent features of TBR items. In simulations of the model, features are set to values of +1 or -1, and if the feature value of one item (say, the irrelevant item) is the same as the feature value of another item (say, the TBR item) then the feature of the TBR item will be modified by changing the primary memory trace and identity of the TBR item. More specifically, the process of matching primary cues to their secondary memory representations becomes degraded – the primary cues fail to match with the correct representation in secondary memory leading to a loss of item and order information. The feature model, therefore, explains the ISE as the result of feature adoption wherein modality-independent features of the irrelevant items overwrite the corresponding features of the TBR item if the presentation of the irrelevant material coincides with rehearsal of the TBR items (Neath, 2000).

One key assumption of the feature model is that feature adoption only occurs with speech sounds (Neath, 2000; Neath & Suprenant, 2001), leading to the problematic conclusion that the ISE is a between-sequence similarity effect. Another challenging aspect is the description of the changing-state-effect (Jones et al., 1993) and the irrelevant sound effect with recourse to the ‘attentional parameter’ (*a*) – a scaling variable which determined the amount of attentional resources available based on factors such as nature of the task and irrelevant material, attentional control of the individual, and task difficulty (Neath, 2000). The model assumes that a stream of items that change from one token to the next (e.g., changing-state speech such as *A*-*B*-*A*-*B*) is more attention-demanding than a sequence of repeated items (e.g., steady-state stimuli such as *A*-*A*-*A*-*A*) because the latter is easier to ignore and will divert less attention away from the focal task. In contrast, the changing-state stimuli are more demanding because they create a situation of divided attention wherein ignoring the sounds is an additional task to focal serial recall (e.g., Neath & Suprenant, 2001). Thus, in the simulations, the attentional parameter for steady-state conditions is set at a higher value than the changing-state condition to reflect that more attention is available when an easy-to-ignore irrelevant sequence is used versus when a difficult-to-ignore sequence is used (Neath, 2000). Likewise, to model non-speech effects on serial recall performance, the model suggests adjustments to the *a* parameter to reflect a dual-task setting as with changing-state stimuli.

There are obvious problems with the feature model with regards to its conceptualization of attention, the distinction between speech and non-speech effects, explanation of the changing-state effect, and the process of feature adoption as a mechanism for disruption. The arbitrary adjustment of the attentional parameter suggests that attention is viewed as a unitary mechanism despite evidence to show that it is a multi-faceted construct (Pashler, 1991; Vogel, Woodman, & Luck, 2005; Woodman, Vogel, & Luck, 2001). Neath (2000) also does not provide any theoretical rationale for the addition of the parameter to explain non-speech and changing-state effects. In addition, the suggestion that the irrelevant sound effect is distinct from the irrelevant speech effect contradicts extant findings that show disruption occurs in a similar manner with speech and non-speech sounds (Jones, Alford, Bridges, Tremblay, & Macken, 1999; Jones & Macken, 1993, 1995a; Jones, Macken, & Murray, 1993; Tremblay, Nicholls, Alford, & Jones, 2000) and that speech and non-speech distractors have similarities in their effects on visual serial recall (e.g., token-set size effects are present for speech and non-speech distractors; Tremblay & Jones, 1998). Moreover, the model suggests that the changing-state effect is the result of attentional capture, however, there is considerable evidence to show that this is not the case (Bridges & Jones, 1996; Hughes & Jones, 2001; Jones et al., 2010; Hughes et al., 2007, this is detailed in sections 1.2.2 and 1.2.3). The model also suggests that steady-state speech should result in disruption (albeit less than changing-state speech) even though there is evidence to the contrary showing that steady-state disruption is minimal or not consistently observed (e.g., Bridges & Jones, 1996; Hughes, Tremblay, & Jones, 2005; Jones & Macken, 1993). Finally, testability of the feature-adoption process is seriously limited by the model's requirement that irrelevant items should coincide with the rehearsal of TBR items. To set up an experiment such that there is synchrony between the irrelevant events and rehearsal seems an elusive empirical goal particularly if rehearsal is covert (Jones & Tremblay, 2000). Finally, the legitimacy of feature adoption is also questionable given evidence that rhyming and non-rhyming sequences disrupt recall to a similar degree (LeCompte & Schaibe, 1997) and irrelevant speech tokens that rhyme with the TBR tokens are less disruptive than non-rhyming sequences (Jones & Macken, 1995b).

Non-influential factors in the ISE.

The role of speech and meaning.

Speech is neither a necessary or sufficient condition for disruption to occur (e.g., Salamé & Baddeley, 1989; Jones, Madden, & Miles, 1992). Although initial research suggested that disruption may be dependent on the irrelevant material consisting of speech (Colle & Welsh, 1976; Jones, Miles, & Page, 1990; Salamé & Baddeley, 1982, 1987, 1989), there is now ample evidence to show that non-speech sounds (Beaman, 2005), tones (Jones & Macken, 1993; Tremblay & Jones, 1998), instrumental music (Salamé & Baddeley, 1989; Schlittmeier, Hellbrück, & Klatte, 2008), and traffic noise (Hygge, Boman, & Enmarker, 2003) can also cause disruption to cognitive task performance. Therefore, the disruptive impact of irrelevant auditory material is not dependent on its speech status (cf. Little, Martin, & Thomson, 2010; Viswanathan, Dorsi, & George, 2013). The disruptive potential of speech and tones, however, is dependent on the level of change or fluctuation in the irrelevant sequence – irrelevant sequences with little or no variation (such as repeated tones; e.g. Jones et al., 1999) cause minimal disruption to short-term memory (especially memory for order) compared to sequences that vary (e.g., Jones et al., 1992; Jones & Macken, 1993; Schlittmeier, Weiβgerber, Kerber, Fastl, & Hellbrück, 2012). This notion is supported by the finding that white noise (Colle & Welsh, 1976; Hintzman, 1965; Murray, 1965; Weisz & Schlittmeier, 2006) and continuous pitch glides cause little or no disruption whereas when pitch glides are interrupted by periods of quiet, they are again disruptive of serial recall performance (Jones et al., 1993). Similarly, when a single speech or tone token is played repeatedly, disruption is substantially lower than when there are variations (e.g., Jones & Macken, 1993; Jones et al., 1992). The aspect that renders irrelevant material disruptive is, therefore, the presence of acoustic change and not its content (Jones, 1994; Jones et al., 1999; Jones et al., 1993).

The meaning of the irrelevant material also appears to be unimportant in determining disruption to short-term memory. Equivalent levels of disruption to serial recall have been observed when irrelevant speech comprises meaningful speech compared to foreign speech, reversed speech, and non-sense words (Baddeley & Salamé, 1986; Buchner, Irnem, & Erdfelder, 1996; Colle & Welsh, 1976; Jones et al., 1990; LeCompte & Schaibe, 1997; Marsh, Hughes, & Jones, 2009; Salamé & Baddeley, 1982, 1986, 1989). However, an effect of meaningfulness has been observed in a study by LeCompte, Neely, and Wilson (1997), but, it accounted for only 12% of the irrelevant speech effect emphasising the small effect that meaningfulness has on levels of disruption. Neely and LeCompte (1999) also showed that distractors that were strong free associates of the TBR items were more disruptive than words not strongly associated with the TBR words – however, the difference in disruption was minimal. Although these two studies suggest a role for meaning, the disruption (observed in

LeCompte et al., 1997) may actually be attributable to the greater acoustic complexity of speech over tones rather than the meaning of speech (Schlittmeier et al., 2012; Tremblay et al., 2000). When acoustic variability is controlled, speech and non-speech sounds produce equally large disruptive effects (Jones & Macken, 1993). In addition, the effect of meaningfulness that was observed was very small (2% decrement in performance when irrelevant speech was related compared to unrelated to the TBR items; Neely & LeCompte, 1999).

Phonological similarity.

To date, there has been only one instance where phonological similarity influenced the irrelevant speech effect (Salamé & Baddeley, 1982 – Experiment 5). Salamé and Baddeley (1982) found that recall of digits was poorer in the presence of irrelevant digits and words that were phonemically similar to the TBR digits than in the presence of dissimilar disyllabic words. However, attempts at replicating this experiment have consistently shown that phonological similarity between visual and auditory items do not increase disruption (e.g., Bridges & Jones, 1996; Hanley & Bakapolou, 2003; Jones & Macken, 1995b; Marsh, Vachon, & Jones, 2008; however, see Eagan & Chein, 2012, who show that overlap between to-be-ignored (TBI) and TBR phonetic features lead to poorer recall). The phonological similarity effect is the finding that phonologically similar items are harder to remember than dissimilar items (Conrad & Hull, 1964). According to the working memory model, when phonological traces of the items from the focal task are similar to those from the irrelevant sequence confusion among the traces is more likely to occur in the phonological store which then manifests as poorer recall in the presence of phonologically similar distractors (Baddeley, 1968). However, the opposite pattern has been observed in the irrelevant sound paradigm – phonologically similar tokens in the irrelevant sequence are less disruptive than those that differ from one another because highly similar tokens would have less acoustic change in them compared to dissimilar tokens and would result in less disruption (Jones, 1999; Jones & Macken, 1995b; the CS effect, see section 1.2.2). When TBR and TBI items were phonologically similar, the disruption to memory for order was low (Jones & Macken, 1995b; Larsen, Baddeley, & Andrade, 2000; LeCompte & Schaibe, 1997). Disruption was also low when TBI items rhymed with one other but not with the TBR items and although the disruption was significantly greater than the phonologically dissimilar condition this was restricted to the recency portion of the serial position curve only and accounted for a small amount of additional disruption (Jones & Macken, 1995b), further emphasizing that within-sequence phonological similarity does not influence the magnitude of disruption.

Intensity of sound.

Early research into the effects of irrelevant sound suggested that the sounds had to be very loud for any disruption to take place (sounds ranging from 100 dB (A) to 113 dB (A); e.g., Jerison, 1959; Miles 1953; for a review on early studies see, Plutchik, 1959). However, later research has focused on effects of moderate levels of noise such as those between 48 to 76 dB(A) given the detrimental impact of exposure to loud noises and the arousal associated with noises above 80dB(A) (Hughes & Jones, 2001). Although intuition would suggest that higher intensity will cause greater distraction, detrimental effects have been observed even with low to moderate intensity sounds and consistently suggest that intensity of the irrelevant sound does not affect the magnitude of disruption (Colle, 1980; Ellermeier & Hellbrück, 1998; Jones et al., 1990; Tremblay & Jones, 1999). Within the serial recall paradigm, Tremblay and Jones (1999) showed that even though irrelevant sounds and speech were disruptive and caused a changing-state effect on serial recall there was no difference between disruption across the intensity range of 55 to 85 dB(A). These findings also concur with earlier results by

Colle (1980) who found no difference in levels of disruption when sounds were at the level of a whisper [20dB (A)] or at the level of a shout [approx. 76-78 dB (A)]

1.2.2 Acoustic variation over phonological content: Introducing the changing-state effect.

The foregoing section highlighted the factors that do not influence level of disruption, however, a factor that does influence the level and type of disruption is the presence of acoustic variation in the irrelevant sequence (Jones & Macken, 1993). Experiments by Jones and colleagues (e.g. Jones et al., 1992; Jones & Macken, 1993) showed that the presence of speech (and hence phonology) was not a necessary or sufficient condition for disruption to occur. It was, instead, the presence of acoustic variation that determined the disruptive potential of the sound. Jones et al. (1992) found that a single repeated speech sound (e.g. A-A-A-A) or one that was sustained (e.g., a continuous “ah” sound) was not as disruptive to recall as a speech sequence that contained variation throughout (e.g. A-B-A-B). In addition, Jones and Macken (1993) found that a sequence of tones that changed in frequency was more disruptive to serial recall than a single repeated tone. Similarly, Jones et al., (1993) demonstrated that errors in serial recall were greater when a pitch glide was interrupted with periods of silence than when it was quiet or a continuous pitch glide was played.

The pattern of disruption where irrelevant sound sequences (whether speech or non-speech) containing variation produced substantially more disruption to serial order recall than a sequence consisting of a single repeated item (e.g., Campbell, Beaman, & Berry, 2002; Jones, 1993, 1994; Schlittmeier, Weisz, & Bertrand, 2011) was labelled the changing-state effect (CS effect). From an auditory processing point of view, the CS effect can be explained by reference to two perceptual processes essential for auditory processing, namely, segmentation and streaming (Macken et al., 1999). For a changing-state sound to be disruptive, it must be segmentable into discrete elements with each element differing from the preceding one (Macken et al., 2009). The finding that humming causes less disruption compared to speaking and singing supports this assumption (Morris & Jones, 1990; Morris, Quayle, & Jones, 1989). Humming presents limited opportunities for segmentation compared to the abrupt transitions in singing or speaking. Similarly, segmentation of ‘babble’ speech (a compound signal of speech consisting of multiple speakers, for example, 8 or even 100 speakers; Kilcher & Hellbrück, 1993) is limited because there are fewer discernible cues (Jones & Macken, 1995a). It appears from this evidence that it is easier to identify the variation (peaks and troughs in the signal that yield segmentation cues) in a single voice than several combined. A single voice, therefore, contains more discernible cues for segmentation than a compound signal of 6, 8, or 100 voices and will increase the disruptive potential of the sound (Hellbrück & Kilcher, 1993; Klatte & Hellbrück, 1993).

In addition to segmentation, the perceptual organization of sound according to its source – also known as auditory scene analysis or streaming (Bregman, 2001) – determines the magnitude of distraction. If each element in the changing-state sequence is different from the preceding one and is perceived as originating from the same source, disruption to recall will occur. The greater the change between elements, the greater the disruption, but only up to a point of fission where successive sounds are perceived as originating from different sources, hence, split into separate streams reducing the distraction generally produced by changing-state sequences (Jones, Saint-Aubin, & Tremblay, 1999). This was demonstrated by Jones et al. (1999) through manipulating the frequency differences between sine tones – in their Experiment 1, errors were greatest when the frequency differences were large as opposed to medium or small (and there was no difference between performance in quiet and the small frequency difference condition). Thus showing that the greater the difference between the elements the higher the disruption. In Experiment 3, however, irrelevant speech and non-speech sequences were modified such that there was either a 2, 5, 10, or 0 semitone difference between each element in the sequence: there were four sequences each for speech and tone elements, three changing-state sequences and one steady-state sequence (i.e. the 0-semitone difference sequence). Disruption increased as the semitone difference increased from 0 to 2 and to 5 only while disruption attenuated in the 10-semitone condition (Jones et al., 1999). These results show a non-monotonic relationship between pitch difference and the degree of disruption and this is in line with the idea that two separate streams will be formed when the difference between successive elements is very high (i.e. the point of fission is reached; e.g., Van Noorden 1977) and the disruptive potential of these streams will be lower because they contain much less changing-state information (Bregman & Campbell, 1971).

In the context of order information and the CS effect, disruption will be greater when there are bigger mismatches between consecutive elements so long as the mismatches do not reach the point of fission. This is because it will still be possible to perceive the sequence as originating from a single source and process order cues in the sequence. By contrast, when there are larger mismatches, changing-state interference is expected to be lower on account of the auditory sequence being split into discrete streams (or perceived as originating from different sources) and order cues being lost as a result (Jones et al., 1999). This is also confirmed in the study by Jones & Macken (1995c) where the perceived spatial location of irrelevant elements in a sequence is varied – the sequence is either presented monaurally or stereophonically. When presented monaurally, each element is perceived as originating from one spatial location and is organized as a changing-state sequence (e.g., C – U – O). However, in stereophonic presentation, each element is perceived as originating from different locations (“C” played on both auditory channels, “O” and “U” on the right and left channels, respectively) and hence perceptually organized as three separate streams of repeating elements (i.e., a stream of “C”s, stream of “O”s, and a stream of “U”s). The CS effect is present when the sequence is perceived as originating from one location but disappears when stream segregation results in the perception of three separate steady-state sequences (Jones & Macken, 1995c). The auditory processing view only provides an explanation of the nature of changing-state sequences. The exact mechanism through which disruption occurs is not mentioned. The Object-Oriented Episodic Record Model (O-OER; Jones, 1993), outlines such a mechanism.

The Object-Oriented Episodic Record Model’s account of the CS effect.

The O-OER model (Jones, 1993; Jones et al., 1996) explains the CS effect as the result of a conflict between pointers that link a list of TBR items together in the order they were presented through the deliberate process of subvocal rehearsal and those pointers that were derived from pre-attentive processing of auditory material. Items from the focal task and irrelevant speech are organized within memory as streams of objects that are linked by pointers and are represented on the same episodic surface. Once in memory, these objects and pointers are undifferentiated in terms of their modality of origin and the links between them are assumed to decay with time. This decay could be offset by engaging in subvocal rehearsal to keep the pointers and the objects fresh in memory. However, attempts to rehearse focal task items in the presence of irrelevant speech leads to confusion among the objects and pointers and this manifests as errors upon recall. Two main hypotheses are generated from this model.

The changing-state hypothesis states that the disruption by changing-state sounds occurs in memory when order cues from the irrelevant sequence and the focal task compete. Order cues from the irrelevant sequence are produced pre-attentively while those from the focal task are generated through rehearsal. Confusion occurs between the two types of cues resulting in lower recall output. This hypothesis leads to two main predictions: First, when serial rehearsal is prevented (e.g., through articulatory suppression; Klatte, Lee, & Hellbrück, 2002; Macken & Jones, 1995) or altogether absent (e.g. in a missing-item task, Hughes et al., 2007; Macken & Jones, 1995; also see section 2.3.3 and 3.3.3) the CS effect will not occur (Hughes et al., 2007; Jones & Macken, 1993). Second, variation in the auditory sequence is essential for disruption to take place and sounds without variation from one element to the next will cause little or no disruption compared to a quiet control condition (e.g. Campbell et al., 2002; Jones et al., 1993).

The second hypothesis of the O-OER model is the equipotentiality hypothesis which stipulates that speech and non-speech will show equivalent disruption as they will generate order information in a similar manner (Jones & Macken, 1993). There is some evidence, however, that words or speech are more disruptive than non-speech sounds (e.g., LeCompte et al., 1997). LeCompte et al. (1997) did find greater disruption by speech but were unable to provide a satisfactory explanation with recourse to any theory of attention or shot-term memory. The weight of evidence, however, is in favour of the equipotentiality hypothesis (Jones et al., 1992; Jones & Macken, 1993; Jones & Tremblay, 2000; Neath, Surprenant, & LeCompte, 1998; Tremblay et al., 2000) and it stands in sharp contrast to those accounts (e.g., Neath, 2000; Salamé & Baddeley, 1982, 1989) emphasizing the importance of speech or speech-like properties in producing disruption.

1.2.3 The duplex-mechanism account: interference-by-process and attentional capture.

The duplex-mechanism account was proposed by Hughes et al. (2007) and stipulates that there are two distinct forms of distraction with functional differences in the way they impact recall. While one is the outcome of an overlap between processing of auditory distractors and focal task processing (CS effect), the other occurs because of irrelevant sounds capturing attention away from the focal task, the deviation effect.

The CS effect is an empirical example of *interference-by-process* and occurs in tasks that encourage a serial rehearsal strategy (Hughes, 2014). Irrelevant sounds presented with TBR items are processed involuntarily while the TBR items must be rehearsed if they are to be maintained in short-term memory. When the sounds are of a changing-state nature, they elicit cues relating to the order of the sounds. These irrelevant order cues interfere with an individual’s ability to rehearse TBR items and give rise to order errors upon recall (Jones et al., 2010; Marsh et al., 2009). In comparison, steady-state sounds cause minimal or no disruption because there are no order cues being generated by the sound. The CS effect is an example of interference-by-process because it shows how seriation processes directed towards a focal task can be disrupted by irrelevant sounds (Hughes et al., 2007). Interference-by-process has also been observed outside of the serial recall paradigm in category-exemplar recall tasks and experiments assessing phonetic and semantic fluency wherein the disruption is the result of interference with semantic processing (e.g., Beaman, 2004; Jones, Marsh, & Hughes, 2012; Marsh, Hughes, & Jones, 2008, 2009; Neely & LeCompte, 1999). Therefore, the interference-by-process account emphasizes how an overlap in processing can lead to disruption of those activities that are essential for the focal task to be completed and this is not restricted to serial recall.

The second type of distraction in this account outlines the role of attention. It has been labelled the Deviation effect, given that novel or unexpected sounds (called deviants), that deviate from what is expected based on an established pattern of recent events, capture attention away from the focal task (e.g. Hughes et al., 2005; Vachon, Hughes, & Jones, 2012). This type of distraction, unlike the CS effect, occurs regardless of the processing involved in the focal task (Vachon et al., 2016).

Hughes (2014) outlines that attentional capture may be specific or aspecific: specific attentional capture is driven by the nature of the stimulus which could make it interesting or particularly salient to the listener (e.g., hearing your favourite song begin on the radio, or hearing one's own name); however, aspecific attentional capture occurs when there is a sudden and unexpected change in the prevailing irrelevant auditory sequence; there is nothing in the stimulus that gives it attention capturing power. The cocktail party effect is a popular example of specific attentional capture that highlights how one may hear their own name being mentioned in a crowded room even when surrounded by a myriad of other incoming sounds (Conway et al., 2001; Moray, 1959). Experiments in the irrelevant sound paradigm have focused more on aspecific attention capture to explore distraction mechanisms, for example, the addition of the letter *B* in an otherwise steady sequence of the letter *A*; *A-A-A-**B**-A-A*.

The unexpected items in the auditory sequences have been called 'deviants' and the deviation effect is the disruption to recall performance caused by the deviants capturing one's attention away from the focal task. This effect has been observed in a variety of tasks and is not restricted to the serial recall paradigm (Hughes et al., 2007; Parmentier, Elford, Escera, Andrés, & San Miguel, 2008). This suggests that a variety of cognitive functions are vulnerable to attentional capture. Much of what is known about attentional capture has stemmed from the concept of the orienting response (OR; Cowan, 1988; Sokolov, 1963) which refers to a range of psychological (e.g., capture of attention) and physiological effects (e.g., changes in skin conductance response and slower heart rate) elicited by a novel stimulus that breaks the prevailing pattern of events. OR theory suggests that when stimuli are repeated, a neural model is established to represent the pattern, and results in habituation of the OR. The neural model allows for novelty detection by comparing each incoming stimulus to the existing model and assessing whether there is a match. When a deviant stimulus is heard, it elicits the OR because of an absence of a model that matches the incoming deviant stimulus and attention gets diverted momentarily to the novel stimulus and away from the focal task (e.g., Vachon et al., 2012).

There is ample research to support the dichotomy between the CS and deviation effects as outlined by the duplex-mechanism account. The first of these relates to the disruption observed in different types of tasks. For example, while serial recall tasks are vulnerable to the CS effect, other non-seriation based tasks such as the missing-item task and free recall tasks are immune to the effect. On the other hand, the attentional capture or deviation effect manifests regardless of task type (Hughes et al., 2007; Vachon et al., 2016). When participants are asked to identify the missing-item from a well-known fixed list of items (e.g., digits from 1 to 9) their performance is not affected by the presence of irrelevant speech (Beaman & Jones, 1997). Performance in the missing-item task is also compared to a probed recall task – a task requiring the retention of order information by asking participants to identify which item followed another in the list. Results show that although performance is lower for both tasks in the presence of irrelevant speech (compared to quiet), disruption is markedly greater for probed recall performance (Beaman & Jones, 1997; for similar findings with irrelevant tones, see Jones & Macken, 1993). Studies have also shown that the missing-item task is immune to the CS effect but the probed recall task is not (Elliott et al., 2016; Hughes et al., 2007). In addition, Hughes et al. (2007) found that the deviation effect (unlike the CS effect) was present in both serial recall and missing-item tasks. These findings further dissociate the two forms of distraction and demonstrate how only the CS effect is the result of shared processing (i.e. serial order processing) between the irrelevant material and the focal task. In contrast, the deviation effect is not task-process sensitive and can occur on any task that demands attentional resources (although it is likely that some tasks may become automatized because of how easy they are or how little attention needs to be devoted to it and hence will be immune to the deviation effect; cf. Neumann, 1987).

The two types of distraction are also differentiated through their amenability to cognitive control. While the deviation effect can be attenuated by top-down cognitive control, the CS effect is not amenable to such control. When task difficulty is increased (to promote greater task engagement) and when participants had a forewarning of the presence of a deviant, the deviation effect was eliminated (Hughes et al., 2013). The CS effect, however, was not eliminated by greater task engagement and foreknowledge. When WMC was assessed using a complex span task (Operation Span), a negative relationship between working memory capacity and the deviation effect was found but WMC did not correlate with the CS effect. This fits well with evidence that high WMC individuals are better able to inhibit attentional capture than those with lower WMC (e.g., Beaman, 2004; Conway et al., 2001; Elliott & Cowan, 2005; Sörqvist, 2010a; Sörqvist et al., 2013). It must be noted, however, that recent evidence casts some doubt on the distinction between these two forms of distraction. For example, no relation was observed between WMC and the CS and deviation effects regardless of distractor complexity in a recent study by Körner, Röer, Buchner, and Bell (2017). However, the deviation effect observed in their study was small and the proportion of trials containing a deviant was peculiarly high. Therefore, it is possible that the apparent deviant effect in their study maybe a specious one unrelated to commonplace deviant effect that manifests only via the presentation of a deviant on rare trials (e.g., Hughes et al., 2013). Furthermore, the CS effect has also been shown to be attenuated by foreknowledge in some cases (specific foreknowledge that enables individuals to create a mental representation of upcoming distraction and reduces the unpredictability of the distractor sequence attenuates the CS effect; Röer, Bell, & Buchner, 2015) which suggests it may be amenable to top-down cognitive control.

1.2.4 The unitary account of distraction.

While the duplex-mechanism account distinguishes between distraction underpinned by rehearsal and that underpinned by attentional capture, the unitary account of distraction proposes that both forms of distraction are the result of attentional capture (Elliott, 2002). The unitary account of distraction is based upon theory of the orienting response (OR; Sokolov, 1963) and the embedded processes model (Cowan, 1995). The OR refers to a set of physiological and psychological effects evoked as the result of stimuli that deviate from the recent past. In OR theory, when stimuli are repeated, a neural model is formed to represent the pattern of stimuli. Repetitions of stimuli lead to habituation of the OR while changes in the stimuli elicit the OR (Cowan, 1995; Sokolov, 1963). When stimuli are repeated (e.g. steady-state sounds; *A-A-A-A*), a neural model to represent the pattern is formed and when each incoming stimulus matches the existing model, habituation occurs. Conversely, incoming changing-state stimuli fail to match the neural model and elicit an OR, which in the context of irrelevant sound paradigm, leads to a capture of attention away from the focal task (Elliott & Cowan, 2001; Gati & Ben-Shakhar, 1990). The capture of attention away from the focal task interferes with the rehearsal processes and leads to poorer recall (Elliott, 2002).

The deviation effect is also considered the result of attentional capture (as is postulated in the duplex-mechanism account as well; Hughes et al., 2007). The unitary account proposes that levels of disruption will vary depending on the background in which the deviant is placed. A deviant placed with a steady-state sequence would be more disruptive than that in a changing-state sequence. If each token in a changing-state sequence is already capturing attention then the addition of a deviant should not have much of an additional effect. However, the addition of a deviant to a steady-state sequence would cause a greater deviation effect because prior to the deviant the repeated tokens were not capturing attention and habituation should have taken place (Elliott & Cowan, 2001).

Although the unitary account appears to describe distraction effects in a parsimonious manner, there are four lines of evidence that suggest the account may be untenable. First, if the CS effect is underpinned by attentional capture then it should manifest regardless of the processes employed in tasks. However, the evidence shows that the CS effect does not occur when rehearsal is prevented (e.g., Hanley, 1997; Jones et al., 2004) or absent due to the task not requiring serial rehearsal (e.g., Beaman & Jones, 1997; Perham, Banbury, & Jones, 2007). The second line of evidence comes from experiments showing that the effects of irrelevant speech do not habituate across trials (Jones & Macken, 1995; Bell, Röer, Dentale, & Buchner, 2012; Tremblay & Jones, 1998) and across experimental sessions (Hellbrück, Kuwano, & Namba, 1996). If distraction is determined by attention it should follow that prolonged exposure to irrelevant sounds should lead to habituation and a decrease in disruption. More recently, however, some evidence has emerged that habituation does occur but only if individuals are able to process the irrelevant auditory stimuli in the absence of a concurrent working memory load (Bell et al., 2012).

The proposed difference in disruption between steady and changing-state deviant sequences by the unitary account has not been reliably observed and evidence suggests that the magnitude of disruption caused by deviants in steady and changing-state sequences do not differ (Hughes et al., 2005, 2007). Hughes et al. (2005) suggested that changing-state sequences (without deviants) were not capturing attention because the neural model for the sequence would embody the notion that each token will differ from the preceding one. Similarly, the neural model for a steady-state sequence would reflect that each item will be the same. Therefore, when a deviant was added to these sequences it would be the only item within each sequence with the propensity to capture attention. In line with this prediction, results showed that the magnitude of the deviation effect in changing- and steady-state sequences did not differ (Hughes et al., 2005, 2007).

Finally, additional evidence contrary to the unitary account shows a non-monotonic relationship between token-set size and disruption to visual serial recall (Tremblay & Jones, 1998). Token-set size refers to the number of unique tokens in an irrelevant sequence and typically disruption increases when tokens increase from one to two tokens but any further increase in token-set size does not correspond with additional disruption (Bridges & Jones, 1996; Campbell et al., 2002; Hughes & Jones, 2005; Tremblay & Jones, 1998). The unitary account would predict that token-set size and disruption should increase monotonically because a greater number of tokens in an irrelevant sequence would slow down the rate of habituation and allow more time for disruption to take place (Cowan 1995, 1999). This, however, has not been observed – when the number of tokens increase beyond two (to five or seven tokens, for example) levels of disruption do not increase (Tremblay & Jones, 1998; but see also Campbell et al., 2002, who found a monotonic increase in disruption but only for auditory serial recall).

At the outset, the unitary account may have appeared a tenable account of distraction. However, upon closer investigation this is not the case and the need for a more detailed account of distraction is warranted. The differences between the CS effect and deviation effect suggest a double dissociation is present in the effects of distraction on short-term memory (however, see Körner et al., 2017). The evidence discussed in this section question the credibility of the unitary account and also lay a foundation for a more comprehensive account that considers the role of rehearsal and attention in determining distraction, namely, the duplex-mechanism account (Hughes et al., 2007; Hughes 2014). Having set the background, it will become clearer how the changing-state and deviation effects manifest in children who have poor rehearsal abilities and limited attentional control. This, in turn, may uncover the mechanisms responsible for distraction in children as compared with adults. The analysis of developmental research in distraction should allow for a more detailed consideration of the applicability of the duplex-mechanism account compared to the unitary account of distraction.

1.3 Developmental Differences in Irrelevant Sound Effects

The differences in the way the changing-state and deviation effects affect short-term memory raise questions about the likely developmental differences in sensitivity to these forms of distraction and the underlying mechanisms that govern them. Cognitive abilities, working memory capacity, attentional control, and motor-plan generation that underpin serial rehearsal undergo several changes across childhood and continue well into adolescence (e.g., Flavell, Beach, & Chinsky, 1966; Gathercole, 1998; Fair et al., 2009). These developmental changes, along with individual differences in distractibility and task performance, can determine one’s susceptibility to distraction. As such, the study of the irrelevant sound effect with a focus on developmental differences in susceptibility to distraction, is especially important, as it is a window into the cognitive and attentional mechanisms that underlie distraction at different points in the lifespan. Some research comparing distraction effects between young (18 to 30 years old) and old adults (60 to 85 years old) has failed to find any differences in age-related susceptibility to auditory distraction (Beaman, 2005; Bell & Buchner, 2007; Röer et al., 2015;

Rouleau & Belleville, 1996). This age equivalency in distraction is at odds with the inhibitory deficit theory which suggests that older adults are less able to inhibit irrelevant information from entering working memory and competing with goal-oriented behaviour and should therefore show greater distraction than young adults (Hasher & Zacks, 1988; Lustig, Hasher, & Zacks, 2007). The age equivalency found in these studies also suggests that a modification of inhibitory deficit theory is essential to incorporate the pattern of results – as Rouleau & Belleville (1996) and Röer et al. (2015) suggest, inhibition is not a monolithic construct that declines with age but it may contain specific subsystems some of which may be sensitive to age-related change in inhibitory capability while others may not (e.g., reduced inhibition of semantic distractors with age but an age-invariant inhibition of spatially-cued distractors; Carlson, Hasher, Connelly, & Zacks, 1995). An alternative explanation was suggested by Röer et al. (2015) in that the age equivalency may be interpreted in line with the age-invariant view of distractibility (Guerreiro, Murphy, & Van Gerven, 2010; Guerreiro & Van Gerven, 2011) which suggests that cross-modal auditory distraction may be immune to age effects because the ability to filter out auditory information at earlier processing stages (e.g., at sub cortical levels) is intact even in advanced age. Further, although Röer et al. (2015) showed that WMC was lower for older adults than young adults, this did not result in age-related differences in distraction – showing again that findings are more in line with an age-invariant view of distraction (Guerreiro et al., 2010; Guerreiro & Van Gerven, 2011).

In contrast to the findings among young and old adults, research comparing susceptibility to distraction between children and adults is somewhat mixed with some studies suggesting children are more susceptible to auditory distraction than adults (e.g., Elliott & Briganti, 2012; Elliott et al., 2016) while others have found no difference between the two groups (e.g., Klatte et al., 2010). Elliott (2002) set out to determine if a robust CS effect would manifest in children as it has in studies with adults (e.g., Hughes, Vachon, Hurlstone, Marsh, Macken, & Jones, 2011; Jones et al., 2010). Irrelevant speech (and tones) were included as distractors and participants were given list lengths for recall that had been adjusted to their individual memory span, ensuring equivalent levels of difficulty across participants and age groups. The classical Irrelevant Sound Effect (ISE; Jones & Macken, 1993) – poorer recall in the presence of irrelevant sounds compared to silence – was replicated in this study for adults and for children. Similarly, the CS effect was observed among all ages but was more pronounced for the youngest children (with an average age of 8 years 3 months). The key outcome of this study was that the magnitude of the ISE diminished with increasing age, suggesting that children were more affected by irrelevant sound than adults. The changing state effect was also larger among children than adults and changing-state speech was more detrimental to recall than tones among children, but not the adults. Further, the analysis of span showed significant increases from childhood to adulthood (ranging from an average of five items recalled by the youngest children to 7.5 items by the adults with a mean age of 19 years. This, coupled with the age-related findings regarding the ISE would suggest that the more capable individuals—older children and adults—were better able to resist distractive effects of sounds. As will become clear, this result does not cohere with the notion that susceptibility to the CS effect is underpinned by rehearsal (Elliott et al., 2016).

1.3.1 Auditory distraction and serial recall.

Elliott (2002) predicted that since rehearsal undergoes change as children develop (Flavell et al., 1966; Tam et al., 2010), it was reasonable to expect that younger children would show less interference-by-process relative to adults, if distraction was underpinned by rehearsal. Thus, children who rehearse TBR items less efficiently or not at all (rehearsal emerges around age 7; Flavell et al., 1966) would have poorer linkages between the items compared to older children and adults, thereby resulting in *smaller* disruptive effects that stem from an interference of rehearsal in the youngest group. However, if distraction was based on attentional control then there should be larger effects of distraction for younger children. Developmental improvements in memory and efficiency of attention would mean that children show much more disruption by irrelevant sounds because their attentional control is inferior relative to adults. The results obtained by Elliott (2002) were in favour of the latter prediction based on attentional control and children were more distracted by speech than sounds while adults were not. Less efficient attentional control may have compromised children's ability to tag and rehearse relevant visual items and to ignore irrelevant auditory elements thereby leading to poor recall with more errors than older participants (Elliott, 2002; Klatte et al., 2010).

The link between the ISE and short-term memory capacity (as assessed by a digit span test) and working memory capacity (as evaluated by operation span) among children was considered in a study by Elliott and Cowan (2005). The findings from this study were, on the whole, concordant with evidence that memory span is not an indicator of individual sensitivity to the ISE (Beaman, 2004; Ellermeier & Zimmer, 1997; Neath, Farley, & Surprenant, 2003; Sörqvist, Marsh, & Nöstl, 2013; cf. Elliott, Barrilleaux, & Cowan, 2006). However, there were some *positive* correlations between memory span, operation span and the magnitude of the ISE for adults and children. This pattern of results conflicts with the expectation of smaller disruptive effects for more capable individuals (i.e. those with a higher span) as suggested by Elliott (2002), Sörqvist, (2010a), and Sörqvist et al. (2013). In a Bayesian meta-analysis, Sörqvist et al. (2013) showed that the magnitude of the ISE and / or CS effect is unrelated to WMC, however, the deviation effect is modulated by WMC such that an increase in WMC leads to a decrease in the deviation effect (similar results observed by Hughes et al., 2013 & Sörqvist, 2010a; for a review, see Sörqvist & Rönnberg, 2014).

While Elliott and Cowan (2005) propose that the correlations could be a “statistical artefact” as span may be related to recall scores in the silent condition that were used to calculate the magnitude of the ISE, they are more likely to reflect a deleterious effect of irrelevant sounds on mnemonic processing such as rehearsal that was used in the focal task (e.g., Beaman & Jones, 1997; Jones, 1993). Higher span individuals may rely on rehearsal more than less capable individuals and if this processing was interrupted by irrelevant sounds then those who engaged in a greater level of rehearsal would experience greater disruption as manifested by more errors in recall (e.g. Beaman & Jones, 1997, 1998; Jones & Macken, 1993). The absence of a negative correlation between digit span and the magnitude of the ISE is surprising as one would expect the factors responsible for improvements in span to also account for the developmental decrease in sensitivity to disruption by irrelevant sounds. These factors could include the developmental improvements in attentional control (e.g., Lane & Pearson, 1982; Zukier & Hagen, 1978) and covert rehearsal abilities (e.g., Flavell et al., 1966). However, given the evidence from this study, it appears that there may be different influences on the development in span and the degree of the ISE. In fact, as Macken et al. (2009) have shown, serial recall performance does not correlate with distractibility, therefore, a measure of WMC (i.e. memory span) that relies on such a task will not correlate with the ISE and / or CS effect either. Furthermore, as Sörqvist (2010a) and Sörqvist et al. (2013) suggest, a relation between distraction and WMC may be evident only when distraction is the result of attentional capture and not when it is underpinned by an interference of rehearsal processes. High and low WMC individuals will be equally susceptible to the ISE and / or CS effect because these effects depend on the conflict between rehearsal and obligatory streaming of auditory information rather than the availability of executive resources (as indexed by WMC). When this is extended to developmental differences, it could suggest that children and adults should show equivalent irrelevant sound / CS effects but should vary in the deviation effect on account of different attentional capacities (high and low WMC individuals vary in the magnitude of the deviation effect; Sörqvist, 2010a; Sörqvist et al., 2013; see also Klatte et al., 2010).

In contrast with the foregoing studies, a study by Klatte et al., (2010) showed that the ISE was present for both children and adults but there was not the same striking difference between adults and children in the magnitude of disruption as noted by Elliott (2002). Klatte et al. (2010) required participants to recall the order in which a list of pictorially represented common nouns were presented. The nouns were phonologically dissimilar and of long (e.g., “Schmetterling”; the German word for butterfly) or short spoken duration (e.g., “Hund”; the German word for dog). Serial recall was completed in quiet, in the presence of irrelevant foreign speech (an article read from a Danish newspaper), and classroom noise which comprised typical classroom sounds but no speech (e.g., rattling of writing equipment, moving chairs, coughing). It is important to note here that the nature of the classroom noise was such that there was no predictable order among the sounds, therefore, the likelihood of order cues in the sequence was very low (Klatte et al., 2010). Results showed that recall performance of the youngest children (median age of 7 years, 0 months) was poorer in the presence of classroom noise compared to quiet unlike the older children (median age of 8 years, 5 months) and adult participants (median age of 22 years) who did not show significant disruption by classroom noise. By contrast, children and adults exhibited disruption by irrelevant speech. The expected differences in attentional control between the age groups coupled with the notion that classroom noise would not generate order cues were cited as reasons for the age-related finding.

These results were taken to be an indication of two separate forms of distraction, in line with the duplex-mechanism account (Hughes et al., 2007), where irrelevant speech caused distraction by interfering with rehearsal processes, and, classroom noise captured attention. The magnitude of the former was similar for children and adults while the latter was more pronounced for the young children as compared with the older children and adults. The finding that younger children were distracted by classroom noise (in addition to speech) suggested that they may show greater susceptibility to distraction because of poorer attentional control — similar to the conclusions drawn in studies by Elliott (2002) and Elliott et al. (2016). However, this study has been criticised for using a methodology that places lower demands on rehearsal and attentional control than a standard serial recall task with verbal material as the TBR items (Elliott et al., 2016). If the demands on rehearsal and attention were so low as to automatize their task performance then the effects of distraction would be minimal (Neumann, 1987).

Although Klatte et al. (2010) hinted that their results may be in line with the duplex-mechanism account of distraction (Hughes et al., 2007), they did not interpret the results within this framework. Instead, they explained the disruption to recall by irrelevant speech with reference to the O-OER and phonological store models (Baddeley, 1996; Jones & Macken, 1993) while the disruption by classroom noise for the youngest children was best accounted for as attention capture within the Feature model (Neath, 2000). In line with the phonological store perspective, the results showed that disruption among older children and adults was dependent on the distraction consisting of speech. Incoming visual and auditory information enter the phonological store through rehearsal and automatic access, respectively (Baddeley, 1996). The process of rehearsal serves two purposes — to convert visual information from graphemes to phonemes (for entry into the phonological store) and to maintain the traces of visual information within the phonological store (Baddeley, 2002). A conflict arises between the information that originates from the visual and auditory modalities because of their phonological similarity; and, since the irrelevant speech is processed automatically it masks the traces of TBR items leading to poorer recall (Salamé & Baddeley, 1982). However, this model is unable to account for the disruption by classroom noise since it emphasizes the need for phonological similarity in determining disruption.

According to the O-OER model, the detriment to recall is attributed to interference between relevant and irrelevant order cues. Therefore, the model can account for disruption by speech and non-speech effects so long as there are order cues in the irrelevant material that could interfere with those from relevant items (Jones & Macken, 1993). Nevertheless, in the study by Klatte et al. (2010), classroom noise was assumed to be devoid of order cues and as such should not be expected to cause disruption to serial recall. Therefore, the disruption by classroom noise among the youngest children contradicts this assumption and does not align with the O-OER model. This leaves the Feature Model (Neath, 2000) to account for the effects of classroom noise among the youngest group of children. According to this model, non-speech sounds do not cause disruption through the feature adoption process but rather through the capture of attention. To incorporate their results within the feature model, Klatte et al. (2010) suggested that because classroom noise contained many different acoustic events in an unpredictable order it would be difficult to ignore. This would be especially true for the youngest children because of their poor attentional control. From the perspective of the feature model, this would translate to a smaller attentional parameter to reflect children's poor attentional control and the nature of classroom noise (Neath & Suprenant, 2001). Taken together, this would result in disruption to recall performance by classroom noise only for the youngest children. However, given the difficulties of the feature model to adequately explain irrelevant speech and non-speech effects (discussed in Section 1.2.1), the interpretation of results using the model should be treated with caution.

The findings from Klatte et al (2010) suggested there may be scope for the application of the duplex-mechanism account to distraction effects among children. This was explored to a larger extent in a study by Elliott et al. (2016) and shed light on the contribution of rehearsal and attentional control in auditory distraction effects among children and adults. Among adults, greater disruption to serial recall was observed when irrelevant sounds coincided with points wherein the demands on serial rehearsal were particularly great (Macken et al., 1999). Armed with the knowledge that children’s rehearsal is still emerging, Elliott et al. (2016) tested the hypothesis that children will show greater sensitivity to distraction than adults as the rehearsal load increased. Children and adults completed a serial recall task in the presence of irrelevant speech and in quiet. Serial recall for children and adults was impaired by speech particularly in the latter half of presentation and all through the retention interval when the rehearsal load was at its highest. In addition, the results showed that children were more susceptible to disruption than adults which concurs with previous work showing that the magnitude of the ISE was greater for children than college students (Elliott & Briganti, 2012) and those studies showing an increased ISE for younger children compared to older children (e.g., Elliott, 2002; Elliott et al., 2007). Although the evidence from this study suggested that children’s inefficient rehearsal may make them more susceptible to distraction of the interference-by-process type, Elliott et al. (2016) offered an alternative explanation which attributes children’s particular susceptibility to distraction to attentional control factors. They proposed that since children have smaller working memory capacities (Cowan et al., 2005), and less inhibitory control over irrelevant stimuli (Hwang et al., 2010), the underdeveloped rehearsal could actually impose an attentional load that makes them particularly unable to ignore irrelevant sound and rehearse TBR items.

For the purposes of isolating rehearsal or attentional control as the basis of children's greater distractibility, Elliott et al. (2016, Experiment 2) contrasted distraction effects in tasks with and without a serial rehearsal component. Differences, if any, in the effects across these tasks, would demonstrate whether children's greater distractibility was simply a result of poor attentional control or a greater susceptibility to interference-by-process. As mentioned in the foregoing, among adults, studies have consistently shown that the CS effect is absent when serial rehearsal –the process essential for interference-by-process to occur —is suppressed (e.g., Hanley, 1997; Jones et al., 2004) or absent altogether (e.g., Beaman & Jones, 1997; Perham et al., 2007). However, the study by Elliott et al. (2016) was the first to test if this pattern also holds for children. If children's greater susceptibility is underpinned by attentional control and not rehearsal, then they should show disruption regardless of the processes needed for the focal task and regardless of the type of irrelevant sound (steady or changing). Elliott et al. (2016) demonstrated that children and adults were susceptible to interference-by-process in the task involving serial rehearsal and the magnitude of this effect was similar across ages. The finding that children's short-term memory was affected appreciably in both tasks by sound in general (steady or changing) supports the notion that children's poor attentional control underpins their greater sensitivity to distraction.

1.3.2 Effects of irrelevant speech outside the serial recall paradigm.

The research discussed in the foregoing has focused solely on serial recall but Klatte et al., (2007) expanded the research in the ISE paradigm beyond serial recall to assess the impact of irrelevant speech on phonological short-term memory (without order retention), speech perception, and sentence comprehension, among children.

Children completed these tasks in quiet, in the presence of irrelevant speech, and in the presence of continuous train sound. In the phonological short-term memory task, children were required to identify if non-word pairs were same or different. Performance was reduced by about 20% in the irrelevant speech condition compared to quiet and was unaffected by the train sound. In the speech perception task, children were required to identify a word that they heard in the different sound conditions by matching it with a picture representing the word. Speech perception (assessed as the number of correctly identified pictures) was unaffected by background speech but impaired by continuous train sound which concurs with previous studies that showed better intelligibility with background speech when compared to continuous noise (thought to be because of the greater concentration of spectral acoustical energy overlapping with that of speech from the focal task; Festen & Plump, 1990). For the sentence comprehension task, children were given verbal instructions which had to be carried out on response sheets (e.g., "Put a cross under the book that lies next to the chair"). Their performance was significantly lower in the presence of irrelevant speech compared to quiet but there was no effect of train sounds on sentence comprehension. The results observed in this study show that children's short-term memory performance and ability to store details derived from spoken language were affected by background speech (Klatte et al., 2007). The effects of irrelevant speech on performance in these domains cannot be attributed to masking because in the speech perception task, even though the target and distractor stimuli were auditory, there was no effect of irrelevant speech on performance.

Klatte et al. (2007) also assessed the impact of auditory distraction on phonological awareness, which has been identified as an important pre-reading skill (Burgess & Lonigan, 1998; Lonigan, Anthony, Phillips, Purpura, Wilson, & McQueen, 2009; Wagner & Torgesen, 1987). Children completed an "Odd One Out" task (e.g., Hogan, 2010) where they had to decide which of three words was different from the others. In addition, parents rated their child’s reading and spelling abilities which upon analysis correlated positively with the child’s performance in the task and confirmed that this task is linked with reading and spelling abilities. Performance in the phonological awareness task was severely affected by background speech but unaffected by continuous train sounds. A 25% decrease in performance was observed in the speech condition relative to the silent control condition. Collectively, the results from this study demonstrate the detrimental effects of noise (speech and non-speech) on children’s cognitive performance. The minimal disruption by train noise compared with the greater disruption by irrelevant speech show that the effects may be dependent on the varying acoustic nature of the sound (speech, in this study; Schlittmeier et al., 2012; Jones & Macken, 1993). This study is a good example of how the effects of irrelevant speech are not limited to serial recall, as marked disruption was noted in phonological awareness, language processing, and sentence comprehension.

A developmental ISE has also been found on semantic memory (Meinhardt-Injac et al., 2015). Children completed word classification and mathematical equation verification tasks in the presence of changing-state foreign speech and changing-state classroom noise (identical to that used by Klatte et al. 2010). The aim of using of irrelevant speech that the children did not understand and classroom noise was to prevent interference effects that could stem from semantic processing of the irrelevant material (Marsh et al., 2008, 2009; cf. Jones et al., 1990). Overall, their results showed that the younger children were more susceptible to auditory distraction than the older children, which is in line with findings regarding disruption of serial recall (Elliott, 2002; Klatte et al., 2010). Younger children performed poorly on both tasks in the presence of irrelevant sound (whether meaningless speech or classroom noise). However, there was no significant effect of classroom noise or speech on the older children’s performance in the word classification task. These results point to a clear developmental difference between the two groups of children in the way irrelevant sound affects retrieval from semantic memory. Research with adults has previously shown that meaningless speech was not disruptive of semantic processing because while the focal task required this type of processing, the irrelevant sequence did not, and therefore an interference-by-(semantic) process did not occur (Jones et al., 1990; Jones, Marsh, & Hughes, 2012; Sörqvist, Nöstl, & Halin, 2012). Contrary to these findings with adults, an ISE with meaningless speech was observed for the younger group of children. Since meaningless speech was used and did not require semantic processing like the focal task the disruption was not attributed to interference-by-process. Instead, Meinhardt-Injac and colleagues (2015) suggested that in the absence of interference-by-process effects, this pattern of results points to attention being drawn away from the focal task. This would be especially true for the younger children because of their immature attentional control increasing the likelihood that attention will be drawn away more easily regardless of the nature of the irrelevant material.

A convergence can be seen with regards to the effects of irrelevant speech among children of different ages. The overall pattern shows that younger children may be more susceptible to distraction by irrelevant speech and sounds regardless of processes involved in the task, for example, serial order processing, language-based tasks, or semantic processing (Elliott, 2002; Elliott et al., 2016; Klatte et al., 2010; Klatte et al., 2007; Meinhardt-Injac et al., 2015). The foregoing studies also show that children are distracted by irrelevant sounds regardless of its acoustic nature (steady- or changing-state), content (speech or non-speech), and meaning. In terms of developmental differences, these studies also show that differences in disruption as measured by the ISE or CS effect are likely to emerge because of differences in attentional control among different age groups rather than differences in rehearsal efficacy (Elliott et al., 2016; Meinhardt-Injac et al., 2015). It is worth noting here, that, the empirical studies in this thesis will also consider developmental differences in the ISE and CS effect and the processes that underlie these distraction effects. However, equally important in this thesis is the consideration, for the first time, of age-related differences in the deviation effect which will enable a more direct understanding of how attentional control can underpin distraction in childhood and adulthood. The assessment of a deviation effect among children and a developmental analysis of the effect between children and adults has not been assessed previously.

1.4 Rationale for a cross modal study of distraction

Research into distraction effects have used unimodal and cross-modal designs to assess the impact of distraction on cognition and behaviour – in unimodal distraction studies the distractor is from the same modality as the focal task while in cross-modal distraction the distractor is from a different modality to the focal task (e.g., Connelly, Hasher, & Zacks, 1991; SanMiguel, Corral, & Escera, 2008). In the present thesis, a cross-modal design was used as a means to understand the susceptibility of cognitive processes to distraction: a visual-verbal focal task was coupled with auditory distraction to assess how the irrelevant auditory material affects performance on the visual task (e.g., Colle & Welsh, 1976; Salamé & Baddeley, 1982, 1987). While extant literature shows that sudden changes in the environment, whether they are visual or auditory, may distract one’s attention even when the changes are irrelevant to the task at hand (Berti & Schröger, 2001), the decision to use a cross-modal design specifically with an auditory distractor and visual focal task was based on three reasons.

In real-life situations, we constantly deal with incoming stimuli from different sensory modalities. From this point of view, the scope of unimodal distraction paradigms appear limited compared to cross-modal settings where the impact of multisensory inputs can be assessed in relation to cognition, attention, and behaviour (Santangelo & Spence, 2008). Therefore, research that considers attention and distraction should be reflective of this complexity. In the context of the present study, the use of auditory distraction and a visual focal task could be considered analogous of school environments that are may be distracting because of traffic noise (e.g., near airports; Hygge, 2003; but see also Sörqvist, 2010b), classroom acoustics (e.g., Shield & Dockrell, 2003; Evans, 2006), and because of speech that is irrelevant to the task at hand (e.g., Klatte et al., 2010; Sörqvist, 2010b). Research has shown that these environments can have an impact on a wide range of attainments among children such as literacy, mathematics, problem solving, language comprehension, and memory (Elliott et al., 2016; Klatte, Bergstrom, & Lachmann, 2013; Klatte et al., 2010; Shield & Dockrell, 2008). Given the far-reaching effects of irrelevant sounds on cognitive performance and scholastic achievement, this experimental series considers the effects of irrelevant speech on visual verbal memory and the developmental differences in cognition and attention that may make children more susceptible to distraction.

Another reason for the cross-modal design to study developmental differences in distraction is because much of the research on age effects have come from unimodal distraction experiments while there is limited research using cross-modal paradigms that explores age effects. Unimodal visual experiments and auditory experiments have consistently shown that older adults are more vulnerable to distraction than young adults (e.g., Bialystok, Craik, Klein, & Viswanathan, 2004; Connelly et al., 1991; Elliott, Morey, Morey, Eaves, Shelton, & Lutfi-Proctor, 2014; Helfer & Freyman, 2008; Sommers & Danielson, 1999). In contrast, the evidence from cross-modal studies of distraction is mixed with studies using a cross-modal Simon Task, for example, indicating greater susceptibility to distraction among old adults than young adults (e.g., Proctor, Pick, Vu, & Anderson, 2005) while irrelevant sound studies suggest an age-equivalence between the two groups (e.g., Bell & Buchner, 2007; Enmarker, 2004; Röer et al., 2015; Van Gerven & Murphy, 2010; but see also Bell, Buchner, & Mund, 2008). Irrelevant sound studies also suggest that developmental differences in disruption are not necessarily associated with working memory capacity (Sörqvist, 2010a; Sörqvist et al., 2013). The evidence presented so far seems to suggest that age differences will manifest in unimodal paradigms more reliably than in a cross-modal distraction setting. However, within the irrelevant sound paradigm, developmental research comparing children and adults has shown a greater susceptibility to auditory distraction among children compared to adults (Elliott, 2002; Elliott et al., 2016; cf. Klatte et al., 2010) which contrasts with studies showing an age-equivalence between young and old adults. In light of the findings from research with adults and children thus far, it is hoped that the use of a cross-modal design in this experimental series will provide more information on the mechanisms that underpin developmental differences between children and adults. In addition, this design will allow for an understanding of the cognitive processes underlying such distraction at different points in the lifespan.

Finally, the research that has been conducted among children and adults contradict the hypothesis proposed by Guerreiro and colleagues which suggests that age differences are more likely to occur in a unimodal rather than cross-modal paradigm and if visual distraction is used (Guerreiro, Murphy, & Van Gerven, 2013). The hypothesis is based on evidence that auditory stimuli are filtered much earlier than visual stimuli – auditory information can be suppressed at sub-cortical and higher cortical levels while visual information is filtered only at a central level (e.g., in the visual cortex; Guerreiro et al., 2013). Presumably, this filtering mechanism will vary with age and result in developmental differences. In addition, the higher up distracting stimuli can reach, the more disruption they will cause. Therefore, suggesting that visual distractors will be more distracting than auditory ones because they are filtered at a later stage (Van

Gerven & Guerreiro, 2016). While this hypothesis may be applicable to findings among young and old adults, it does not seem to hold for the developmental differences observed in irrelevant sound studies with children and adults so far. The evidence for developmental differences between children and adults is still fairly limited, and therefore, the experimental series conducted here will enhance the existing body of knowledge and provide evidence to support or refute the hypothesis suggested by Guerreiro et al. (2013).

1.5 Operational definitions.

As the foregoing sections show, the effect of task-irrelevant background on short-term memory has been widely assessed and this research has identified specific forms of disruption to recall. In the interest of clarity, this section summarises the definitions of the most commonly used terms, acronyms, and tasks used in the irrelevant sound paradigm and in the thesis.

1.5.1 Irrelevant speech effect or irrelevant sound effect (ISE).

This refers to the finding that recall performance in the presence of irrelevant speech or sounds is lower than in quiet (e.g., Colle & Welsh, 1976; Jones & Macken, 1993). The ISE has been observed with speech and non-speech sounds and hence the term Irrelevant Sound Effect is used to encompass distraction from both these sources. Within the thesis, the ISE was assessed as the difference between recall performance in quiet and individual irrelevant speech conditions, regardless of whether the speech was steady- or changing-state, or contained deviants (see below).

1.5.2 Changing-state effect.

A changing-state auditory sequence is one wherein each element in the sequence is different to the preceding one (e.g., A – B – A - B) while in a steady-state sequence a single item is repeated (e.g., A – A – A – A). The finding that recall performance is lower in the presence of changing-state speech or sounds compared to steady-state is known as the CS effect (e.g., Hughes et al., 2007; Macken et al., 1999). This pattern of disruption has been observed in the literature consistently but only when the memory task required items to be recalled in the order they were presented (Beaman & Jones, 1997; Hughes et al., 2007). This process of remembering items in order is often supported by a serial rehearsal strategy whereby items are repeated subvocally in the order they were presented. As such, the CS effect is thought to occur only in those tasks that invoke serial rehearsal (e.g., Beaman & Jones, 1997). The CS effect in the present experiments was calculated as the difference between recall scores in changing-state, versus steady-state, speech.

1.5.3 Deviation effect.

This refers to the capture of attention by unexpected changes in the irrelevant auditory stream (Hughes et al., 2007; Vachon et al., 2012). When there are elements in the auditory stimulation that deviate from the prevailing pattern (e.g., G – G – G – G – **L**) the unexpected element triggers attention capture away from the focal task and towards the deviant in the auditory sequence (Hughes et al., 2007). In comparison to the CS effect, the deviation effect is not sensitive to the processes engaged by the focal task and is manifest in a wide range of tasks such as categorization tasks (Parmentier, 2008), visual and audio-visual search tasks (Dalton & Lavie, 2004; Dalton & Spence, 2007), and the missing-item task (Vachon, Labonté, & Marsh, 2016). In the current series, the deviation effect was the difference between performance in steady- or changing-state speech with and without deviants.

1.5.4 Short-term memory tasks used in the thesis.

Serial recall, probed recall, and the missing-item task are commonly used short-term memory tasks within the irrelevant sound paradigm. TBR items in these tasks are often digits (e.g., Hughes & Jones, 2005) and letters (Jones et al., 2004) but can also comprise words (e.g., Marsh, Hughes, Sörqvist, & Beaman, 2015) and pictures (e.g., Klatte et al., 2010). While these tasks differ in terms of the involvement of rehearsal, their successful performance requires the focus of attention. The serial recall and probed recall tasks are thought to require the use of serial rehearsal while the missing-item task does not. The contrast between tasks on the basis of rehearsal involvement is an opportunity to show how the motor-articulatory processes that support rehearsal are affected by auditory distraction and to identify how the developmental differences in motor-planning processes can dictate the level of distraction that is observed.

Serial recall.

In this task, the objective is to reproduce a list of items in the order of presentation. A common strategy used to complete this task is serial rehearsal – repeating the items subvocally in the order that they were presented.

Probed recall.

The retention of order information is also crucial in this task but the response demands vary compared to a typical serial recall task. Instead of recalling the entire list of items in order, the task requires identification of the item that followed another in the list. For example, the list presented could be ‘5 4 7 2 1’ and at the recall stage participants may be asked ‘Which digit followed ‘7’ in the list?’. Therefore, the order in which the items were presented must be retained to identify which item followed the probe. This task, like serial recall, calls upon motor planning which subserves serial rehearsal and the retention of order information.

Missing-item task.

The objective in this task is to identify the one item that was missing or omitted from the list. The TBR lists used for this task generally comprise a well-known or overlearned set of items such as digits from zero to nine (Beaman & Jones, 1997; Elliott et al., 2016; Hughes et al., 2007) or spatial locations of dots (Vachon et al., 2016). TBR items are presented in a similar fashion to the serial and probed recall tasks but at the recall stage, participants are asked ‘Which item was missing from the list?’. The crucial difference between the missing-item task and the other two tasks is the extent to which serial rehearsal is used. Unlike serial and probed recall tasks, the missing-item task is not thought to involve serial rehearsal because the retention of order of information is not essential to complete the task. In other words, the missing-item task does not require motor-planning. This task does, however, require attention for items to be encoded upon presentation and for the missing-item to be identified at recall.

1.6 The present studies

The empirical studies in this thesis explore the role of developmental differences in rehearsal and attentional control in determining one’s susceptibility to auditory distraction. This overarching aim has guided the choice of tasks and the irrelevant material used. In line with the duplex-mechanism account, a distinction is expected between the occurrence of the CS and deviation effects as a function of task type. Furthermore, age-related differences in the involvement of rehearsal and attentional control in the focal task will determine impact upon the patterns of disruption that are observed. If children, like adults, are engaging in rehearsal then the CS effect will be expected (for both groups) in serial recall and probed recall but not missing-item (Hughes et al., 2007). However, if the children are not rehearsing, then the CS effect should be absent among them. Since existing literature suggests that children begin to rehearse around seven years of age (Flavell et al., 1966), the CS effect might be expected with children aged seven years and older but not for those under seven years old. Nevertheless, if the results indicate that there is a CS effect among children under the age of seven then this would in turn suggest rehearsal is present among this age group (e.g., Henry et al., 2012). Further, if the CS effect for children is the result of attentional capture (Elliott, 2002) then it should manifest not only in serial and probed recall tasks but in the missing-item task too. Finally, if attentional capture underpins all distraction among children then there should be no dissociation between the CS effect and deviation effect (Elliott & Cowan, 2001). Alternatively, the extent to which rehearsal is automatized may also play a role — less automatized rehearsal among children (e.g., Bebko, 1984; Clerc et al., 2014) may make them less susceptible to interference-by-process if they are not consistently using rehearsal as a strategy in the serial and probed recall tasks (see also Lehmann & Hasselhorn, 2012). Conversely, a greater susceptibility to the CS effect may be observed among adults because even though their rehearsal is fully automatized, it is the act of engaging in rehearsal (in the presence of changing-state sounds) that gives rise to the CS effect (Hughes et al., 2007)

All three tasks require the focus of attention to encode information, and therefore, a deviation effect is expected to occur in all the tasks subject to the influence of developmental differences in attentional control. It is predicted that children will exhibit a deviation effect in all three tasks and that the effect will be greater than adults since children have poorer attentional control (and rehearsal; Cowan et al., 2001; Lehmann & Hasselhorn, 2007, 2012). Elliott et al. (2016) have shown that children’s underdeveloped rehearsal acts as an additional attentional load that exacerbates their already poor attentional control and makes them more susceptible to distraction. Therefore, within the context of the present empirical series it is predicted that children will exhibit a deviation effect in serial and probed recall tasks because of their inchoate rehearsal acting as an additional attentional load while the deviation effect in the missing-item task (in the absence of a rehearsal strategy) will be due to their poor attentional control. This prediction is in line with the automatization hypothesis because it would follow that the use of rehearsal which is not yet fully automatized would exacerbate children’s limited attentional control (Clerc et al., 2014) and make them more likely to exhibit a deviation effect. In the absence of rehearsal, however, attentional capture will still occur since children have poorer attentional control than adults (Elliott et al., 2016).

For the adults, the deviation effect is expected to be stronger in the missing-item task than in serial or probed recall. This prediction is based on the finding that an increase in task difficulty results in more steadfast task engagement which in turn shields adults from distraction by attentional capture (Hughes et al., 2013). Therefore, when adults complete serial and probed recall tasks they will be less likely to exhibit a deviation effect if rehearsal promotes task engagement. On the other hand, the absence of rehearsal (i.e., greater task engagement) in the missing-item task may make them more likely to exhibit a deviation effect in this task. The extent to which attentional control modulates vulnerability to distraction can be identified through these experiments, however, the role of attention cannot be examined in isolation given that some distraction is governed by the use of rehearsal (e.g., Hughes et al., 2007; Miles, Jones, & Madden, 1991). Since rehearsal is fully automatized in adults, the use of this strategy is less likely to place additional demands on the cognitive system (Clerc et al., 2014) and therefore will not increase the likelihood of attentional capture among adults. However, adults will still be susceptible to the CS effect because the very act of rehearsal makes one susceptible to changing-state disruption.

CHAPTER II

EMPIRICAL STUDY I: ARE THERE AGE-RELATED DIFFERENCES IN THE SUSCEPTIBILITY TO AUDITORY DISTRACTION?

Abstract

This study examines the developmental differences in distraction by irrelevant speech among children and adults. Children aged 7-9 years old (*N* = 40) and adults aged 18-22 years old (*N* = 40) completed three visual short-term memory tasks – serial recall, probed recall, and a missing-item task – the first two requiring serial rehearsal while the latter does not. Irrelevant speech sequences consisting of steady-state (SS; e.g. A-A-A-A), changing-state (CS; e.g., A-B-A-B), and deviant speech sequences (e.g., A-B-**A**-B-A; a male-spoken token – shown here in bold – which was embedded in a sequence spoken by a female voice) were played during each task while baseline performance was assessed in quiet. The duplex-mechanism account predicts that when rehearsal is deployed (as in serial recall and probed recall tasks), performance will be disrupted to a larger extent by CS speech than SS speech and will reflect the classical CS effect; but, no such difference will emerge when rehearsal is absent in the task (i.e., missing-item task). The CS effect differs from the 'deviation effect' which occurs when deviant or unexpected sounds capture attention away from the focal task whether or not rehearsal is used. The deviation effect will be reflected by lower performance in deviant speech than when deviants are absent. In contrast, the unitary account supposes that the CS and deviation effects are the result of attentional capture and, therefore, will occur regardless of the processes underlying each task (Elliott, 2002). In terms of developmental differences, it is argued that children's underdeveloped rehearsal would cause less fluent links between the items that are being rehearsed and allow greater opportunity for CS sounds to interfere with rehearsal and impair recall to a larger extent than among adults

(Elliott et al., 2016; Macken et al., 1999). The alternative possibility, however, is that children's underdeveloped rehearsal may pose an additional attentional load and exacerbate their already poor attentional control leading to a greater susceptibility to distraction than adults (Elliott et al., 2016; Cowan et al., 2005). A study by Elliott et al. (2016) has previously found that children were more susceptible to distraction than adults not because of greater interference with rehearsal but because of children's poorer attentional control that made them more likely to be distracted by any sort of sound (whether steady or changing) whether or not the task involved rehearsal. Two hypotheses are proposed for the present study: first, in line with the duplex-mechanism account the CS effect will occur only when rehearsal is engaged in the task (i.e., in serial and probed recall tasks but not the missing-item task) and the deviation effect will occur regardless of task type. Second, children will show a greater susceptibility to both types of distraction than adults because of their underdeveloped rehearsal and poorer attentional control. The results unequivocally support the first hypothesis – for children and adults, the CS effect was present only when rehearsal was engaged in the tasks while the deviation effect was present whether or not rehearsal was a dominant strategy in the task. The results provide partial support for the developmental hypothesis because although children did not exhibit a greater magnitude of disruption than adults they were susceptible to attentional capture in all three tasks compared to adults who were susceptible only in the missing-item task. The results support the duplex-mechanism account by showing that distraction effects are separable on the basis of their underlying mechanisms. The results also suggest that children may be more susceptible to attentional capture than adults. The results are in line with that of Elliott et al. (2016) in suggesting that children may be more susceptible to distraction on account of their poorer attentional control that may be exacerbated when rehearsal is engaged in the focal task.

2.1 Introduction

Short-term memory is the ability to store small amounts of information over brief periods of time (e.g., 18-20 seconds) for recall either immediately or after a short delay (Baddeley, 2015 as cited in Baddeley, Eysenck, & Anderson, 2015). The need to maintain information over the short-term is an essential ability for a range of activities – whether that be language and sentence comprehension, vocabulary development, problem-solving, and arithmetic tasks (Baddeley, 2014; Majerus, Poncelet, Greffe, & Van der Linden, 2006) or simply remembering a shopping list in the supermarket (Marshuetz, 2017). Evidence from neuroimaging and behavioural studies show that short-term memory is not a unitary system but rather comprises of functionally distinct systems (Atkinson & Shiffrin, 1968; Cabeza & Moscovitch, 2013; Smith & Jonides, 1997; Smith, Jonides, & Koeppe, 1996) that deal with verbal and visuo-spatial material (Gathercole, 1999).

In the present study, the focus will be on understanding the effects of task-irrelevant speech on the efficiency of verbal short-term memory. A common method employed to store verbal information in short-term memory is rehearsal – a process that involves overt or covert repetition of items to assist their entry and maintenance in memory (Baddeley, 2014) and a process that is especially vulnerable to disruption by irrelevant speech (e.g., Jones & Macken, 1993; Jones et al., 1993). According to the working memory model, the phonological loop is specialized in handling verbal information from visual and auditory modalities (Baddeley, 1986). Within the phonological loop is the phonological store, a short-term store where verbal information is stored for about two seconds; and, the articulatory control process which rehearses verbal information in order to maintain the memory trace within the store (Baddeley, 2000; Baddeley & Hitch, 1974). Auditory-verbal information is thought to gain automatic access to the store because it is already in the phonemic code needed for storage while visual-verbal information gains access only after it has been recoded to phonemic code by rehearsal by the articulatory control process (Baddeley, 2003; Jones et al., 2004). Rehearsal serves two purposes – first, it converts graphemes to phonemes to enable entry to the store and second, it maintains the items within the store by refreshing their traces and preventing decay (Jones et al., 2004). The maintenance of information through rehearsal is especially vulnerable to irrelevant auditory material (speech or non-speech) which is automatically processed even when individuals are aware that the auditory material is task-irrelevant (e.g., Colle & Welsh, 1976; Jones & Macken, 1993; Salamé & Baddeley, 1982). The impact of irrelevant sounds on recall is especially evident in serial recall tasks wherein individuals must remember a list of items in the order they were presented – evidence shows that serial recall is particularly vulnerable to disruption by irrelevant sounds because of disruption to rehearsal by irrelevant sounds that change from one element to the next (e.g., Jones, 1994; Jones & Macken, 1993; Jones et al., 1993; Hughes et al., 2005).

The vulnerability of rehearsal to auditory distraction provides an avenue for research concerning developmental differences in susceptibility to distraction as a consequence of differences in the quality and use of rehearsal among children and adults (Elliott et al., 2016). Two opposing viewpoints have emerged with regards to the emergence of rehearsal among children. On the one hand, there is an argument for qualitative change in subvocal rehearsal which proposes that rehearsal emerges around 7 years of age (Flavell et al., 1966) or younger (Gathercole, 1998; Henry et al., 2012). On the other hand, the quantitative view suggests that rehearsal becomes more efficient as articulation rates increase with age (e.g., Hulme, Thomson, Muir, & Lawrence, 1984). However, there are six lines of evidence, which lend support to the qualitative view of rehearsal (see also Section 1.1). First, children under the age of seven tend not to show lip movements, which are indicative of primitive subvocal rehearsal (Flavell et al., 1966). Second, the positive correlation between articulation rates and memory spans seen among adults have only been noted in children over the age of seven (e.g., Ferguson et al., 2002; Gathercole et al., 1994). Third, the presence of the phonological similarity effect when TBR items are presented visually indicates that items have been recoded subvocally and can be linked to phonological rehearsal – these errors occur naturally in phonologically similar lists as spoonerisms but in serial recall tasks as order errors (Jones, Macken, & Nicholls, 2004; MacKay, 1970). Again, this effect has not been reliably noted in children under the age of seven (e.g., Halliday et al., 1990; Hitch et al., 1991). Fourth, the absence of the word length effect among children under the age of seven is also an indication that they are not rehearsing (the word length effect disappears when rehearsal is prevented; Baddeley et al., 1975). Fifth, there is evidence to show that as language proficiency improves, the use of rehearsal as a strategy for recall becomes more likely — therefore, it follows that the automatization of language skills around the age of six or seven gives rise to the use of a more verbal-based strategy (i.e. rehearsal; Bebko & Metcalfe-Haggert, 1997). Sixth, support for the qualitative view also comes from the evidence showing the development of inner speech. From age six onwards, children’s self-directed speech becomes quieter and by the age of eight it is completely internalized (Vygotsky, 1934). Inner speech is akin to rehearsal and children use inner speech to guide their actions and assist in memory performance (Mahy et al., 2016).

In the present study, if children who are between seven and nine years old are rehearsing during the serial recall task then they should be susceptible to the same pattern of disruption (i.e. the CS effect; see section 1.4.2 and 1.4.3) as that observed among adults. However, if the children are not rehearsing then not only should their performance in the serial recall task be poor but the CS effect should not occur either. Both these results would favour the qualitative view of rehearsal because if children are susceptible to the CS effect then it would provide evidence to show this age group of children are in fact using rehearsal. If they are not susceptible to the CS effect it could be the case that children may rehearse at a later age. In terms of rehearsal efficiency, the prevailing pattern of results suggests that children experience greater disruption to serial recall than adults as a consequence of their poorer rehearsal abilities (Elliott, 2002; Elliott & Briganti, 2012; Elliott et al., 2016; cf. Klatte et al., 2010). It is argued that when TBR items are subject to poor rehearsal (as would be the case among children) the links between the items will be less fluent and this would allow greater opportunity for seriation cues that are generated automatically by changing-state irrelevant sounds to interfere with rehearsal and impair recall (Elliott et al., 2016; Macken et al., 1999). There is an alternative possibility, however, which suggests that children's underdeveloped rehearsal may act as an additional attentional load especially in cases where task demands are high – this coupled with smaller working memory capacity (WMC) among children would exacerbate their ability to ignore irrelevant stimuli and may make them more susceptible to distraction than adults (Elliott et al., 2016; Cowan et al., 2005).

The involvement of rehearsal in distraction effects is only part of the picture. Attentional control and WMC can also determine the extent to which task-irrelevant stimuli are processed (Conway et al., 2001) and can capture attention (e.g., Hughes et al., 2013; Sörqvist, 2010; Sörqvist, Stenfelt, & Rönnberg, 2012). Not only do children have less efficient rehearsal compared to adults they also have poorer attentional control and smaller working memory capacities which should in turn modulate the pattern of distraction observed among them (Elliott & Cowan, 2005). Given the complex nature of the factors involved in distraction it would appear that the duplex-mechanism account (e.g., Hughes et al., 2007; Hughes, 2014) is more suited to explain distraction effects compared to the unitary account (e.g., Bell, Dentale, Buchner, & Mayr, 2010; Cowan, 1995). These accounts attribute distraction to different causes. The duplex account delineates distraction into interference-by-process and attentional capture (Hughes et al., 2007). The CS effect is an example of the former while the Deviation effect reflects the latter. The CS effect occurs when the seriation processes obligatorily allocated to irrelevant sounds interfere with the processes deliberately directed towards the focal task (e.g., Jones & Macken 1993; Jones & Tremblay, 2000; Jones et al. 2004). The deviation effect refers to attentional capture away from the focal task by novel or unexpected irrelevant sounds (e.g., Hughes et al., 2005; Vachon et al., 2012) or by a sound that is salient to the listener (such as hearing one's name; Conway et al., 2001). The unitary account, however, attributes both forms of distraction to attentional capture (Cowan, 1995; Elliott, 2002).

Although the unitary account may provide a parsimonious account of distraction, there is ample evidence to support the dichotomy proposed by the duplex-mechanism account (Hughes et al., 2013; Hughes & Jones, 2005; Hughes et al., 2005, 2007; Jones et al., 2010). Two strands of evidence are described below as they are particularly relevant to the present study. In support of the duplex-mechanism view, the CS and deviation effects differ in their sensitivity to task processes and with regards to WMC involvement in modulating distraction. While the deviation effect manifests in tasks regardless of the processes involved, the CS effect is only present when serial rehearsal is deployed in task performance (Beaman & Jones, 1997; Jones et al., 2004; Hughes et al., 2007). WMC modulates the deviation effect but not the CS effect – in studies with adults, those with higher WMC were better able to resist attentional capture by deviants but their susceptibility to the CS effect did not vary as a function of WMC (e.g., Hughes et al., 2013; Sörqvist, 2010a; for a review, see Sörqvist et al., 2013).

The differences observed in sensitivity to task processes and WMC were applied in the present study to test the premise of the duplex-mechanism account. The memory tasks that were used differed in their requirement for serial rehearsal – it is thought that serial and probed recall tasks require serial rehearsal while the missing-item task does not (Beaman & Jones, 1997). It is expected that the CS effect will only manifest in the serial and probed recall tasks if rehearsal is involved. The deviation effect is expected to manifest in all three tasks regardless of processes deployed to complete the tasks (Hughes, 2014; Hughes et al., 2007; Vachon et al., 2016). With regards to developmental differences, the obvious differences between children and adults in rehearsal and attentional control should in turn reflect differences in susceptibility to distraction as a function of age. In line with previous findings (e.g., Elliott 2002; Elliott et al., 2016) children should be expected to show greater susceptibility to distraction than adults. A measure of working-memory capacity (Operation Span; Unsworth, Heitz, Schrock, & Engle, 2005) is incorporated in the present empirical series (in Study I and III) with the aim of showing that the deviation effect (but not CS effect) is modulated by WMC. If smaller working-memory capacities make individuals more susceptible to the deviation effect then it should be the case that children show a greater deviation effect than adults as a function of their WMC. No relation between the CS effect and WMC is expected (cf. Körner et al., 2017; Sörqvist et al., 2013).

Given the complex nature of factors that underpin distraction, it is not surprising that existing evidence about developmental differences in distraction is mixed. While some studies have suggested that children are more susceptible to irrelevant sound than adults (Elliott, 2002; Elliott & Briganti, 2012; Elliott & Cowan, 2005; Elliott et al., 2016), others determine that the magnitude of disruption is roughly equal (Klatte et al., 2010). Many variables have contributed to these varied results such as the children’s age at testing, tasks used, and the type of material employed as the TBR and TBI stimuli.

Given the contradiction in findings, a key aim of the present study was to identify if there were any developmental differences between children and adults in irrelevant speech effects on tasks with and without a serial rehearsal component.

Logically, one would expect developmental differences to emerge following findings that rehearsal (e.g., Flavell et al., 1966; Gathercole et al., 1994), attentional and inhibitory control (e.g., Hwang et al., 2010; Luna et al., 2001), and working memory (e.g., Bayliss, Jarrold, Baddeley, Gunn, & Leigh, 2003) undergo striking developmental change from childhood to adulthood. Some or even all of these developmental changes may give rise to differences in susceptibility to and disruption by irrelevant sound. Investigating the role of attention and rehearsal in distraction among children and adults can serve three purposes. First, it will inform our understanding of short-term memory and its vulnerability to distraction at different points in the life span. Second, it will provide a window into the vulnerability of those cognitive functions and activities reliant upon short-term memory. Finally, identifying developmental differences in the factors that underpin distraction will provide invaluable knowledge that could potentially be applied in schools and learning spaces to curb the negative impact of auditory distraction.

The following experiment capitalizes on the premise that changing-state and deviant sounds disrupt memory for order and the focus of attention, respectively. Poorer recall is predicted in changing-state compared to steady-state speech in the serial and probed recall tasks but not the missing-item task in line with the duplex-mechanism account (Hughes et al., 2007). By contrast, the duplex account predicts recall in all three tasks will be poorer in the deviant speech conditions compared to non-deviant conditions (e.g., Hughes, 2014; Vachon et al., 2016). It is predicted that while rehearsal (in serial and probed recall) will be interrupted by changing-state sounds, attention will be diverted from the focal tasks by deviant speech tokens. From a developmental perspective, it is hypothesised that children will exhibit a greater disruption to recall than adults (Elliott, 2002; Elliott et al., 2016; Klatte et al., 2010). If the underlying mechanism of this developmental difference is rehearsal then the CS effect will be larger for children than adults (Elliott, 2002). Alternatively, if attentional control underpins the difference between children and adults (Elliott et al., 2016) then the deviation effect will be larger for children than adults.

2.2 Method

2.2.1 Participants.

Eighty-seven participants were recruited for this study. Forty undergraduate students aged 18-22 years old (30 females; *M* = 19.84 years, *SD* = 1.07) from the University of Central Lancashire and 40 children aged 7 to 9 years old (24 females; *M* = 8.54 years, *SD* = .61) from a primary school in Lancashire took part in this study. There were initially 47 children who took part, however, data from only 40 of the children were suitable for analysis due to child absences from school, technical issues with the testing equipment, and some children withdrawing from the study. The above reported age range, mean age, and standard deviation are for the sample after accounting for participant attrition.

Ethical approval for this study was obtained from the University of Central of Lancashire (see Appendix A). For the children to participate, consent was obtained from their parents. Information sheets and consent refusal forms were sent to parents two weeks prior to the first testing day (see Appendix B). An opt-out consent procedure was used which required parents to send the consent refusal form back if they did not want their child to participate. No action was required on their part if they were willing to let the child take part. This consent procedure was followed across all three studies.

All participants reported normal hearing and normal or corrected-to-normal vision. Some adult participants wore spectacles and were asked prior to beginning the task whether they could see the information on screen clearly. For the children, teachers advised on whether children had any visual or hearing problems and developmental disabilities; those who were known to have some difficulty were not asked to participate. The university students received course credit or a £5 shopping voucher for their participation and the children were given stickers at the end of testing.

2.2.2 Design

A 5 (Auditory Condition) × 3 (Task Type) × 2 (Age Group) mixed design was used with two within-participant factors and one between-participants factor. The first within-participant factor was Auditory condition and had five levels: Quiet, Changing-State, Steady-State, Changing-State + Deviant, and Steady-State + Deviant. The latter within-participant factor was Task Type and there were three tasks: Serial Recall, Missing-item, and Probed Recall. The between-participants factor was Age Group and had two levels: Adults and Children.

2.2.3 Apparatus and Materials

All tasks across the three studies were run on a desktop computer or laptop using E-Prime 2.0 software (Psychology Software Tools). The screen size (and resolution) was 19" (1920 × 1080 pixels) and 15.6" (1280 × 1024), respectively, for the desktop and laptop computers. Sennheiser HD- 202 headphones were used to present the TBI auditory sequences for the memory tasks. Sounds were approximately 55 dB (A) as measures with a sound level meter and earphone coupler.

To-be-ignored auditory sequences.

The auditory sequences were recorded using a broadcast quality Dictaphone in a sound attenuated chamber and then edited using Sony Sound Forge Pro 11 software

(Sony Creative Software). Four spoken items were recorded, the letters ‘A’ and ‘B’ in a female and a male voice, and then digitally edited to 250ms with a 16-bit resolution and a sampling rate of 44.1 KHz. These were used to construct four types of auditory sequences: changing-state speech (*ABAB…*or *BABA…*all in a female voice), steady-state speech (*AAAA…* or *BBBB…*all in a female voice), a changing-state sequence with one of the female-spoken items replaced with a ‘deviant’ male-spoken item *(AB**A**BA…;* male-spoken item in bold and underlined) and a deviant male-spoken item within a steady-state sequence (*AA**B**AA…*). A quiet condition was also included, making a total of five auditory conditions.

The TBI irrelevant speech sequences were constructed such that there were two speech tokens per TBR item: each of the two speech tokens was 250ms with quiet intervals of 250ms after each token (see Figure 1). Therefore, a four-item TBR list had 8 speech tokens while a 7-item list had 14 speech tokens. The length of the auditory sequence varied with the list length for recall, for example, a four-item list spanned 4000ms but a seven-item list was 7000ms. The onset of the TBI auditory sequence was simultaneous with the presentation of each visual digit.

To-be-remembered material.

Digits from 0 to 9 were used as TBR stimuli for the recall tasks. The digit sequence for each trial was randomly generated using MATLAB ensuring that digits were sampled without replacement, and, with the constraint that no sequence had three or more consecutive digits in ascending or descending order (e.g.: *2, 8, 7, 6, 4*) . Each TBR item appeared in black 72 point *Arial* font on a white background for 1000ms with no inter-stimulus interval.

	1000ms				**1000ms**			
TBR item	8				6			
	250ms	250ms	250ms	250ms	250ms	250ms	250ms	250ms
TBI item	A	Quiet	B	Quiet	A	Quiet	B	Quiet

Figure 1. A schematic representation of timings used for TBR item presentation and TBI distraction sequences for all three recall tasks.

Tasks.

Two memory span tasks were performed in quiet followed by three recall tasks in the presence of irrelevant speech. These were serial recall, missing-item, and probed recall. The list length for each of the three recall tasks was based on the individual's final digit span score.

Automated operation span.

The operation span task (OSpan) is based on that developed by Unsworth et al. (2005). The test is mouse-driven and can be run independently of the Experimenter. Participants were asked to solve a mathematical operation as quickly as possible and then decide whether the answer shown was *True* or *False*. After each mathematical problem, a letter was presented on the screen and participants had to remember the letters in the order they had appeared. At the end of each trial, an array of letters appeared and participants were asked to click on the letters in the order they were presented; if they were unsure they were asked to select ‘Blank’ which would insert a space in the response box. Three trials of each set size were presented and set sizes ranged from 3 to 7. This made for a total of 75 mathematical operations (addition and subtraction only) and 75 letters. Figure 2 depicts the progression of a typical operation span trial. For children, the mathematical operations were simplified and consisted of single digits in the mathematical problem with the constraint that when added the result was also a single digit. For adults, mathematical operations comprised of double digits. The task took approximately 25 min to complete. When scoring the task, points were given for every letter that was correctly recalled across the task.

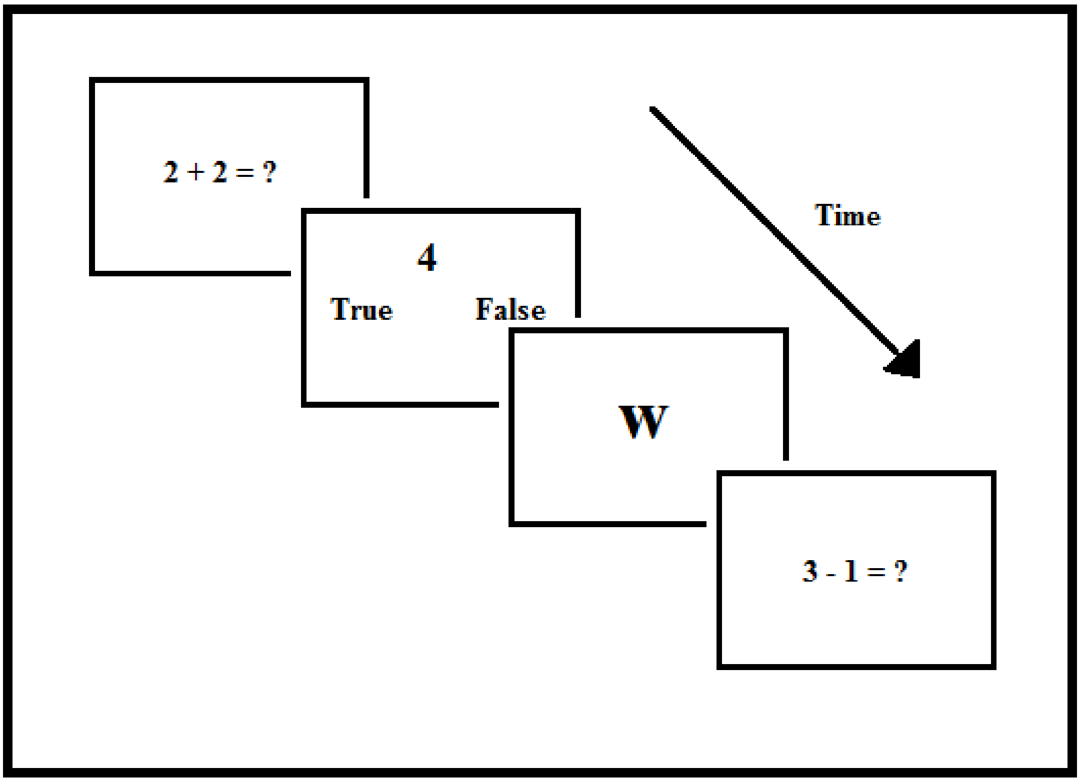


Figure 2. Example of a typical operation span trial for adults and children.

Digit span test.

This was used to assess a participant's verbal short-term memory capacity. Participants were shown digits on screen and were required to recall them in the order they were presented. There were three trials of each set size ranging from three to nine items. The test ended when participants were unable to correctly recall at least two trials of a given set size and the last set size that was correctly recalled at least twice was taken as the individual's digit span. This task took 8-10 min to complete.

Digit serial recall.

Participants were shown a list of digits drawn from 0-9 on screen and were required to recall them in the order they were presented. At the end of each list, the text ‘Click on the numbers in the order they appeared. If you cannot remember a number, just guess’ was shown for 1000ms and the digits 0-9 were displayed in canonical order and the participant had to click the digits in the order of presentation. There was no time-limit on recall and the cue for the next trial – the word ‘Begin’ – appeared when all the response boxes were filled. Participants had to click on ‘Begin’ for the next trial to commence. The task was completed in 18-20 min.

Probed recall task.

This task also involved a fixed list of digits but the recall demands were different. Participants were asked to identify which digit followed another in the list. At the end of each list, the question ‘Which number followed *x* in the list?’ was displayed on the screen for 1000ms. This was followed by the recall screen with the list of digits presented in canonical order and one response box below the list. Once the response was made, the word ‘Begin’ would appear on the screen to indicate the next trial.

Missing-item task.

Participants were instructed that a fixed list of digits would be shown on screen (e.g., Digits from 0-5) and that one digit would be missing from this list. Their task was to identify the missing digit. At the end of each list, the question ‘Which number was missing from the list?’ was displayed on the screen for 1000ms followed by the recall screen with the digit array. Responses were made with mouse clicks and the word ‘Begin’ would appear after the response was registered. Participants needed to click on ‘Begin’ to initiate the next trial. Each digit was missing roughly an equal number of times. The task was completed in 15-18 min.

Table 2.1

Number of trials for each age group and auditory condition in each of the three tasks

Auditory condition	Adults	Children
Quiet (within changing-state block)	8	6
Quiet (within steady-state block)	8	6
Changing-state speech	16	12
Steady-state speech	16	12
Changing-state + deviant	8	6
Steady-state + deviant	8	6
Total number of trials	64	48

2.2.4 Procedure

The order of the two span tests and that of the three recall tasks were counterbalanced across participants so that an equal number of participants were assigned the span tests and recall tasks in one of two and one of six order-permutations, respectively. Participants completed the digit span test prior to operation span or vice versa. The six order permutations for the recall tasks were ABC, ACB, BAC, BCA, CAB, CBA, wherein A was serial recall, B, probed recall, and C, missing-item task.

Within each recall task there was a steady-state and changing-state block and these were also counterbalanced across participants. Counterbalancing of the blocks was programmed within E-Studio such that odd-numbered participants received the steady-state block followed by changing-state (and vice versa for even-numbered participants). The auditory conditions presented within each block were pseudo-randomly organized within the block with the constraint that no more than two consecutive trials would be presented with the same type of auditory condition. Each block had 32 trials for the adults and 24 trials for the children. Table 2.1 shows the number of trials that participants completed for each task and for each auditory condition.

Adult participants were tested in a quiet lab in groups of up to four people and the Experimenter was present throughout the testing session which lasted roughly 60-70 min. Participants were seated at a viewing distance of approximately 60 cm from the display monitor. All participants first completed the span tests and then undertook the recall tasks. They were not required to wear headphones for the span tests. However, for the three recall tasks, headphones were worn for the duration of each task. Participants were instructed to ignore the sounds played through the headphones and reassured that they would not be tested on the auditory material at any point during the study.

Children were tested in a quiet class room arranged to accommodate six children at a time. The testing sessions were drawn out over four weeks and children completed the span tests in the first week followed by one of the three memory tasks in subsequent weeks. This staggered testing was preferred so that the children were not fatigued by the tasks and did not spend more than 20-30 min on any given task.

Laptops were used for these testing sessions and children were seated approximately 60 cm from the display. The Experimenter and an assistant were present throughout the testing session and the tasks were explained verbally and with the use of flash cards to facilitate better understanding. The children were told that noises would be played through the headphones but they were to ignore them and focus on the task. Some of the children required assistance with the use of the mouse and/or keyboard and the Experimenter or the assistant provided this support. Half way through each recall task, participants would be prompted by an on-screen message that they could take a short break and would need to press the Space Bar to continue to the next part.

2.3 Results

This section outlines the performance of children, and adults in the serial recall, probed recall, and missing-item tasks in Study I. The initial ANOVAs for each task incorporated all four irrelevant speech conditions (Changing-State Speech, Steady-State Speech, Changing-State Deviant Speech, and Steady-State Deviant Speech) and Quiet to identify if there are significant differences between recall performance in quiet versus irrelevant speech. Typically, lower performance is observed in one or more irrelevant speech conditions compared to quiet and this is known as the Irrelevant Speech Effect (ISE).

The subsequent ANOVA had a 2 (State: Changing or Steady) × 2 (Deviation: Absent or Present) format which was aimed at identifying the presence of the CS effect and Deviation Effect. The CS effect manifests as lower recall in the changing-state condition (CS) relative to the steady-state condition (SS) and is typically observed in tasks that rely on serial rehearsal (i.e., serial and probed recall). The Deviation Effect is represented by lower recall in the presence of deviants (CS + *d* and SS + *d*) than when they are absent (CS and SS only). Greehouse Geisser corrections were applied to degrees of freedom whenever appropriate. Planned contrasts were used to clarify main effects because there were clear hypotheses regarding the differences between conditions (e.g., recall in irrelevant speech would be lower than in quiet and recall in changing-state speech would be lower than in steady-state speech).

Baseline data (performance in quiet) were used to test for normality and while serial recall data for the adults were normally distributed, the distribution was not normal for probed recall and missing-item. The children’s data for all three tasks were not normally distributed. There were outliers among the adult group in the probed recall and missing-item tasks and among the children in serial recall only. These scores were retained in the analysis because they were flagged as outliers in one out of three tasks only. Additionally, although their baseline scores were the lowest in each group, it was representative of performance in other auditory conditions (i.e., these participants showed a general lower level of performance compared to others). In addition, the scores were not so low to suggest errors in calculation or deliberately poor performance. Although the data were not normally distributed, ANOVA was still used to examine differences in the means because given the large sample size and the nature of the ANOVA itself, the type 1 error rate would still be controlled (Field, 2013).

2.3.1 Children

Serial Recall Task.

The raw data were scored based on the strict serial recall criterion: an item was scored as correct (score of 1) only if the item's recall serial position and presentation serial position were the same. A proportion correct score was calculated for each sound condition as follows:

(a) For each trial, the number of correctly recalled serial positions was divided by the total number of serial positions in the trial. For example, in a serial recall trial with five serial positions, if three serial positions were correctly recalled, then the proportion correct for that trial would be 0.6 (i.e., 3/5).

(b) For each sound condition, children completed 12 trials while adults completed 16 trials. Therefore, there were 12 (or 16) proportion correct scores for children (or adults). The participant's final score for each sound condition was the average of the proportion scores, that is, total of the proportion correct scores divided by the number of trials (either 12 or 16).

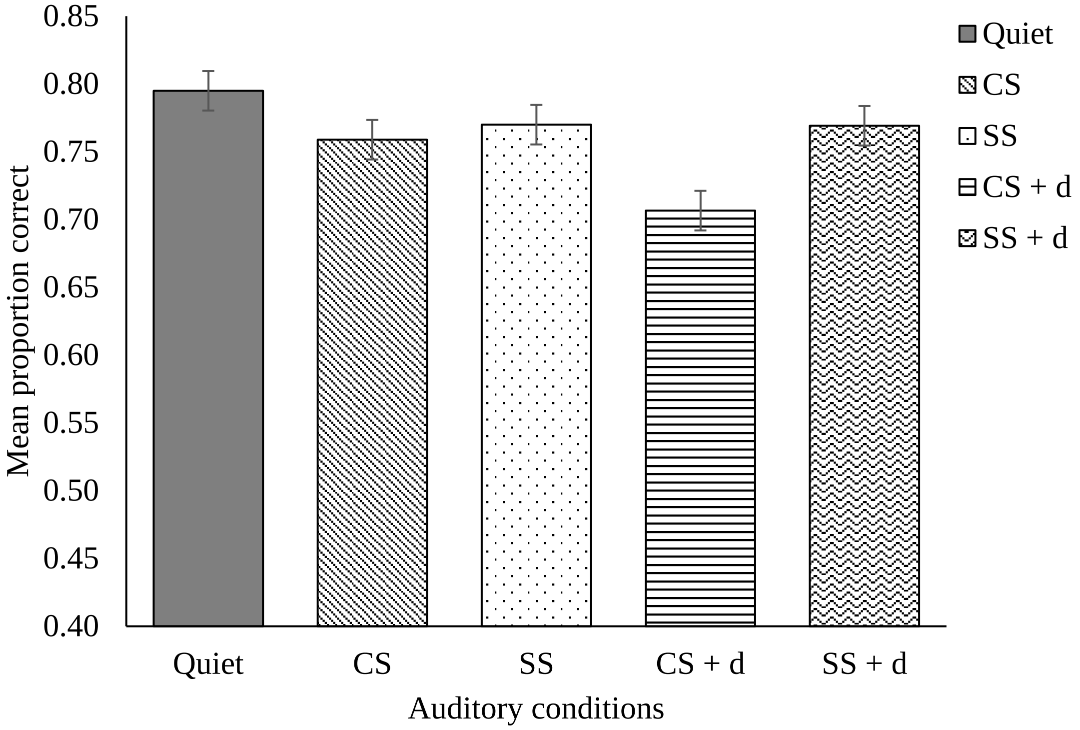


Figure 3. Mean serial recall performance across different auditory conditions for the children. Error bars represent standard error of the mean.

Figure 3 shows the serial recall accuracy of the 7 to 9-year-old children in each of the sound conditions. An initial repeated-measures analysis of variance (ANOVA) which incorporated all five sound conditions showed a significant main effect of Auditory Condition, *F*(3.32, 129.53) = 3.64, *MSE* = .05, $p = .012$, $\eta_p^2 = .08$. Planned contrasts revealed that recall performance in CS (*M* = .76; *SD* = .22) and CS + *d* (*M* = .71; *SD* = .23) were significantly lower than in Quiet (*M* = .79; *SD* = .18; $p = .045$ and $p = .001$, respectively). Performance in SS (*M* = .77; *SD* = .24) and SS + *d* (*M* = .77; *SD* = .23) conditions were not significantly lower than that in Quiet (both *p*s > .05).

A 2 (State: Changing or Steady) × 2 (Deviant: present or absent) repeated-measures ANOVA revealed a significant main effect of State, *F*(1, 39) = 3.55, *MSE* = .05, $p = .033$ (one-tailed), $\eta_p^2 = .08$, while the main effect of Deviation was nearing significance, *F*(1, 39) = 2.70, *MSE* = .03, $p = .054$ (one-tailed), $\eta_p^2 = .06$. These results confirm the presence of the CS Effect: serial recall was poorer when each sound element was different from the preceding element ($M_{\text{CS speech}}$ = .76) compared to when one element was repeated ($M_{\text{SS speech}}$= .77). Although the means show serial recall was poorer in the presence of deviants (*M* = .74) than in their absence (*M* = .76), this was not a significant difference and suggests the absence of a deviation effect. The interaction between State and Deviation was not significant, *F*(1, 39) = 2.39, *MSE* = .03, *p* = .130, η_p^2 = .06, suggesting that the deviation effect was not dependent on the sequence in which the deviants were placed.

Probed Recall Task.

For this task, a score of one was given every time the participant correctly recalled the digit that appeared after the probe. The mean score for each sound condition was calculated as the total number of correct responses divided by the number of trials for that condition. Figure 4 shows children's performance in this task and similar to serial recall, there was a detrimental effect of irrelevant speech on recall performance.

There was a significant main effect of Auditory Condition, *F*(3.12, 121.80) = 6.06, *MSE* = .22, *p* = .001, η_p^2 = .13, and planned contrasts showed performance was lower only in CS (*M* = .65; *SD* = .25) and CS + *d* conditions (*M* = .57; *SD* = .29) compared to Quiet (*M* = .71; *SD* = .22; *p* = .033 and .001, respectively). Performance in SS (*M* = .74, *SD* = .25) and SS + *d* (*M* = .67; *SD* = .31) were not significantly different from that in Quiet (both *p*s > .05). The subsequent 2 (State) × 2 (Deviation) ANOVA indicated a significant main effect of State, *F*(1, 39) = 11.1, *MSE* = .36, *p* = .002, η_p^2 = .22, and Deviation, *F*(1, 39) = 8.90, *MSE* = .24, *p* = .005, η_p^2 = .19. There was a non-significant interaction, *F*(1, 39) = .10, *MSE* = .004, *p* = .751, η_p^2 = .003. These results point to the presence of a CS effect and deviation effect on probed recall performance.

The lack of an interaction suggests the deviation effect is present regardless of which sequence the deviant was placed.

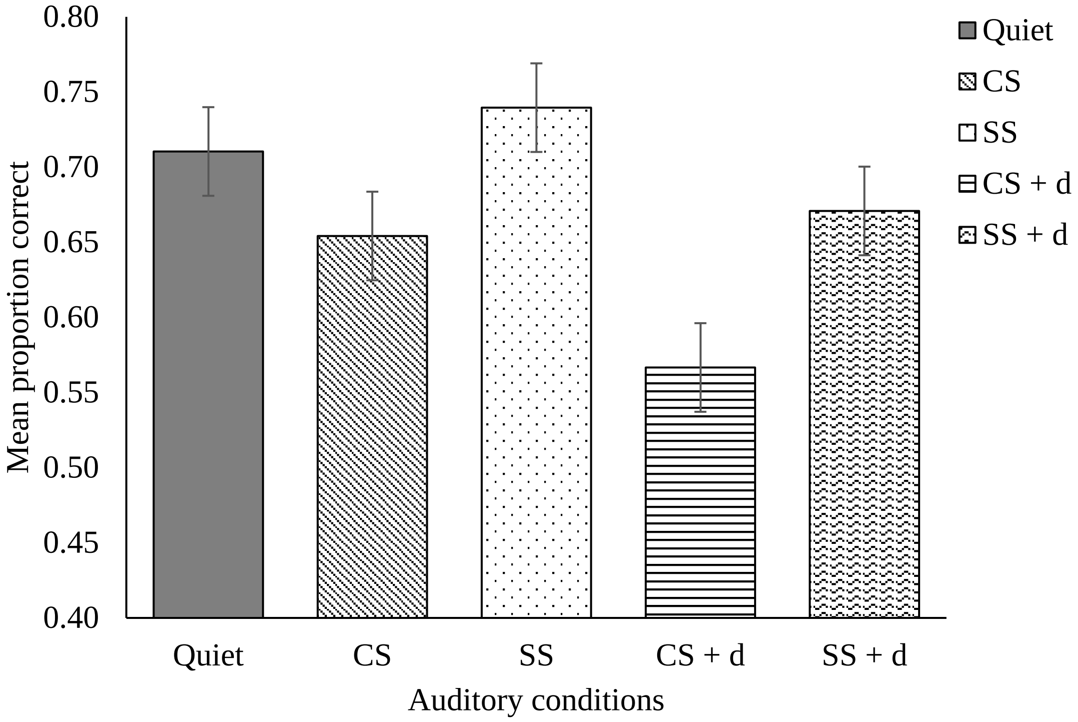


Figure 4. Mean recall performance in the probed recall task across the different sound conditions for children. Error bars represent standard error of the mean.

Missing-item Task.

The effects of irrelevant speech in this task appeared to be minimal (see Figure 5). The main effect of Auditory Condition on recall was not significant, *F*(2.87, 111.81) = 2.44, *MSE* = .06, *p* = .07, η_p^2 = .06. However, planned contrasts indicated that performance in CS + *d* speech (M = .73, *SD* = .26) was significantly lower than that in Quiet (*M* = .81, *SD* = .19; *p* = .010). Recall scores in CS (*M* = .80, *SD* = .18), SS (*M* = .78, *SD* = .19), and SS + *d* (*M* = .79, *SD* = .22) conditions were not significantly lower than in Quiet (all *p*s < .05). Similarly, the main effects of State, *F*(1, 39) = .86, *MSE* = .02, *p* = .359, η_p^2 = .02, and Deviation, *F*(1, 39) = 2.29, *MSE* = .03, *p* = .139, η_p^2 = .05, were not significant. The two-way interaction, however, was significant [*F*(1, 39) =

5.38, $MSE = .07$, $p = .026$, $\eta_p^2 = .12$] and a simple main effects analysis of Deviation (present or absent) in each sequence (changing or steady) indicated a significant effect of Deviation (CS > CS + *d*) only when the voice deviants were placed within changing-state speech, $F(1, 39) = 5.55$, $MSE = .10$, $p = .024$, $\eta_p^2 = .12$.

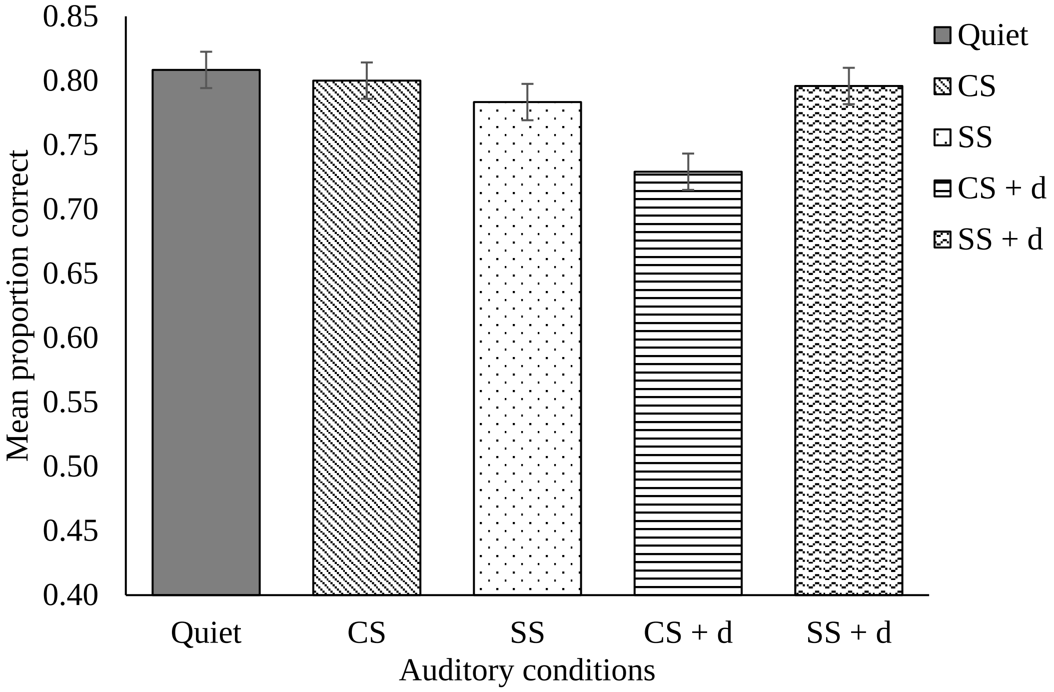


Figure 5. Mean proportion correct in different auditory conditions in the missing-item task. Error bars represent standard error of the mean.

2.3.2 Adults

Serial Recall Task.

Figure 6 shows adults' serial recall performance in all sound conditions. The initial repeated measures ANOVA with all five auditory conditions revealed a significant main effect of Auditory Condition on serial recall accuracy, $F(3.05, 119.02) = 8.75$, $MSE = .07$, $p < .001$, $\eta_p^2 = .18$. Planned contrasts showed that recall performance in Quiet ($M = .81$; $SD = .10$) was significantly higher than recall in CS ($M = .73$; $SD = .13$; $p < .001$), CS + *d* ($M = .72$; $SD = .15$; $p < .001$), and SS + *d* conditions ($M = .77$; $SD = .13$; $p = .022$). Recall in SS speech ($M = .77$; $SD = .13$) was not significantly different from Quiet (*p* = .062). There was also a significant main effect of State, *F*(1, 39) = 8.07, *MSE* = .09, *p* = .007, η_p^2 = .17, indicating the presence of the CS effect where recall was lower in the presence of CS speech than in SS speech.

An examination of the means suggested that the presence of deviants did not have much negative impact on recall performance and this was confirmed by the ANOVA which showed the main effect of Deviation was not significant, *F*(1, 39) = 2.03, *MSE* = .005, *p* = .162, η_p^2 = .05. These results reflect the absence of a deviation effect on serial recall for the adult group. There was also a non-significant interaction between State and Deviation, *F*(1, 39) = .05, *MSE* = .0002, *p* = .817, η_p^2 = .001.

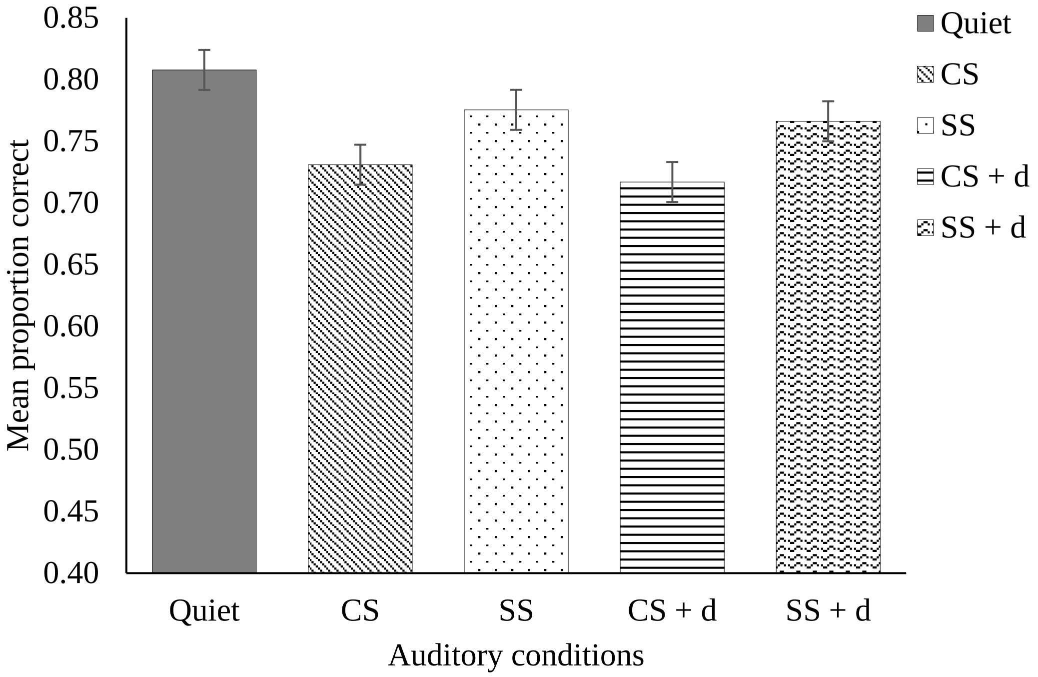


Figure 6. Mean serial recall performance across different auditory conditions for the adults. Error bars represent standard error of the mean.

Probed recall task.

Figure 7 shows the recall accuracy of adult participants in the probed recall task. The initial ANOVA showed a significant main effect of Auditory Condition, *F*(4, 156)

= 6.66, *MSE* = .13, $p < .001$, $\eta_p^2 = .15$. Planned contrasts showed that recall was significantly higher in Quiet (*M* = .75, *SD* = .18) than in CS (*M* = .64, *SD* = .20; $p < .001$), SS (*M* = .68, *SD* = .16; *p* = .010), CS + *d* (*M* = .60, *SD* = .24; $p < .001$), and SS + *d* (*M* = .66, *SD* = .22; *p* = .016) conditions. The main effect of State was significant, *F*(1, 39) = 4.86, *MSE* = .13, *p* = .034, $\eta_p^2 = .11$, however, the main effect of Deviation, *F*(1, 39) = 2.19, *MSE* = .03, *p* = .147, $\eta_p^2 = .05$, and the interaction between State and Deviation, *F*(1, 39) = .27, *MSE* = .005, *p* = .605, $\eta_p^2 = .01$, were not significant.

Missing-Item Task.

The impact of irrelevant speech on recall in this task is not as pronounced as in the previous two tasks. Figure 8 shows recall performance of adults on the missing-item task. There was a significant main effect of Auditory Condition on recall performance, *F*(3.12, 2.72) = 3.69, *MSE* = .08, *p* =.013, $\eta_p^2 = .09$. Planned contrasts showed that recall performance was significantly lower in CS (*M* = .80, *SD* = .16; *p* = .042), SS (*M* = .79, *SD* = .18; *p* = .017), CS + *d* (*M* = .74, *SD* = .20; *p* = .001), and SS + *d* (*M* = .80, *SD* = .18; *p* = .045) conditions compared to Quiet (*M* = .86, *SD* = .12).

The main effects of State, *F*(1, 39) = .53, *MSE* = .01, *p* = .472, $\eta_p^2 = .01$, and Deviation, *F*(1, 39) = 1.79, *MSE* = .03, *p* = .188, $\eta_p^2 = .04$, were not significant. However, the two-way interaction was significant, *F*(1, 39) = 4.26, *MSE* = .04, *p* = .046, $\eta_p^2 = .10$. Simple main effects analyses revealed that a deviation effect was present only when deviants were in a CS speech sequence (CS > CS + *d*), *F*(1, 39) = 5.13, *MSE* = .07, *p* = .029, $\eta_p^2 = .12$.

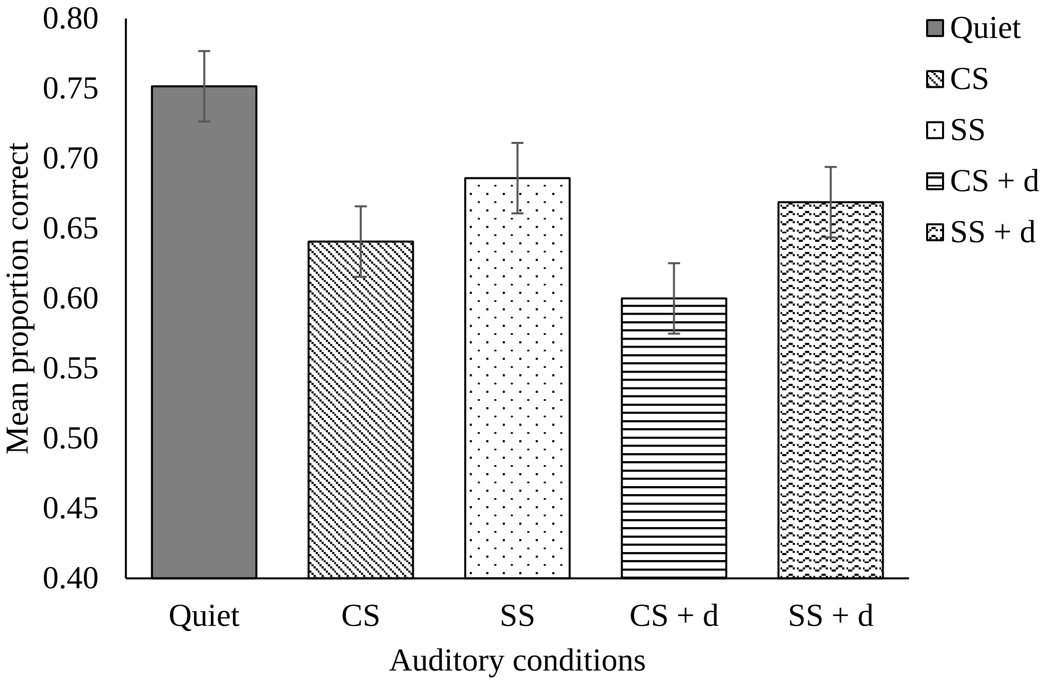


Figure 7. Recall accuracy of the adult group on the probed recall task across different auditory conditions. Error bars represent standard error of the mean.

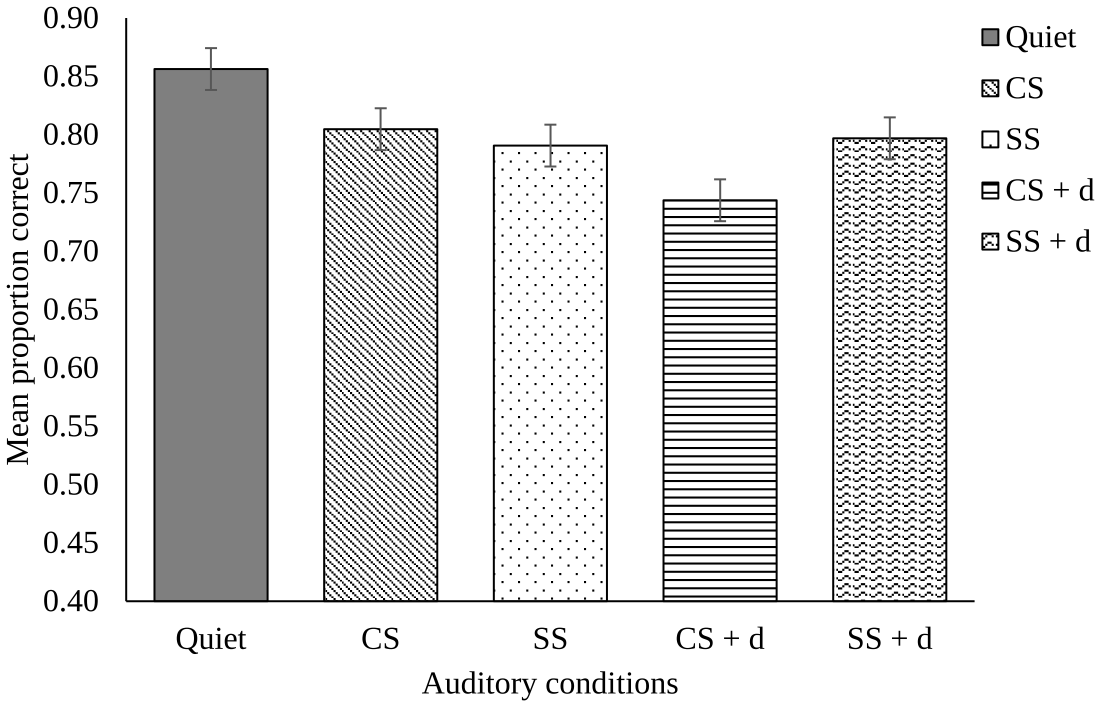


Figure 8. Graph showing the mean recall of adult participants in different auditory conditions on the missing-item task. Error bars represent standard error of the mean.

2.3.3 Developmental differences.

ANOVAs for each task with Age as the between-participants factor and Auditory Condition (Quiet, CS, SS, CS + *d*, and SS + *d*) as the within-participant factor were conducted. There was a significant main effect of Auditory Condition on serial recall, probed recall, and missing-item task performance. However, the two-way interaction (Auditory Condition × Age Group) was not significant in any task. Table 2.2 summarizes the main effects and interactions from this analysis.

Table 2.3 shows results from a 2 (State: Changing or Steady) × 2 (Deviation: Present or Absent) × 2 (Age Group: Adults vs Children) repeated measures mixed ANOVA. As expected, the main effect of State (recall performance in SS > CS) was significant only in those tasks requiring serial rehearsal (i.e. serial recall and probed recall only) and not in the missing-item task for children and adults. There was a non-significant interaction between State and Age. The main effect of Deviation was significant in each task but as there was no significant interaction with Age it suggested there was no significant difference between adults and children with regards to the deviation effect. The two-way State × Deviation interaction was significant only for the missing-item task and simple main effects analyses showed that a deviation effect was present only when deviants were placed in the changing-state speech sequence – recall performance was significantly lower in CS + *d* (M = .73) than in CS speech (M = .80) while there was no significant difference between recall in SS and SS + *d* conditions.

One-way ANOVAs comparing the magnitude of the CS and deviation effects across age-groups showed no significant differences between children and adults with regards to the magnitude of disruption in any task (see Table 2.4).

Table 2.2

Repeated Measures Mixed ANOVA showing the main effect of Auditory Condition and Auditory Condition × Age interaction for each task.

Task	Factors	df	*MSE*	*F*	*p*	η_p^2
Serial recall	Auditory Condition	3.44, 286.01	.10	10.13	**<.001**	.12
	Auditory Condition × Age	4, 312	.01	.61	.652	.01
Probed recall	Auditory Condition	3.26, 254.02	.33	11.37	**<.001**	.13
	Auditory Condition × Age	4, 312	.03	1.23	.298	.02
Missing-item	Auditory Condition	3.14, 245.18	.12	5.74	**<.001**	.07
	Auditory Condition × Age	4, 312	.01	.43	.789	.01

Table 2.3

Results from a 2 (State) × 2 (Deviation) × 2 (Age) Repeated Measures Mixed ANOVA

Task	Factors	df	*MSE*	*F*	*p*	η_p^2
Serial Recall	State	1, 78	.14	10.72	**.002**	.12
	Deviation	1, 78	.09	4.45	**.038**	.05
	Age	1, 78	< .001	.01	.922	< .001
	State × Age	1, 78	.002	.15	.696	.002
	Deviation × Age	1, 78	.004	.68	.411	.01
	State × Deviation	1, 78	.02	2.07	.155	.03
	State × Deviation × Age	1, 78	.01	1.42	.237	.02
Probed Recall	State	1, 78	.46	15.6	**< .001**	.17
	Deviation	1, 78	.23	10.74	**.002**	.12
	Age	1, 78	.002	.04	.842	.001
	State × Age	1, 78	.03	.96	.329	.01
	Deviation × Age	1, 78	.05	2.27	.136	.03
	State × Deviation	1, 78	.01	.33	.569	.004
	State × Deviation × Age	1, 78	< .001	.004	.949	< .001
Missing-Item	State	1, 78	.04	1.37	.25	.02
	Deviation	1, 78	.06	4.05	**.048**	.05
	Age	1, 78	.001	.04	.845	< .001
	State × Age	1, 78	.001	.02	.886	< .001
	Deviation × Age	1, 78	<.001	.004	.948	< .001
	State × Deviation	1, 78	.11	9.64	**.003**	.11
	State × Deviation × Age	1, 78	.001	.11	.740	.001

Table 2.4

Results from a One-Way ANOVA Assessing Age-Related Differences in the Magnitude of the CS Effect and Deviation Effect on Recall Performance

Task	Magnitude of	df	*MSE*	*F*	*p*
Serial Recall	CS effect	1, 78	.02	1.51	.223
	Deviation effect	1, 78	.01	.10	.755
Probed Recall	CS effect	1, 78	.03	1.01	.318
	Deviation effect	1, 78	.02	2.27	.136
Missing-Item	CS effect	1, 78	< .001	.01	.945
	Deviation effect	1, 78	.02	.004	.948

2.3.4 Missing-item vs Probed recall: The role of rehearsal and attention.

Recall performance in missing-item and probed recall tasks were compared in order to assess whether there were differences in the effects of auditory distraction because of the differences in task requirements. These two tasks were compared because although item presentation and response demands (i.e. a single response is needed) were identical they differed with regards to the retention of order – the probed recall task requires retention of order while the missing-item task does not. Since the missing-item task is considered to be devoid of serial rehearsal in contrast to the probed recall task, the CS effect should not manifest in the missing-item task. As both tasks require the focus of attention for successful execution, it is expected that there will be a deviation effect present for both tasks because of attention being diverted from the focal task.

A 2 (State: Changing or Steady) × 2 (Deviation: Present or Absent) × 2 (Task: Missing-item or Probed recall) × 2 (Age Group: Children and Adults) mixed ANOVA was conducted. The focus of this analysis was to identify the differences in the CS and deviation effect between the two tasks whilst also noting any differences because of age.

There was a significant main effect of Task, *F*(1, 78) = 48.11, *MSE* = 2.59, *p* < .001, η_p^2 = .38, which reflected better performance in the missing-item task (*M* = .78, SD = .16) compared to probed recall (*M* = .65, SD = .20). There was also a significant main effect of State, *F*(1, 78) = 12.19, *MSE* = .39, *p* = .001, η_p^2 = .14, which was further clarified by the presence of a significant interaction with Task [*F*(1, 78) = 4.28, *MSE* = .12, *p* = .042, η_p^2 = .05]. Simple main effects analyses showed that for the probed recall task (but not missing-item) participants performed significantly lower in CS speech (*M* = .65, *SD* = .22) than in SS speech (*M* = .71, *SD* = .21). There was no significant difference between performance in CS speech (*M* = .80, *SD* = .17) and SS speech (*M* = .79, *SD* = .18) in the missing-item task. These results point to the presence of a CS effect only in the task requiring serial rehearsal (i.e. probed recall task).

The main effect of Deviation was also significant, *F*(1, 78) = 15.50, *MSE* = .27, *p* < .001, η_p^2 = .17, and performance in the presence of deviants (*M* = .70) was significantly lower than in their absence (*M* = .74). The absence of a significant interaction between Deviation and Task, *F*(1, 78) = 1.28, *MSE* = .03, *p* = .261, η_p^2 = .02, suggests that the effect is present regardless of task type and is consistent with the notion that deviants disrupt performance regardless of processes involved in the task.

The main effect of Age Group, *F*(1, 78) = .001, *MSE* < .001, *p* = .977, η_p^2 < .001, was not significant. The four-way interaction between State, Deviation, Task, and Age Group was also not significant, *F*(1, 78) = .06, *MSE* = .001, *p* = .812, η_p^2 = .001. The interactions between State, Deviation, and Age Group, *F*(1, 78) = .02, *MSE* < .001, *p* = .898, η_p^2 < .001, State, Task, and Age Group, *F*(1, 78) = .39, *MSE* = .01, *p* = .535, η_p^2 = .01, and Deviation, Task, and Age Group, *F*(1, 78) = .1.13, *MSE* = .02, *p* = .291, η_p^2 = .01, were not significant. The two way interactions between State and Age group, *F*(1,

78) = .59, *MSE* = .02, *p* = .444, η_p^2 = .01, Deviation and Age Group, *F*(1, 78) = 1.51, *MSE* = .03, *p* = .223, η_p^2 = .02, and Task and Age Group, *F*(1, 78) = .19, *MSE* = .01, *p* = .666, η_p^2 = .002, were also not significant.

2.3.5 Analyses with Span measures

Correlation analysis.

The relationship between span measures (Digit span and Operation Span) and the magnitude of the CS effect and deviation effect were assessed using Pearson's product-moment correlation. Since deviants were embedded in changing- and steady-state contexts, the effects of deviants were assessed separately for each context (i.e. a Changing-State deviation effect and a Steady-State deviation effect). Correlations are presented in Table 2.5.

For the children, digit span and the magnitude of the changing-state deviation effect in the probed recall task were weakly positively correlated. On the other hand, Operation Span did not correlate with any of the effects. For the adults, Digit Span was weakly negatively correlated with the magnitude of the changing-state deviation effect in the serial recall task only. There was a weak negative correlation between Operation Span and the magnitude of the steady-state deviation effect for the probed recall task among adults.

Correlations between span scores and the magnitude of the deviation effects that were significant for adults and / or children in each task were subsequently compared using Meng's test (Meng, Rosenthal, & Rubin, 1992) as per the calculations in Eid, Gollwitzer, & Schmitt (2011) using an online calculator available at https://www.psychometrica.de/correlation.html#fisher. Results showed that the correlations between digit span and the magnitude of the CS + *d* effect for adults versus children in serial recall were not significantly different, *Z* = -1.33, *p* = .092. Similarly, correlations between digit span and the magnitude of the CS + *d* effect for adults versus children in probed recall was also not significantly different, $Z = -.93$, $p = .176$. However, the correlations between OSpan scores and the magnitude of the SS + *d* effect in probed recall for adults versus children was significantly different, $Z = -2.4$, $p = .008$. This shows that working memory capacity (as assessed by OSpan) is negatively correlated with the magnitude of the steady-state deviation effect among adults but not children and this difference is significant.

Children vs adults on working memory performance.

Paired samples t-tests showed that adults had significantly higher digit span and WMC scores compared to the children. The average digit span was 6.5 items for adults and 4 items for children; $t(39) = 4.60$, $p < .001$. The average score for operation span was 41.63 points for adults and 25.37 for children; $t(39) = 11.56$, $p < .001$.

The scatterplots in Figure 9 show the positive correlation between Ospan scores and Digit Span for adults and children (as described in Table 2.5). Participants with higher digit spans had higher OSpan scores reflecting greater short-term memory capacity alongside greater working memory capacity. However, the small number of adult and child participants with higher spans (e.g., two adults with span of 9 and one child with digit span of 7) limits the generalizability of these findings.

Table 2.5

Pearson's Product Moment Correlations for Digit Span and Operation Span with Magnitude of CS Effect and Deviation Effect for Children and Adults.

		Adults				**Children**			
Magnitude of disruption	Task	Digit Span		OSpan		Digit Span		OSpan	
		R	*p*	*R*	*p*	*R*	*p*	*R*	*p*
	Digit Span	1	-	.536	< **.001**	1	-	.576	< **.001**
	OSpan	.536	< **.001**	1	-	.576	< **.001**	1	-
Magnitude of CS Effect	SR	-.010	.950	.047	.755	.187	.249	.078	.633
	PR	.192	.234	.127	.434	-.036	.824	-.039	.811
	MIT	.237	.141	.242	.132	.063	.701	.093	.569
Magnitude of CS + *d* Effect	SR	-.354	**.025**	-.249	.121	-.061	.710	.136	.401
	PR	.131	.419	-.146	.365	.335	**.035**	.050	.761
	MIT	.237	.501	.079	.627	.295	.065	-.002	.992
Magnitude of SS + *d* Effect	SR	.111	.495	.064	.695	-.232	.149	-.106	.516
	PR	-.307	.234	-.370	**.019**	.224	.165	.168	.301
	MIT	.045	.781	.119	.465	-.036	.378	-.002	.353

Note. SR – Serial Recall; PR – Probed Recall; MIT – Missing-item task.

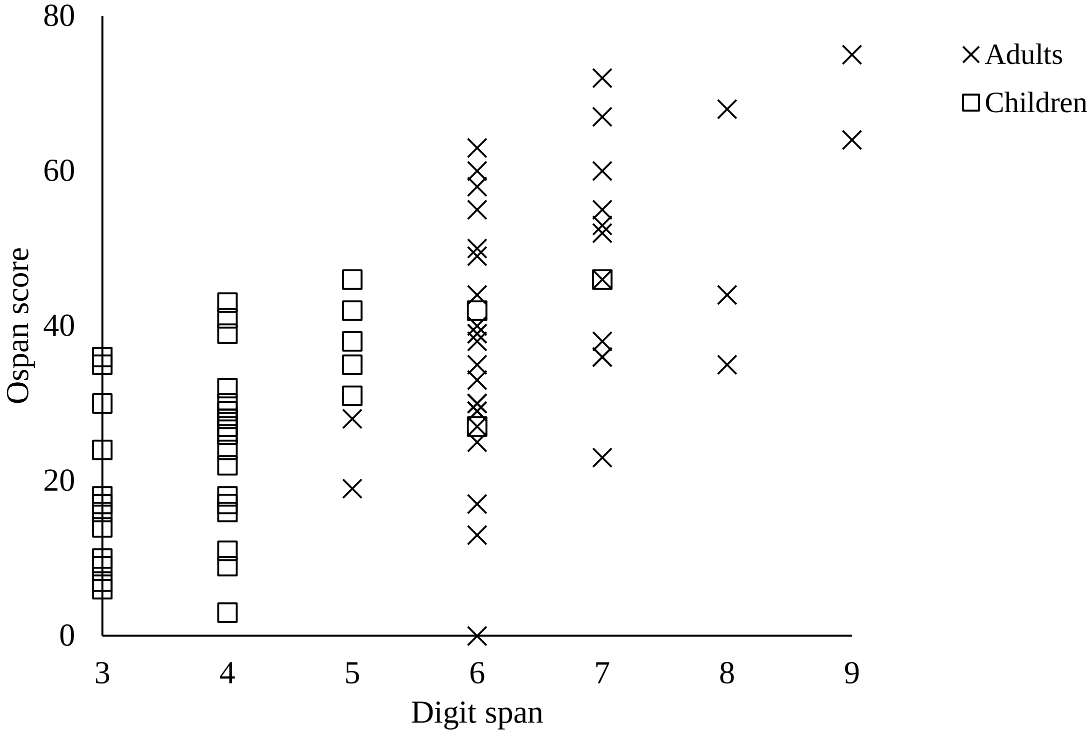


Figure 9. Scatterplots showing association between digit span and operation span scores for adults and children.

2.4 Discussion

The main aim of this study was to identify whether there were developmental differences in susceptibility to distraction among adults and children. The Discussion will address the results of the study within the context of extant findings. Overall, adults and children performed poorly in the presence of irrelevant speech compared to when it was quiet. The CS effect was present for both age groups and as expected, manifested only when serial rehearsal was required for task performance (in probed and serial recall tasks but not the missing-item task). The deviation effect was present for children in all three tasks but appeared for the adults only in the missing-item task. Although there was no developmental difference in the magnitude of disruption exhibited among children and adults, the finding that children were susceptible to attentional capture in more tasks than adults could suggest a developmental difference in distraction underpinned by attention. At this juncture, it is worthwhile to note that this study is the first to use voice deviants as irrelevant speech in experiments with children.

2.4.1 The Irrelevant Speech Effect.

Experiments by Klatte et al. (2010) like the present study, showed that children and adults experienced roughly the same level of disruption by irrelevant speech. These results may reflect that the irrelevant speech effect (ISE) is independent of age and is a result of task-irrelevant speech interfering with the execution of a motor plan for recall on account of the speech's ability to gain automatic access to those processes supporting recall (Hughes et al., 2005, 2007). This description ties in with the interference-by-process explanation of the duplex-mechanism account (Hughes, 2014). The tasks in this study used participants' final digit span score to assign list lengths for recall. As a consequence of this manipulation, children received shorter lists for recall (4 items) on average than adults (6 items) which is indicative of memory span increasing from childhood to adulthood (Elliott, 2002; McCormack, Brown, & Vousden, 2000). If the ISE varied as a function of span, one would expect the magnitude of disruption to be different for high (e.g. adults) and low span (e.g. children) individuals. However, not only was baseline performance in Quiet comparable for the participants at different list lengths, there was also no difference between the age groups in the magnitude of the ISE. The absence of a link between span length and ISE has been observed prior to this study (e.g. Elliott & Cowan, 2005) and suggests that those factors responsible for a developmental increase in span may not be the same as those determining the level of disruption by irrelevant speech. In addition, since digit span is a measure of short-term memory capacity (Baddeley, 2014), the lack of a relation between span and ISE could reflect the independence of memory capacity in determining distraction.

However, the absence of a developmental difference in the overall irrelevant speech effect in the present study is contrary to findings by Elliott and colleagues (e.g., Elliott, 2002; Elliott et al., 2007; Elliott & Cowan, 2005; Elliott et al., 2016) and may be a product of differences in methodology such as the age of children at testing and the experimental design adopted. Elliott and colleagues (Elliott, 2002; Elliott et al., 2016) have consistently found that children are more susceptible to irrelevant speech and sounds than adults on serial recall, probed recall, and missing-item tasks. Therefore, drawing contrasts between this and previous studies may be helpful for understanding the present results. In the first study to identify developmental differences in the ISE (Elliott, 2002), the children who participated ranged from 7 – 12 years old while those in the current study were only 7 – 9 years old; perhaps a larger age range in the present study would have been beneficial to identify developmental differences in irrelevant sound effects, if any exist. In addition, the experimental design in Elliott's study incorporated four list lengths randomly presented in each block of trials – span length, span minus 1, span minus 2, and span minus 3 – and the unpredictability of list length may have had a negative influence on performance especially for the children. The analyses and results presented in the paper are based on recall at span length; however, there is no clarification on whether the inclusion of other list lengths may have confounded the recall accuracy on the target length. Although span was varied across participants in the present study, the list length within each task and block of trials was fixed to span length only.

2.4.2 The Changing-State Effect.

The classical CS effect was replicated in the current study for children and adults on the tasks that required serial rehearsal. Again, the magnitude of the effect was roughly equal for both age groups which leads to questions about the underlying mechanisms responsible for the effect. While unitary accounts (Bell et al., 2010; Cowan, 1995; Neath, 2000) suggest that the CS effect is a result of an attentional capture, there is ample evidence that contradicts this theoretical perspective (e.g., Hughes & Jones, 2005; Hughes et al., 2005; Jones et al., 1992). In fact, the results from Study I do not support the unitary accounts which predict larger CS effect for children than adults given that their limited attentional control would make them more susceptible to attentional capture by each successive change in the irrelevant sequence. In addition, if the CS effect was caused by attentional diversion then the effect should have been present across all three tasks and not only in those requiring serial rehearsal.

The duplex-mechanism account (Hughes et al., 2007, Hughes, 2014), however, is able to account for the developmental findings in the CS effect. This type of disruption is considered an example of interference-by-process and occurs when automatic processing of order cues within the irrelevant speech interferes with the deliberate ordering of TBR items and leads to order errors upon recall (e.g., Hughes, 2014; Hughes & Jones, 2005; Hughes et al., 2005, 2007; Jones et al., 1996; Jones et al., 2010). Presumably, the participants in the present experiment were engaging in serial rehearsal for two out of three tasks and the changing-state irrelevant sequence interfered with the processes (i.e. rehearsal) needed to remember items in order.

Prior to this study, there have been two occasions where a developmental difference was noted for the CS effect (Elliott, 2002; Elliott et al., 2016). Elliott’s (2002) study showed that the magnitude of disruption by changing-state words was largest for the youngest children and reduced with an increase in age. The study also identified that the CS effect (for irrelevant tones and words) reduced with age and although Elliott acknowledged that rehearsal develops from childhood to adulthood, the pattern of results did not support the idea that greater engagement in rehearsal will bring about greater disruption. However, the results were a good fit for attention-based accounts stipulating that as attentional control increased, individuals were better able to resist distraction by irrelevant sounds including those that were changing-state. Elliott et al. (2016) also demonstrated that children experienced a larger CS effect than adults but explained these results using the more recent duplex-mechanism account (Hughes et al., 2007). Through a series of experiments using the probed order recall and missing-item tasks, they showed that children's performance was not only more susceptible to sounds (changing and steady-state sounds) but that their under-developed rehearsal acted as an additional attentional load which further exacerbated their limited attentional control. As such, poorer rehearsal in children produced a larger CS effect not by increasing interference-by-process but rather by worsening their attentional control during task performance.

The duplex-mechanism account affords an explanation for the present findings regarding the CS effect in that both children and adults experienced an interference-by-process whereby the order information from the changing-state sequence interfered with the participants' intent to retain TBR items in order. The absence of a developmental difference would suggest that both age groups were engaging in serial rehearsal to perform the probed and serial recall tasks but not the missing-item task (Beaman & Jones, 1997). At this juncture, however, it would be appropriate to address two methodological decisions made in this study that may have also contributed to the pattern of results. First, the age range of children (7-9 years old) taking part may have restricted the extent to which any clear developmental differences between children and adults would have emerged. The inclusion of younger and older children may help to show how differences in rehearsal efficiency and attentional control across childhood impacts upon the susceptibility to distraction. Second, the list length for recall was based on individual span and this may have stifled any differences in performance that could have been attributed to age. The use of tasks with span-adjusted list lengths may have resulted in a serial and probed recall task with relatively low attentional load (especially for those with shorter list lengths) whereby the processes to recall information were automatized to such an extent that the task was immunized against any form of interference (Neumann, 1987). Therefore, the effect for the lowest span achievers (3 and 5 items for children and adults, respectively) may have been minimal and reduced the overall developmental differences in magnitude of disruption.

2.4.3 The Deviation Effect

Research studies with young (18 to 30 years) and old adults (60 years and above; e.g., Röer et al., 2015) have found no difference between the two age groups on the deviation effect – the magnitude of disruption caused by sudden and unexpected changes in the irrelevant speech sequence which divert attention from the focal task to the irrelevant material. According to the duplex account, the deviation effect (unlike the CS effect) is amenable to top down control and therefore avoidable when such control is exerted to maintain attention on the focal task (e.g., Hughes, 2014, Hughes et al., 2013). Working memory capacity has long been assumed an indicator of attentional control and therefore it has followed that individuals who have a relatively higher working memory capacity (WMC) are better able to shield cognition from task-irrelevant stimuli much better than those with a lower capacity (Conway et al., 2001). Therefore, we may expect individuals with relatively low WMC to be more susceptible to the deviation effect than those with higher WMC (e.g., Hughes et al., 2013; Marsh, Vachon, & Sörqvist, 2017). This can also be extended to developmental differences wherein children who have lower WMC should be more susceptible to the deviation effect than higher WMC adults. It seems logical to expect a similar pattern for younger versus older adults whereby younger adults are less susceptible because of their larger WMC compared to older people. However, evidence within the irrelevant sound paradigm suggests that there is an equivalence in the deviation effect for young and older adults even when task difficulty and intensity of sound is adjusted to individual ability (Bell & Buchner, 2007; Röer et al., 2015). The lack of a difference poses problems for the inhibitory deficit hypothesis which suggests that aging makes older adults less able to inhibit irrelevant stimuli because of the deficits in their attention and cognitive abilities (Hasher & Zacks, 1988; Lustig et al., 2007). This also raises questions about the differences that may emerge between children and adults given especially that attentional control among this age group of children is still developing (e.g.: Cowan et al., 2006; Guttentag, 1997; Lane & Pearson, 1982) and their ability to exert top-down control in order to inhibit irrelevant information is less efficient than in adults (Hwang et al., 2010).

The results from individual analyses of children's and adults' data showed that while children experienced a deviation effect in all three tasks, the adults experienced this effect only in the missing-item task. The presence of a deviation effect across all three tasks for the children shows that attention was captured by deviants in the irrelevant sequence and lends support to the duplex account's assertion that the deviation effect is the result of attentional capture and is a task-insensitive and domain general type of distraction (Hughes et al., 2007). However, the absence of an effect of age on the magnitude of the deviation effect does not fall in line with predictions made by unitary and duplex accounts that children's limited attentional control should have made them more susceptible to the deviation effect compared to adults. In addition, the absence of a deviation effect for two out of three tasks for the adults poses some difficulty for both accounts and stands in sharp contrast to several previous findings with adult participants that the deviation effect manifests regardless of task-type (e.g., Hughes et al., 2005, 2007; Vachon et al., 2016).

Nevertheless, an alternative explanation that focuses on task engagement may be more suited to the unusual pattern of results. Previous research has shown that when task engagement is encouraged by increasing perceptual difficulty of TBR stimuli, individuals are shielded from attentional capture (Hughes et al., 2013). Although the present study did not alter perceptual load, task engagement may have been promoted through the use of rehearsal. This would explain why, for adults, there was no deviation effect in the serial and probed recall tasks – tasks that rely on rehearsal – but a deviation effect was present in the missing-item task. The unique feature of the missing-item task is that participants have *a priori* knowledge of the list items and need to identify which item was left out of the list at presentation (Buschke, 1963). As such, serial order retention is not necessary and participants often engage in a mental ‘checking off’ strategy which allows them to eliminate presented items from the list of potential items and select the one that was missing (Beaman & Jones, 1997; Buschke, 1963; Murdock & Smith, 2005). In the present study, performance in the missing-item task in Quiet and all irrelevant speech conditions was better than that in serial and probed recall tasks. The use of serial rehearsal was not needed for this task (Beaman & Jones, 1997) and could imply that a lower level of attention and task engagement were needed to complete the task. Therefore, the adults may have not benefitted from the shield against distraction otherwise provided by greater task engagement and higher cognitive load (Hughes et al., 2013; Marsh et al., 2016; Sörqvist et al., 2016).

In contrast to adults, the task engagement explanation could be applied as follows: children’s attempts to engage in rehearsal to support performance in serial and probed recall tasks may have acted as an attentional load rather than a shield, thus, leading to a deviation effect in these tasks (Elliott et al., 2016). The deviation effect in the missing-item task may be the result of poor attentional load alone that makes children more likely to have their attention captured by deviants. Furthermore, if children have poor attentional control then it should follow that they will be susceptible to attentional capture regardless of task type – as is the case here since the deviation effect was present for children in the missing-item task as well. Therefore, if greater task engagement imposes a further attentional load, it will exacerbate children’s attentional control and make them more susceptible to distraction (Elliott et al., 2016) in contrast to adults for whom greater task engagement can act as a shield against attentional-based distraction (Hughes et al., 2013; Sörqvist, Dahlström, Karlsson, & Rönnberg, 2016). Given that children exhibited a deviation effect in more tasks than adults, it is surprising that no statistical effect of age was observed. However, the absence of an interaction with age could simply reflect that the magnitude of disruption was roughly the same for children and adults. In addition, the experimental design catered for each individual's short-term memory capacity which may have suppressed developmental differences in the deviation effect. Following from this, in Study II, children aged five to eleven are included in the study to generalize findings across a wider age range of children; and, list length for recall is fixed to ensure similar levels of difficulty across participants.

In the present study, OSpan (Unsworth et al., 2005) was used to assess WMC and although adults had higher WMC than children, this did not result in an age-related difference in the magnitude of the deviation effect. The only relationship that was observed between WMC and the deviation effect was for adults in the probed recall task where higher WMC was associated with a lower deviation effect when deviants were in a steady-state sequence only. There was no relation between magnitude of disruption and WMC for children. The pattern of results among adults is similar to that in previous studies where individuals with high WMC were better able to resist attentional capture than those with low WMC (e.g., Hughes et al., 2013; Marsh et al., 2017; Sörqvist et al., 2013). Considering this previous evidence and the pattern seen here among adults, it is surprising that the magnitude of the deviation effect did not vary between adults and children even though WMC for adults was higher than that of the children. However, results from further analyses (in Section 2.3.5) indicated that the relation between WMC and the deviation effect may be more likely to occur among adults than children. Furthermore, given that children in this study were susceptible to attentional capture on more tasks than adults, it could be the case that developmental differences in distraction (at least between children and adults) are more likely to be qualitative than quantitative. In other words, even though the magnitude of the disruption did not vary as a function of age, children were still more susceptible to attentional capture by auditory distraction than adults (in line with findings from Elliott et al., 2016) as evidenced by the presence of the deviation effect for children in more tasks than adults.

2.4.4 Missing-item vs Probed Recall: The role of serial rehearsal

Study I employed the missing-item and probed recall tasks along with the changing-state and deviant irrelevant sequences to provide a unique way to assess the role of attention and serial rehearsal in task performance. There are theoretical implications of using this experimental set-up especially when providing support for the unitary (Bell et al., 2010; Cowan, 1995; Elliott, 2002) or duplex accounts (Hughes et al., 2007; Hughes et al., 2014) in the irrelevant sound paradigm. According to the unitary account, the CS effect is an attentional phenomenon whereby each successive token captures participants' attention from the focal task (e.g., Chein & Fiez, 2010; Cowan, 1995). However, in the duplex-mechanism account, the CS effect is the result of interference-by-process wherein order information from the irrelevant sequence interferes with the ability to process serial order cues from the focal task (Hughes et al., 2007). The present results showed that the CS effect was present only when the task (i.e. probed recall) required serial order processing and therefore bolsters the premise of the duplex-mechanism account. Indeed, if the CS effect was a consequence of attentional capture, it should have been present for both tasks as they require the focus of attention.

It would be an incomplete argument to conclude that the absence of a CS effect in the missing item task is sufficient evidence to discount the role of attention in distraction. It is at this point where the deviation effect becomes relevant as it was noted across both tasks for the adults and children. The presence of the effect across the two tasks suggests that there is a common attribute being affected by deviant speech and given that attention is required for the completion of any task it seems appropriate to conclude that the effect was a result of attentional capture occurring regardless of task. The use of a task comparison along with exploiting the different effects of irrelevant speech provides more support for the duplex-mechanism account from a developmental perspective and makes clear that while irrelevant speech can gain automatic access and cause disruption, there is also a role for attention in determining susceptibility to distraction (Hughes et al., 2005; Vachon et al., 2016).

2.4.5 Conclusions and subsequent research

The first study in this series has allowed for an analysis of the developmental differences between children and adults on the irrelevant speech effects. The results suggest an absence of a developmental difference in the magnitude of disruption between these two age groups. While most of the results can be explained with reference to the duplex account, the absence of an age effect to show children's greater susceptibility to attentional capture (than adults) because of their poorer attentional control poses a problem for the duplex account's predictions of developmental differences. Nevertheless, the pattern across tasks showed that children exhibited attentional capture more often than adults. These findings also provide a stepping stone for research (in Chapter III) that will include a larger sample size, changes to the irrelevant sequence, and task modifications for a better understanding of age effects in the irrelevant speech paradigm.

To this end, in Study II, the children who participated ranged from five to eleven years old which is representative of the age range of children in primary school. The age range of the adult sample was maintained at 18-22 years old and altogether there were 197 participants in the second study. A change was made to the Steady-State Deviant sequence in order to correct the inadvertent error causing deviations on two dimensions (i.e. voice and letter deviation). The sequence was changed to ensure there would be a deviation in voice only (A-A-<u>**A**</u>-A; male-spoken token in bold and underlined). Three task-related changes were made in Study II and related to the TBR stimuli, the list length for recall, and the span measures. First, digits were replaced by colour patches for the TBR items for all children under the age of seven. Initial testing sessions with the youngest age group showed that they were not very familiar with digits and performed poorly even in Quiet. The children fared better when colours were presented and also engaged with the task more willingly. The second change was to use a fixed list length for different age groups: the list lengths were four, five, six, and eight items for children under seven, children who were 7-9 years old, children who were 10-11 years old, and adults, respectively. The fixed list length allowed for a more in-depth analysis of results especially on the serial recall task and helped to minimize the variations in performance that could have arisen from using individual list lengths for recall. The third and final change was to remove the span tasks as there were no clear cut correlations noted when they were used in Study I. This modification also allowed for shorter testing times which was especially beneficial when working with pupils in schools.

CHAPTER III

EMPIRICAL STUDY II: EXTENDING OUR UNDERSTANDING OF DEVELOPMENTAL DIFFERENCES IN DISTRACTION EFFECTS

Abstract

The duplex-mechanism account is built on the premise that there are at least two functionally different forms of distraction – one that is the result of changing-state sounds interfering with rehearsal (the CS effect) and the other which is the result of attentional capture by deviant sounds (the deviation effect; Hughes et al., 2007, Jones et al., 2010). One line of support for this account has come from the finding that the CS effect occurs only in tasks with a serial rehearsal component (serial and probed recall tasks but not missing-item; Elliott et al., 2016; Hughes et al., 2013) but the deviation effect is present regardless of task type and involvement of rehearsal (Hughes et al., 2007; Vachon et al., 2016). In the present study, a developmental approach is used to test the duplex-mechanism account by assessing the impact of irrelevant speech on recall performance in serial recall, probed recall, and missing-item tasks among children aged 5 to 11 years old (N = 147) and adults aged 18 to 22 years old (N = 50). Since research suggests that children rehearse around the age of seven (Flavell et al., 1966), it would be expected, in line with the duplex account, that the CS effect should be present among children of this age and older but not among children under the age of seven. Therefore, the absence of the CS effect in serial and probed recall tasks for children aged 5-6 years old would indicate that they are not rehearsing and are therefore immune to the CS effect. Conversely, if 5-6 year old children are rehearsing then they should be susceptible to the CS effect like the older children and adults. Another line of support for the duplex-mechanism account comes from the finding that the deviation effect, but not the CS effect, is greater for adults with low WMC compared to those with high

WMC (Hughes et al., 2013; Sörqvist et al., 2013). Flowing from this is the prediction that children's low WMC compared to adults (Cowan et al., 2005; Elliott & Cowan, 2005) should make them more susceptible to attentional capture (the deviation effect) than adults. This developmental difference should be especially pronounced if there is a greater attentional or cognitive load being imposed (Elliott et al., 2016; Lavie, 2005). In Study I, the results suggested that poorer attentional control compared to adults underpinned children's susceptibility to distraction (in the missing-item task) while the use of rehearsal in the serial and probed recall tasks imposed an additional attentional load that exacerbated their poor attentional control and led to attentional capture in these tasks. In comparison, adults were immune to the deviation effect in the serial and probed recall tasks (but not missing-item) because rehearsal promoted task engagement which has been shown to shield against attentional capture (Hughes et al., 2013). Therefore, in the present study, it is expected that the deviation effect will be more prominent for younger children because of poorer attentional control compared to older children and adults. Children who are rehearsing will also show a greater deviation effect than adults if rehearsal acts as an attentional load that exacerbates poor attentional control. The results showed that the impact of irrelevant speech on recall among children aged 5 and 6 years was minimal – probed recall performance was lower in irrelevant speech compared to quiet but they were immune to the CS effect and deviation effect. These results may either be because of floor effects given the general low level of performance or the task stimuli used for this group (colour patches as to-be-remembered items instead of digits). The CS effect was observed only for the 10-11 year old children and adults, suggesting that children aged 5-9 years old may not be rehearsing in the serial and probed recall tasks which is at odds with children's results from Study I. The developmental trajectory in the deviation effect was as predicted (with the exception of the youngest children) – 7-9-year-old children showed a deviation effect in serial recall and missing-item task, 10-11-year-old children exhibited the effect in the probed recall task only, and adults did not experience a deviation effect on any task. This pattern suggests that our susceptibility to the CS effect is underpinned by the involvement of rehearsal and that distraction by attentional capture decreases with chronological age. Results are discussed in relation to findings from Study I and that of Elliott et al. (2016), and with reference to the duplex-mechanism account of distraction.

3.1 Introduction

In Chapter II, the examination of developmental differences in susceptibility to distraction suggested that age may not influence susceptibility to distraction. Logically, given that the efficiency of rehearsal and attentional control changes with age it was expected that distraction effects underpinned by rehearsal and attentional control would also vary with age. Although statistical analysis did not show an effect of age on distraction, the general pattern of results did coincide with previous findings on the CS effect and deviation effect (e.g. Beaman & Jones, 1997; Elliott et al., 2016; Hughes et al., 2007; Jones & Macken, 1993). Children and adults were vulnerable to the CS effect in serial and probed recall tasks but not in the missing-item task – leading to two conclusions. First, the presence of the CS effect suggests that children aged 7 to 9 years old are engaging in rehearsal to support recall perhaps in a similar fashion to adults. Second, the presence of the CS effect only in those tasks where serial rehearsal is deployed highlights the specific vulnerability of rehearsal to disruption by irrelevant speech. The deviation effect manifested for children in all three tasks while the adults were susceptible only in the missing-item task. This pattern of results suggested that children may be more susceptible to attentional capture compared to adults because of their poorer attentional control (Elliott et al., 2016). The results were also indicative of the role played by greater task engagement among adults and children, wherein, adults' use of rehearsal in the serial and probed recall tasks may have promoted greater task engagement and in turn shielded them against attentional capture (Hughes et al., 2013); however, greater task engagement in the form of rehearsal among children may have constituted an additional attentional load in serial and probed recall tasks that exacerbated their already poor attentional control and resulted in attentional capture in these tasks (Elliott et al., 2016). This account of the developmental differences in the deviation effect also ties in with the finding that adults exhibited a deviation effect in the missing-item task because they were less engaged in the task (not using rehearsal) but children exhibited a deviation effect in the missing-item task because of their poor attentional control that makes them susceptible to distraction regardless of task type. It must be noted, however, that these results were obtained from a limited age range of children (7-9 years old only) and as such generalizability of these findings is limited.

In Study I, list lengths for recall were based on individual digit span and there was an inadvertent error in the steady-state deviant sequences leading to an inequivalence between the steady-state and changing-state deviant sequences. In addition, the age range of children was 7-9 years old only – a period during which children are thought to employ rehearsal to support memory (Flavell et al., 1966; cf. Henry et al., 2012; Lehmann & Hasselhorn, 2007, 2012). Study II improved upon the methodology that was used in Study I. Individually adjusted list lengths for recall were replaced by fixed lengths for each age group. It was reasoned that individually adjusted list-lengths might have resulted in tasks that were either too difficult or too easy for participants to complete. On the one hand, adults in Study I with a digit span of nine items had to complete tasks with nine TBR items – not only did this dramatically increase testing time but also caused fatigue among these participants. On the other hand, there were children with span of three and adults with span of five items. That there were only three or five items may have led to performance being automatized to such an extent that the distraction effects were minimized or absent altogether (Neumann, 1987). A larger sample size was used to extend developmental findings from Study I (with 7-9-year-old children) to children aged 5 to 11 years old and to compare them with adults who were 18 to 22 years old. The rationale for including children under the age of seven was to assess the impact of irrelevant speech on memory in children who may not be using rehearsal yet and instead may rely on a non-verbal memory maintenance strategy (e.g., visual imagery; Miller, McCulloch, &

Jarrold, 2015). Younger children may also use labelling – naming each item just after it is presented – a primitive strategy thought to be a precursor of rehearsal (Lehmann & Hasselhorn, 2007). The inclusion of older children (10 and 11 years old) was influenced by the knowledge that children of this age use rehearsal to support memory for longer periods of time than younger children and the more they use rehearsal the better their recall performance (Lehmann & Hasselhorn, 2012). These potential differences in memory strategies are likely to result in age-related differences in the disruption by irrelevant speech that can in turn be used to inform our understanding of memory maintenance strategies in young children and how these strategies can be vulnerable to distraction.

After a preliminary run of the tasks with children aged five and six years old, it was noted that they were not very familiar with digits, struggled to retain this information, and performed poorly even with a quiet background. Therefore, the digits were replaced with colour patches as the TBR material which allowed for more comparable performance between age groups. Children that completed the task with digits performed very poorly – sometimes scoring zero even in the Quiet condition. When the colour patches were used, however, their performance was better, albeit still lower than all other age groups as will be seen in the results.

In Study I, no correlations were found between working memory capacity as assessed by an operation span task (OSpan; Foster et al., 2015) and the magnitude of the CS and deviation effects for children. A relationship between working memory capacity as assessed by OSpan and the irrelevant speech effect has been observed for children before (Elliott & Cowan, 2005) and therefore it seems surprising that the similar pattern of results did not emerge in Study I. However, the absence of a relationship may be because of the smaller sample size used in Study I (*N* = 40) compared to that in Elliott and Cowan's (2005) study (*N* = 63). The use of a larger sample size in Study I would have been beneficial for detecting statistically significant relationships between WMC and the magnitude of disruption. It was also observed during testing that the 7-9-year-old children in Study I found the OSpan task difficult to follow and their low scores may reflect the difficulty they experienced in completing the task rather than purely lower WMC. Therefore, keeping in mind that an even younger sample of children (5 and 6 years old) were participating in Study II, the OSpan measure was excluded from the present study. It was hoped that by incorporating these changes the results would reflect more accurately any developmental differences should they exist.

The experimental series being described here is the first to incorporate children ranging in age from 5 to 11 years in a single study of auditory distraction effects on memory. Previous research has addressed the effects of distraction among children within this age range but not within a single study (e.g., Elliott, 2002; Elliott et al., 2016; Klatte et al., 2010). The assessment of distraction effects among children aged 5 to 11 years old will show how age-related differences in rehearsal and attentional control can influence susceptibility to distraction. Conversely, the study of distraction effects will also provide a window into the strategies children use to maintain information in memory – for example, the absence of a CS effect for children under the age of seven could indicate that these children are not rehearsing and may instead be using an alternative strategy to remember information. However, the presence of a CS effect for children aged 7 to 11 years old will not only provide evidence for rehearsal but any differences in the magnitude of CS disruption will show how rehearsal efficiency varies among children of different ages and how this can influence the magnitude of disruption that occurs. The added comparison of distraction effects between children and adults will provide an insight to whether children are more susceptible to distraction and why this may be. Previous research has suggested greater susceptibility among children compared to adults was because children have poorer attentional control (e.g., Elliott, 2002; Elliott et al., 2016; cf. Klatte et al., 2010). However, these studies have not included children under the age of seven and have not considered attentional capture with deviants (as in Study I and in the present study).

The experiments in this series will show how rehearsal and attentional control influence distraction effects among children and adults. As with Study I, it is predicted that the CS effect will occur in serial and/or probed recall tasks but not in the missing-item task; however, the deviation effect will manifest in all three tasks in line with the duplex-mechanism account (Hughes, 2014). The presence of the CS effect will be indicated by poorer performance in CS versus SS speech while the deviation effect will be reflected in lower performance in with-deviant conditions compared to speech without deviants. From a developmental differences perspective (e.g., Elliott & Cowan, 2005; Elliott et al., 2016), children under the age of seven who may not yet be rehearsing (Flavell et al., 1966) will not exhibit the CS effect whereas older children and adults who do rehearse (Elliott, 2002; Lehmann & Hasselhorn, 2012) will be susceptible to this effect (e.g., Hughes et al., 2007; Macken et al., 1999). If the results indicate age-related differences in the CS effect, it would suggest that rehearsal underpins developmental differences in distraction (cf. Elliott et al., 2016; Klatte et al., 2010). However, differences in the deviation effect as a function of age would indicate that differences in attentional control are responsible for developmental differences in distraction between children and adults (Elliott et al., 2016).

3.2 Method

3.2.1 Participants.

One hundred and ninety-seven participants were recruited for this study. Fifty undergraduate students aged 18-22 years old (40 females; *M* = 20.16 years) from the

University of Central Lancashire and 147 children from three schools in Lancashire took part in this study. The number of children in each age group were as follows: 47 children aged 5-6 years old (33 females; *M* = 5 years, 9 months), 50 children aged 7-9 (24 females; *M* = 7 years, 10 months), and 50 children aged 10-11 years old (17 females; *M* = 10 years, 11 months). All participants reported normal hearing and normal or corrected-to-normal vision. The university students received course credit or a £5 shopping voucher for their participation and the children were given stickers at the end of testing. Consent procedures were the same as in Study I.

3.2.2 Apparatus, materials, and procedure.

To-be-ignored sequences.

The auditory sequences for this study were similar to those used in Study I with two key modifications. The pitch of the female-spoken letters was shifted up by one semitone while that of the male-spoken letters was shifted down by two semitones using Sony Sound Forge Pro 11 software (Sony Creative Software). Accentuating the differences between the female and male spoken items should have helped create a deviant that was more likely to capture attention. In addition, an oversight was noted in relation to the Steady-State + Deviant sequences for Study I. There was a deviation on two dimensions in this sequence (i.e. voice and letter change –*AA**B**AA*; male spoken item in bold and underlined) instead of only one dimension (i.e. voice change only – *AA**A**AA*) which caused a lack of parity between this condition and the Changing-State + Deviant condition. Indeed, having deviations on two dimensions would be expected to cause more disruption than a single deviation therefore making the SS + *d* sequence more disruptive than the CS + *d*. This issue was rectified in Study II by ensuring that there was only a voice deviation in the Steady-State + Deviant sequence (*AA**A**AA*…).

Tasks and to-be-remembered stimuli.

The three memory tasks—serial recall, missing item, and probed recall—were used in this study but the span tests were excluded. The absence of consistent correlations between span measures and disruption by irrelevant speech and the observation that the children found the operation span task difficult prompted the decision to omit them in this study. The list length on each trial was predetermined: the youngest children (5-6 years old) received only four items while participants aged 7-9, 10-11, and 18-22 years old received five, six, and eight items, respectively. For the tasks with five items, TBR items were drawn from the digit set 1-6; for those with six items, TBR items were drawn from the set 1-7; and, for the eight-item tasks, TBR items were drawn from the set 1-9. The list lengths were decided based on experimental procedures used with adults and children in previous literature (e.g., Elliott & Cowan, 2005; Hughes et al., 2005, 2007).

It was necessary to adapt the memory tasks for the youngest children and colour patches were used as TBR stimuli instead of digits (see Figure 10 for an example of the serial recall task with colour patches). The colours were chosen based on their mean Age of Acquisition ratings in years (Kuperman, Stadthagen-Gonzalez, & Brysbaert, 2012) and only if they were single syllable words. The chosen colours and their mean Age of Acquisition ratings in years were: Black (3.56), Blue (3.53), Green (3.79), Red (3.68), and Pink (3.8). In hindsight, it would have been appropriate to include a test for colour blindness given the nature of the task. However, to ascertain whether the children could identify the colours correctly, they were shown cards with the colours on them and asked to name the colour. All the children correctly identified each colour patch.

The consent and administration procedures were the same as in Study I with the minor change that the youngest children were tested two or three at a time to ensure that instructions were followed closely and to provide assistance if necessary.

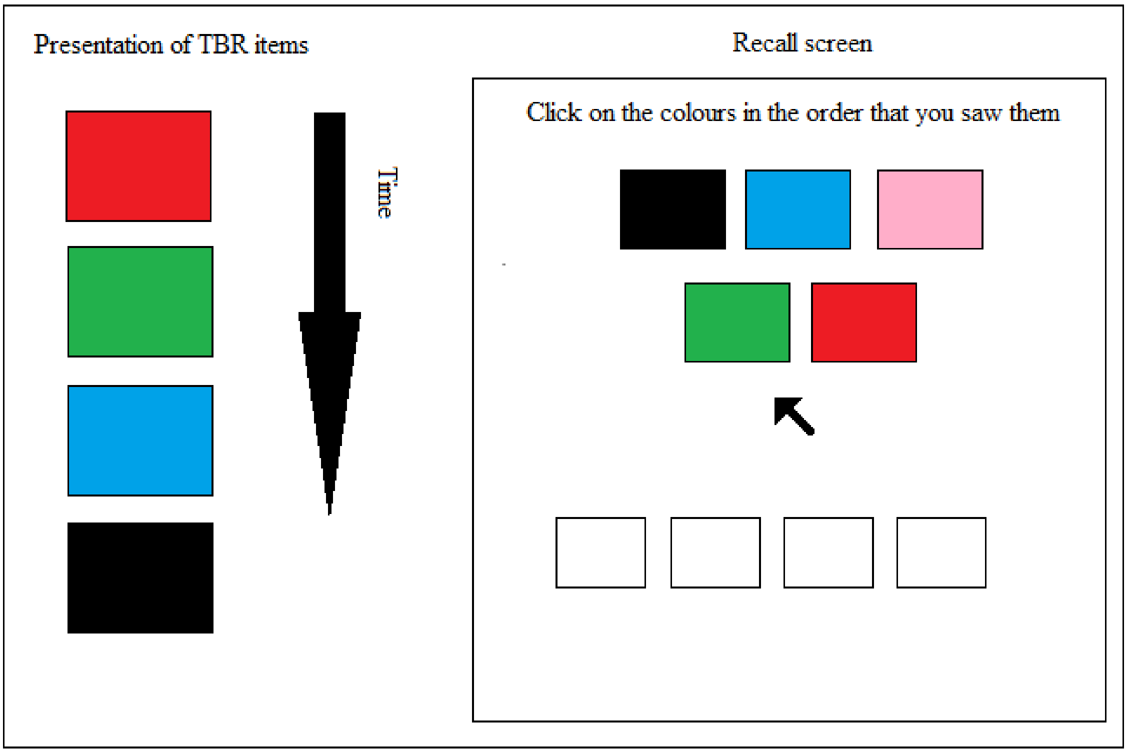


Figure 10. An example of a serial recall trial with colour patches. Recall tasks with colour patches were used only with 5-6-year-old children.

3.2.3 Design.

The experiment had a 5 (Auditory Condition: Quiet, Changing-State speech, Steady-State speech, Changing-State + Deviant speech, and Steady-State + Deviant speech) × 3 (Task Type: Serial Recall, Missing Item, and Probed Recall) × 4 (Age Group: 5-6 years old, 7-9, 10-11, and 18-22 years old) mixed design. The number of trials that participants completed was the same as in Study I. The order of the three memory tasks and that of the blocks within each task was counterbalanced across participants.

3.3 Results

This section describes the performance of 197 participants who completed serial recall, probed recall, and missing-item tasks in the presence of irrelevant speech and in quiet. Data from all 197 participants were included in the analyses. The Shapiro-Wilks test for normality showed that baseline serial recall data were normally distributed for all age groups except 5-6-year-old children. There were two outliers in this group but upon inspection of their baseline scores (.85 and .75 in Quiet), the data were retained as they were not so high as to suggest ceiling effects and because the pattern of results remained the same even when these outliers were removed. Data from probed recall and missing-item tasks were also normally distributed with the exception of data from 5-6-year-old children and adults in the probed recall task and 7-9-year-old children in the missing-item task. The box plots, however, did not show any extreme outliers in probed recall and missing-item data and the data were retained.

An overview of performance for all tasks and age groups is provided in Figures 11, 12, and 13. Two ANOVAs were conducted for each task – the first assessed the presence of the Irrelevant Speech Effect while the second considered the presence of the CS effect and deviation effect. For all analyses, if Mauchly's Test of Sphericity was significant, a Greenhouse-Geisser correction was applied. Proportion correct scores for the serial recall task were calculated as described in Chapter II (see Section 2.3.1).

3.3.1 Children.

Five to six-year-old children.

Serial recall.

Overall performance in this task was low: mean recall in Quiet was .44 (*SD* = .13), .44 (*SD* = .11) in CS speech, .44 (*SD* = .12) in SS speech, .39 in CS + *d* (*SD* = .21), and .42 (*SD* = .23) in SS + *d*. An initial one-way repeated measures ANOVA was conducted incorporating all four irrelevant speech conditions and Quiet. There was a non-significant main effect of Auditory Condition, *F*(2.4, 113.81) = 1.76, *MSE* = .02, *p* = .138, η_p^2 = .04, and planned contrasts did not show any significant differences between performance in irrelevant speech conditions versus Quiet (all *p*s > .05). The subsequent 2 (State: Changing or Steady) × 2 (Deviation: Absent or Present) ANOVA (Quiet was omitted) showed that the main effects of State, *F*(1, 46) = 1.75, *MSE* = .02, *p* = .193, η_p^2 = .04, and Deviation, *F*(1, 46) = 2.03, *MSE* = .06, *p* = .161, η_p^2 = .04, were not significant. There was also a non-significant interaction, *F*(1, 46) = 1.31, *MSE* = .01, *p* = .258, η_p^2 = .03. These results suggest the absence of the irrelevant speech effect, CS effect, and deviation effect on serial recall for the five- and six-year old children.

Probed recall.

There was a significant main effect of Auditory Condition in this task, *F*(4, 184) = 4.18, *MSE* = .11, *p* = .003, η_p^2 = .08. Planned contrasts indicated that recall in CS (*M* = .34; *SD* = .18; *p* = .009), CS + d (*M* = .32; *SD* = .21; *p* = .006), and SS + d (*M* = .34; *SD* = .24; *p* = .046) conditions were significantly lower than in Quiet (*M* = .42; *SD* = .23). There was no significant difference between SS (*M* = .41; *SD* = .21) and Quiet (*p* = .777). There were non-significant main effects of State, *F*(1, 46) = 1.75, *MSE* = .02, *p* = .193, η_p^2 = .08, or Deviation, *F*(1, 46) = 1.75, *MSE* = .02, *p* = .193, η_p^2 = .08; nor an interaction, *F*(1, 46) = 1.31, *MSE* = .01, *p* = .258, η_p^2 = .03. Therefore, recall in the presence of irrelevant speech (except SS speech) was lower than in quiet but neither the CS effect nor deviation effect were present in this task.

Missing-item task.

Overall performance in this task was better than that in serial and probed recall tasks: mean recall was .51 (SD = .22) in Quiet, .50 (SD = .19) in CS speech, .51 (SD =

.18) in SS speech, .53 (SD = .25) in CS + *d*, and .47 (SD = .26) in SS + *d*. The initial repeated measures ANOVA showed that the main effect of Auditory Condition was not significant, *F*(3.21, 147.49) = .71, *MSE* = .02, *p* = .554, η_p^2 = .01. Similarly, the main effects of State [*F*(1, 46) = .88, *MSE* = .03, *p* = .354, η_p^2 =.02] and Deviation [*F*(1, 46) = .03, *MSE* = .001, *p* = .852, η_p^2 = .001] and, the interaction, *F*(1, 46) = 1.51, *MSE* = .04, *p* = .255, η_p^2 = .03, were not significant. These results point to the absence of an irrelevant speech effect, changing-state, and deviation effect on recall for this task.

Five- and six-year-old children did not exhibit an irrelevant speech effect (ISE; lower recall in irrelevant speech than quiet) on the serial recall and missing-item tasks. However, the ISE was present for the probed recall task. The changing-state effect (CS effect) and deviation effect were not present for this group on any of the tasks.

Seven to nine-year-old children.

Serial recall.

There was a significant main effect of Auditory Condition, *F*(4, 196) = 2.54, *MSE* = .03, *p* = .041, η_p^2 = .05, which was clarified by planned contrasts showing that performance in CS + *d* (*M* = .39, *SD* = .20) was significantly lower than in quiet (*M* = .45, *SD* = .19). No other contrasts with Quiet were significant (all *p*s > .05). There was a non-significant main effect of State, *F*(1, 49) = 2.12, *MSE* = .03, *p* = .151, η_p^2 = .04, reflecting the absence of CS effect on serial recall (M_{CS} = .43, *SD* = .22; M_{SS} = .45, *SD* = .23). However, the main effect of Deviation was significant, *F*(1, 49) = 5.59, *MSE* = .05, *p* = .022, η_p^2 = .10, indicating that recall in the presence of deviants (M_{CS+d} = .39, *SD* = .20; M_{SS+d} = .42, *SD* = .23) was lower than in their absence. There was a non-significant interaction between State and Deviation (*F*(1, 49) = .009, *MSE* < .001, *p* = .925, η_p^2 < .001) which showed that the deviation effect was present regardless of whether the deviant was placed within a changing- or steady-state sequence (CS > CS + *d* and SS > SS + *d*).

Probed recall.

Mean recall in Quiet was .43 (*SD* = .24), .40 (*SD* = .24) in CS, .45 (*SD* = .24) in SS, .41 (*SD* = .26) in CS + *d*, and .43 (*SD* = .27) in SS + *d*. The main effect of Auditory Condition was not significant [*F*(2.86, 140.17) = .55, *MSE* = .02, *p* = .639, η_p^2 = .01]. There were also non-significant main effects of State [*F*(1, 49) = 1.28, *MSE* = .04, *p* = .632, η_p^2 = .02] and Deviation [*F*(1, 49) = .08, *MSE* = .002, *p* = .777, η_p^2 = .002]; and a non-significant interaction, *F*(1, 49) = .45, *MSE* = .01, *p* = .506, η_p^2 = .009. The results showed that there was no irrelevant speech effect, CS effect or deviation effect in this task.

Missing-item task.

There was a significant main effect of Auditory Condition, *F*(4, 196) = 4.52, *MSE* = .12, *p* = .002, η_p^2 = .08, and planned contrasts showed poorer recall in CS + *d* (*M* = .41, *SD* = .26) and SS + *d* (*M* = .40, *SD* = .28) compared to Quiet (*M* = .51, *SD* = .25; all *p*s < .05). In the subsequent ANOVA there was a non-significant main effect of State, *F*(1, 49) = .34, *MSE* = .01, *p* = .560, η_p^2 = .01. However, there was a main effect of Deviation, *F*(1, 49) = 10.02, *MSE* = .28, *p* = .003, η_p^2 = .17, showing that recall in the presence of deviants was lower than in their absence (M_{CS} = .46 vs $M_{\text{CS} + d}$ = .41; M_{SS} = .50 *vs* $M_{\text{SS} + d}$ = .40). There was a non-significant interaction between State and Deviation, *F*(1, 49) = 1.11, *MSE* = .03, *p* = .296, η_p^2 = .02, which suggested that the deviation effect was present regardless of whether the deviants were in a changing- or steady-state sequence.

In sum, for 7-9 year olds, serial recall in CS + *d* and missing-item task performance in SS + *d* and CS + *d* were significantly lower than in Quiet. The CS effect did not manifest in any of the tasks, however, the deviation effect was present in the serial recall and missing-item tasks. The deviation effect manifested regardless of the sequence in which the deviant was placed. To clarify, performance on the probed recall task for children in this age group (7-9 years old) does not appear to have been affected by irrelevant speech as indicated by the absence of a significant irrelevant speech effect, CS effect, and deviation effect on recall. It must be noted, however, that their general low level of performance may have caused this pattern of results.

Ten to eleven-year-old children.

Serial recall.

The initial ANOVA with all four speech conditions and quiet showed that there was a significant main effect of Auditory Condition on serial recall, $F(3.25, 159.49) = 12.81$, $MSE = .17$, $p < .001$, $\eta_p^2 = .21$, and planned contrasts showed that recall performance in CS ($M = .44$, $SD = .22$) and CS + *d* ($M = .44$, $SD = .25$) were significantly lower than in Quiet ($M = .55$, $SD = .22$; both *p*s < .0001). Recall in the SS ($M = .52$, $SD = .24$) and SS + *d* ($M = .52$, $SD = .23$) conditions were not significantly different from Quiet (both *p*s > .05). The second ANOVA revealed a significant main effect of State, $F(1, 49) = 24.15$, $MSE = .37$, $p < .001$, $\eta_p^2 = .33$, and recall in CS speech was lower than in SS speech. The main effect of Deviation was not significant, $F(1, 49) = .76$, $MSE = .02$, $p = .388$, $\eta_p^2 = .01$, and neither was the interaction between State and Deviation, $F(1, 49) = 1.00$, $MSE = .02$, $p = .322$, $\eta_p^2 = .02$, indicating the absence of a deviation effect in this task.

Probed Recall.

The first ANOVA with all four irrelevant speech conditions and quiet revealed a significant main effect of Auditory Condition, *F*(3.16, 155.08) = 4.03, *MSE* = .13, *p* = .008, η_p^2 = .08, however, planned contrasts showed that only recall performance in SS + *d* (*M* = .42, *SD* = .32) was significantly lower than recall in Quiet (*M* = .52, *SD* = .22; *p* = .002). The contrasts between performance in CS (*M* = .49, *SD* = .25), SS (*M* = .54, SD = .25), and CS + *d* (*M* = .48, SD = .29) and Quiet were not significant (all *p*s > .05). The main effect of State was not significant [*F*(1, 49) = .01, *MSE* = .001, *p* = .902, η_p^2 < .001] suggesting the absence of a CS effect in this task. However, the effect of Deviation, *F*(1, 49) = 5.91, *MSE* = .20, *p* = .019, η_p^2 = .11, and the interaction between State and Deviation, *F*(1, 49) = 7.26, *MSE* = .12, *p* = .010, η_p^2 = .13, were significant. Simple main effects analysis showed that recall in the presence of deviants (SS + *d* specifically) was significantly lower than when deviants were absent (SS) but only if the deviant was placed within a steady-state sequence, *F*(1, 49) = 11.12, *MSE* = .32, *p* = .002, η_p^2 = .18. Put simply, SS + *d* (*M* = .42, *SD* = .32) < SS (*M* = .54, *SD* = .25).

Missing-item task.

Performance in this task was generally better than in serial and probed recall tasks. Mean recall in Quiet was .55 (SD = .22), .50 (SD = .23) in CS, .52 (SD = .22) in SS, .46 (SD = .26) in CS + *d*, and .52 (SD = .25) in SS + *d*. The main effects of Auditory Condition, *F*(4, 196) = 1.93, *MSE* = .06, *p* = .107, η_p^2 = .04, State [*F*(1, 49) = 1.95, *MSE* = .08, *p* = .169, η_p^2 = .04], and Deviation [*F*(1, 49) = .76, *MSE* = .02, *p* = .388, η_p^2 = .01] were not significant. The interaction between State and Deviation, *F*(1, 49) = 1.00, *MSE* = .02, *p* = .322, η_p^2 = .02, was also not significant.

Therefore, for the oldest children, although the irrelevant speech effect was present for probed and serial recall tasks, planned contrasts suggested that the effect is representative of significantly poorer recall in CS and SS conditions compared to Quiet in the serial recall task and significantly poorer recall in the SS + d condition versus Quiet in the probe recall task. For the missing-item task, the irrelevant speech effect was not present. The CS effect was present only in the serial recall task while the deviation effect manifested only in the probed recall task when deviants were placed in a steady-state sequence.

3.3.2 Adults.

Serial recall.

The initial ANOVA showed a significant main effect of Auditory Condition, $F(2.67, 130.75) = 6.72$, $MSE = .08$, $p = .001$, $\eta_p^2 = .12$. Planned contrasts comparing performance in irrelevant speech conditions versus Quiet showed that performance in CS ($M = .55$; $SD = .19$; $p < .001$), SS ($M = 58$; $SD = .19$; $p = .025$), CS + d ($M = .54$; $SD = .18$; $p < .001$), and SS + d ($M = .59$; $SD = .19$; $p = .030$) conditions were significantly lower than in Quiet ($M = .62$; $SD = .19$).

While there was a significant main effect of State, $F(1, 49) = 4.70$, $MSE = .08$, $p = .035$, $\eta_p^2 = .09$, there was a non-significant main effect of Deviation, $F(1, 49) = .001$, $MSE < .001$, $p = .976$, $\eta_p^2 < .001$, and non-significant interaction, $F(1, 49) = .382$, $MSE = .002$, $p = .539$, $\eta_p^2 = .008$. Taken together with the means, the results showed that recall in CS speech ($M = .55$, $SD = .19$) was significantly lower than in SS speech ($M = .58$, $SD = .19$), hence replicating the CS effect on serial recall. The lack of a main effect of Deviation suggests that recall in the presence of deviants was not significantly different to performance in the absence of deviants.

Probed recall.

The initial ANOVA showed a significant main effect of Auditory Condition, *F*(3.25, 159.34) = 9.71, *MSE* = .19, $p < .001$, η_p^2 = .16. Planned contrasts revealed that mean recall in CS (*M* = .50; *SD* = .23), SS (*M* = .55; *SD* = .24), CS + d (*M* = .49; *SD* = .30), and SS + d (*M* = .52; *SD* = .31) conditions were significantly lower than in Quiet (*M* = .62; *SD* = .19; all *p*s < .001). There was a significant main effect of State, *F*(1, 49) = 4.12, *MSE* = .07, *p* = .048, η_p^2 = .08, but not of Deviation [*F*(1, 49) = .51, *MSE* = .01, *p* = .478, η_p^2 = .01]. There was a non-significant interaction between State and Deviation [*F*(1, 49) = .26, *MSE* = .004, *p* = .615, η_p^2 = .005].

Missing-item task.

The results of the initial ANOVA showed a significant main effect of Auditory Condition, *F*(4, 196) = 3.40, *MSE* = .08, *p* = .010, η_p^2 = .06. Planned contrasts with Quiet indicated that recall performance in CS (*M* = .58; *SD* = .24; *p* = .015), CS + *d* (*M* = .53; *SD* = .29; *p* = .002), and SS + *d* (*M* = .57; *SD* = .28; *p* = .017) conditions were significantly lower than in Quiet (*M* = .64; *SD* = .19). There was no significant difference between SS (*M* = .60; *SD* = .25) and Quiet (*p* = .114). The main effects of State, *F*(1, 49) = 1.81, *MSE* = .05, *p* = .184, η_p^2 = .04, and Deviation, *F*(1, 49) = 2.97, *MSE* = .08, *p* = .091, η_p^2 = .06, and their interaction, *F*(1, 49) = .08, *MSE* = .002, *p* = .774, η_p^2 = .002, were not significant.

The results for the adults showed the presence of an irrelevant speech effect across all three tasks. Recall performance on the missing-item task was lower than quiet in all speech conditions except SS. However, performance on the serial recall and probed recall tasks were lower for all speech conditions compared to quiet. The CS effect is present only on the probed and serial recall tasks while the deviation effect was not observed in any of the tasks.

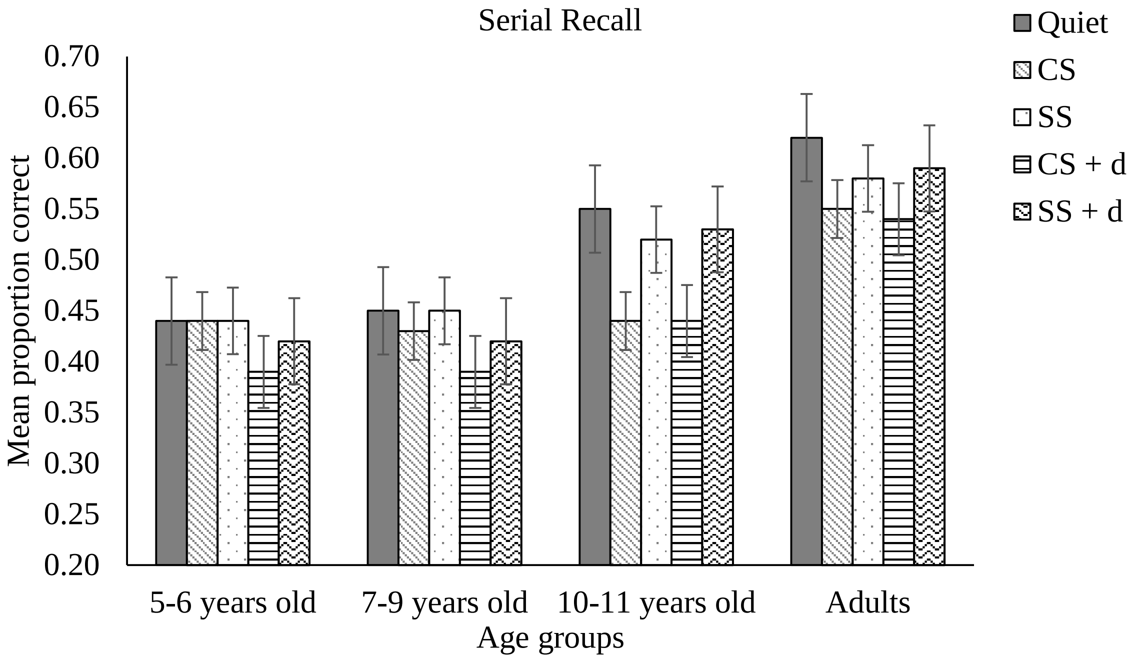


Figure 11. Mean proportion correct in serial recall for each age group. Error bars represent standard error of the mean.

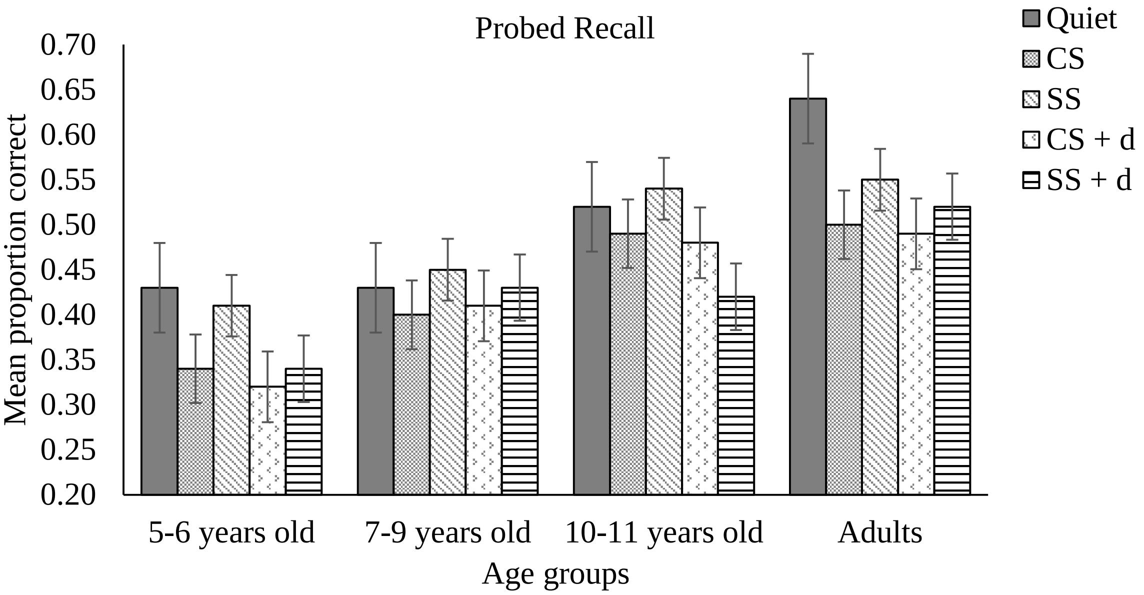


Figure 12. Mean proportion correct in probed recall for each age group. Error bars represent standard error of the mean.

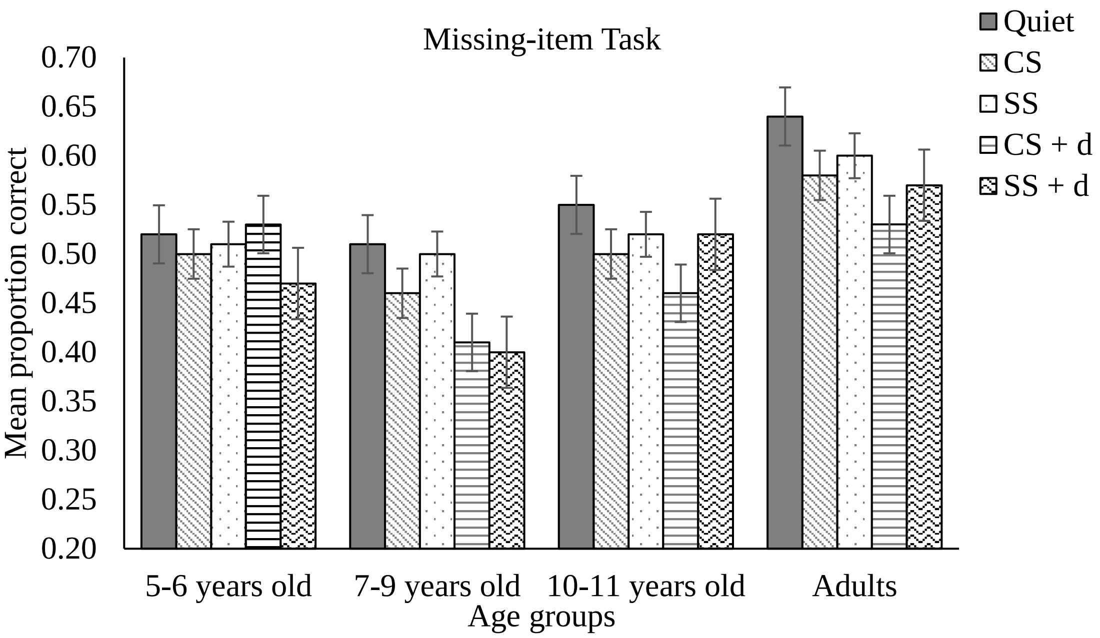


Figure 13. Mean proportion correct in the missing-item task for each age group. Error bars represent standard error of the mean.

3.3.3 Developmental differences.

The following ANOVAs were undertaken to identify developmental differences in vulnerability to auditory distraction in each task:

- 5 (Auditory Condition: Quiet, CS, SS, CS + *d*, SS + *d*) × 4 (Age Group: 5-6 years old, 7-9 years old, 10-11 years old, Adults)
- 2 (State: Changing or Steady) × 2 (Deviation: Present or Absent) × 4 (Age Group: 5-6 years old, 7-9 years old, 10-11 years old, Adults).

For all analyses, when Mauchly's Test of Sphericity was significant, a Greenhouse-Geisser correction was applied.

Serial recall.

The initial ANOVA revealed a significant main effect of Auditory Condition, $F(3.46, 667.19) = 16.24$, $MSE = .20$, $p < .001$, $\eta_p^2 = .08$, with planned contrasts showing that recall in all irrelevant speech conditions except SS speech was significantly poorer than that in quiet (all *p*s < .05). There was also a significant main effect of Age Group, *F*(3, 193) = 7.66, *MSE* = .25, $p < .001$, $\eta_p^2 = .11$. Gabriel's procedure was used in the post hoc analysis on account of sample sizes being slightly different (Field, 2013) and showed that adults' performance (*M* = .57) was significantly better than the 5-6-year-old children (*M* = .42; *MD* = .15, $p < .001$) and the 7-9-year-old children (*M* = .43; *MD* = .15, $p < .001$). Levels of performance among the different age groups of children were not significantly different. The Auditory Condition × Age Group interaction was also significant, *F*(10.37, 667.19) =.2.01, *MSE* = .02, *p* = .028, $\eta_p^2 = .03$.

Simple main effects analyses showed that the simple main effect of Auditory Condition was not significant for the 5-6-year-old group, *F*(2.47, 113.81) = 1.76, *MSE* = .04, *p* = .168, $\eta_p^2 = .04$. For the 7-9-year-old group, the simple main effect of Auditory Condition was significant, *F*(4, 196) = 2.57, *MSE* = .03, *p* = .041, $\eta_p^2 = .05$, and planned contrasts showed that only recall performance in CS + *d* was significantly lower than in Quiet (*p* = .024). The simple main effect of Auditory Condition was significant for the oldest children (10 – 11 years old) as well, *F*(3.25, 159.49) = 12.81, *MSE* = .17, $p < .001$, $\eta_p^2 = .21$, with planned contrasts showing that only performance in CS and CS + *d* was significantly lower than Quiet (both *p*s < .001). Similarly, for the adults, there was a significant main effect of Auditory Condition, *F*(2.67, 130.75) = 6.72, *MSE* = .08, *p* =.001, $\eta_p^2 = .12$, and planned contrasts showed that recall performance in all irrelevant speech conditions were significantly lower than in quiet (all *p*s < .05)

The mixed ANOVA assessing the effects of State and Deviation showed a significant main effect of State, *F*(1, 193) = 24.69, *MSE* = .36, $p < .001$, $\eta_p^2 = .11$, indicating the presence of the CS effect, where recall in CS speech (*M* = .46; *SD* = .20) was lower than that in SS speech (*M* =.50; *SD* = .21). There was also a significant main effect of Deviation, $F(1, 193) = 5.04$, $MSE = .06$, $p = .026$, $\eta_p^2 = .02$, indicating that recall in the presence of deviants ($M = .46$; $SD = .21$) was significantly lower than in their absence ($M = .48$; $SD = .19$).

Furthermore, the two-way State × Age Group interaction was significant, $F(3, 193) = 3.00$, $MSE = .04$, $p = .031$, $\eta_p^2 = .04$, and simple main effects analyses showed that the main effect of State was not significant for the 5-6 year old group ($F(1, 46) = 3.17$, $MSE = .001$, $p = .683$, $\eta_p^2 = .004$), 7-9 year old group [$F(1, 49) = 1.74$, $MSE = .02$, $p = .193$, $\eta_p^2 = .03$], nor the adults [$F(1, 49) = 3.27$, $MSE = .03$, $p = .077$, $\eta_p^2 = .06$]. The lack of a significant effect of State for the adults contradicts findings in the earlier ANOVA for adults' data which showed a significant main effect of State. The lack of a significant effect may be attributed to the absence of CS + *d* and SS + *d* trials in the present analysis. This will be addressed in more detail in the Discussion that follows. The simple main effect of State was significant for 10-11-year-old children, $F(1, 49) = 19.90$, $MSE = .18$, $p < .001$, $\eta_p^2 = .29$, and their recall in CS speech ($M = .44$; $SD = .22$) was significantly lower than in SS speech ($M = .52$; $SD = .24$).

Contrary to earlier results regarding the deviation effect in serial recall (the effect was evident for 7-9-year-old children but no other age groups; see section 3.3.1), there was a non-significant interaction between Deviation and Age Group in the present analysis, $F(3, 193) = 1.40$, $MSE = .017$, $p = .243$, $\eta_p^2 = .02$. The deviation effect noted earlier for the 7-9 year old group may have, in the present analysis, been obscured by the lack of a deviation effect for all other groups. There were also a non-significant interactions between State and Deviation [$F(1, 193) = .76$, $MSE = .003$, $p = .780$, $\eta_p^2 = .006$] and State, Deviation, and Age Group [$F(3, 193) = .36$, $MSE = .003$, $p = .780$, $\eta_p^2 = .006$].

Probed recall.

The initial mixed ANOVA showed that the main effect of Auditory Condition was significant, *F*(3.42, 659.93) = 11.36, *MSE* = .33, *p* < .001, η_p^2 = .06, and planned contrasts showed that recall performance in all irrelevant speech conditions except steady-state speech was significantly lower than in quiet (all *ps* < .001). There was also a significant effect of Age Group, *F*(1, 193) = 6.37, *MSE* = .28, *p* < .001, η_p^2 = .09, and a post hoc analysis using Gabriel's procedure showed that the youngest children's performance (*M* = .37) was significantly lower than that of 10-11-year-old children (*M* = .49; *MD* = -.12, *p* = .026) and adults (*M* = .54; *MD* = -.17, *p* < .001), and performance of the 7-9 year old group (*M* = .42) was significantly lower than adults only (*M* = .54; *MD* = -.12, *p* = .035). The Auditory Condition × Age Group interaction was nearing significance, *F*(10.26, 656.93) = 1.81, *MSE* = .05, *p* = .054, η_p^2 = .03, and subsequent simple main effects analyses showed that the simple main effect of Auditory Condition was significant for adults and all age groups of children except the 7-9-year-old group (which corresponds with results observed for each age group).

The ANOVA assessing the main effect of State and Deviation showed a significant main effect of State, *F*(1, 193) = 5.63, *MSE* = .17, *p* = .019, η_p^2 = .03, and Deviation, *F*(1, 193) = 7.19, *MSE* = .21, *p* = .008, η_p^2 = .04. There were no significant interactions between State and Age Group [*F*(3, 193) = .90, *MSE* = .03, *p* = .442, η_p^2 = .01] and Deviation and Age Group [*F*(3, 193) = 1.11, *MSE* = .03, *p* = .348, η_p^2 = .02]. There was also no significant three-way interaction [*F*(3, 193) = .79, *MSE* = .02, *p* = .503, η_p^2 = .01]. However, the State × Deviation interaction was significant, *F*(1, 193) = 6.36, *MSE* = .13, *p* = .012, η_p^2 = .03 and further analysis showed that the deviation effect was present when deviants were placed in a steady-state sequence [*F*(1, 196) = 12.37, *MSE* = .34, p = .001, η_p^2 = .06] but not within a changing-state sequence [F(1, 196) = .22, *MSE* = .005, p = .638, η_p^2 < .001]. This suggests that the deviation effect was driven solely by the impact of a deviant embedded in a steady-state speech sequence. The absence of an interaction between State, Deviation, and Age Group is in contrast to previous findings which showed a deviation effect for 10-11 year old when deviants were in a steady-state sequence. However, it is possible that the lack of a deviation effect for all other age groups of children and for the adults has obscured the effect observed among the 10-11-year-old children.

Missing-item task.

The initial mixed ANOVA showed a significant main effect of Auditory Condition on recall, F(3.53, 680.57) = 6.37, *MSE* = .19, p < .001, η_p^2 = .03. Planned contrasts showed that overall recall performance in all irrelevant speech conditions except steady-state speech were significantly lower than in Quiet (all *p*s < .05). The interaction between Auditory condition and Age Group was not significant, F(10.58, 680.57) = 1.34, *MSE* = .04, p = .200, η_p^2 = .02. The between groups ANOVA showed a significant main effect of Age Group, F(3, 193) = 3.87, *MSE* = .14, p = .010, η_p^2 = .06 and post hoc analysis using Gabriel’s procedure showed that recall performance of the 7-9-year-old children (*M* = .46) was significantly lower than adults (*M* = .59; *MD* = -.13; p = .005). Performance levels among all other age groups were not significantly different from each other.

There was no significant main effect of State, F(1, 193) = 1.46, *MSE* = .05, p = .229; η_p^2 = .01, indicating no significant difference between recall scores in CS (*M* = .51; *SD* = .23) and SS speech (*M* = .53; *SD* = .23) in this task – in other words, an absence of a CS effect which was expected for the missing-item task. However, the main effect of

Deviation was significant, *F(*1, 193) = 9.48, *MSE* = .24, *p* = .002, η_p^2 = .05, and performance in the presence of deviants (*M* = .49; *SD* = .23) was significantly lower than when they were absent (*M* = .53; *SD* = .20). There were no significant interactions between State and Age Group [*F*(3, 193) = 1.19, *MSE* = .04, *p* = .315, η_p^2 = .02], Deviation and Age Group [*F*(3, 193) = 1.83, *MSE* = .05, *p* = .142, η_p^2 = .05] and no significant three-way interaction either [*F*(3, 193) = 1.13, *MSE* = .03, *p* = .339, η_p^2 = .02].

Developmental differences in the magnitude of CS and deviation effects.

The magnitude of the CS effect was calculated as the difference between mean recall in SS speech and mean recall in CS speech. The magnitude of the deviation effect was calculated separately for changing-state and steady-state sequences as the difference between performance in CS or SS speech and CS + *d* or SS + *d* speech, respectively. A one-way ANOVA with Age Group as the between factor and magnitude of CS and deviation effects as the dependent variable was undertaken (results are reported in Table 3.1). There was a significant effect of Age Group on the magnitude of the CS effect in serial recall only, *F*(3, 193) = 3.64, *MSE* = .06, *p* = .014, η_p^2 = .05. As mentioned earlier, the CS effect was absent for children aged 5-6 and 7-9 years old. However, post-hoc tests using Gabriel’s procedure showed that the magnitude of the CS effect exhibited by 10-11 year old children (*M* = .09) was significantly greater than that among 5-6 year old children (*M* = .01; *p* = .011). Although the oldest children exhibited a numerically greater CS effect (*M* = .09) than adults (*M* = .03), the difference between these two groups was not significant (*p* = .229) and there were no other significant differences among age groups for this task (all *p*s > .05). The magnitude of the CS effect for probed recall and missing-item task were not significant. There were also no significant differences among age groups in the magnitude of the deviation effects in any of the tasks (see Table 3.1). Similar findings were obtained in Study I as well, however, given that children in both studies exhibited a deviation effect in more tasks than the adults did, it is surprising that there was no significant effect of age.

Table 3.1

One-way ANOVA results showing magnitude of deviation effects as a function of Age Group

Magnitude of	Task	df	*MSE*	*F*	*p*
CS effect	SR	3, 193	.06	3.64	**.014**
	PR	3, 193	.01	.36	.781
	MIT	3, 193	.01	.28	.841
CS + *d* effect	SR	3, 193	.02	1.19	.317
	PR	3, 193	.01	.16	.927
	MIT	3, 193	.06	1.17	.324
SS + *d* effect	SR	3, 193	.02	.83	.479
	PR	3, 193	.09	1.69	.171
	MIT	3, 193	.09	1.78	.152

Note. SR – Serial recall; PR – Probed recall; MIT – Missing-item task

3.3.4 Task comparisons: Probed recall vs. Missing-item.

The aim of this analysis was to exploit the differences between the probed recall and missing-item task and show how the two forms of distraction as set out by the duplex-mechanism account can be distinguished from one another. The presentation of TBR items and the requirement of a single response are identical for the two tasks. There is, however, a variation in the strategy used for the tasks: for the probed recall task, participants must identify which item followed another in the list and so must remember the order of the items in the list; but, for the missing-item task they must choose the one item that was missing during presentation and the retention of order is not essential. While the probed recall task is thought to involve the use of serial rehearsal, the missing-item task does not require such processing, and, as Morrison, Rosenbaum, Fair, and Chein (2016) have found, individuals engage in a variety of strategies (e.g., checklists, grouping) to ascertain the missing item. This is a key difference which generally results in the presence of the CS effect only in the task with serial rehearsal (i.e. probed recall; Beaman & Jones, 1997). However, the presence of the deviation effect regardless of task type will show how attention is vulnerable to capture regardless of the processes used in the focal task (e.g., Hughes et al., 2007 Vachon et al., 2016). The addition of age group comparisons to the analysis will provide information on how these underlying processes determine disruption by irrelevant auditory material in children versus adults.

A 2 (State: Changing or Steady) × 2 (Deviation: Present or Absent) × 2 (Task: Probed Recall and Missing-item) × 4 (Age Group: 5-6, 7-9, 10-11-year-old children, and 18-22-year-old adults) mixed ANOVA was conducted. State, Deviation and Task were the within-subjects factors. The main effects of the within- and between-group factors were all significant (see Table 3.2). The main effect of State showed that overall performance in CS speech was lower than that in SS speech. Recall was lower in the presence of deviants compared to when they were absent as indicated by a significant effect of Deviation. The significant effect of Task showed that probed recall performance was lower than that of the missing-item. Finally, the significant effect of Age showed that adults' performance was significantly better than 5-6 and 7-9 year old children only. However, the focus of this section is on the interactions of State and Deviation with Age and/or Task. These interactions would show whether the CS and deviation effect manifested differently in the probed recall and missing-item task as a direct consequence of whether serial rehearsal was used in the task or not. The addition of Age Group as a factor was to ascertain whether the CS and deviation effect vary in their presentation in the two tasks as a function of age-related differences in the use of rehearsal and attentional control.

As there were several non-significant interactions between factors, these are presented in Table 3.3. There were, however, two significant interactions: State × Deviation, *F*(1, 193) = 4.10, *MSE* = .10, *p* = .044, η_p^2 = .02 (the simple main effects are not reported here so as to remain focused on those interactions with Task and Age Group); and, Task × Age Group, *F*(3, 193) = 4.32, *MSE* = .36, *p* = .006, η_p^2 = .06, which showed that performance levels in the tasks varied with age. Simple main effects analyses showed that performance in the probed recall task (*M* = .35, *SD* = .16) was significantly lower than the missing-item task (*M* = .50, *SD* = .18) for children aged five and six years old, *F*(1, 46) = 21.23, *MSE* = .53, *p* < .001 η_p^2 = .32. The effect of Task was not significant for 7-9-year-old children [*F*(1, 49) = .50, *MSE* = .01, *p* = .481, η_p^2 = .01], 10-11-year-old children [*F*(1, 49) = .60, *MSE* = .01, *p* = .444, η_p^2 = .01], and adults [*F*(1, 49) = 3.35, *MSE* = .08, *p* = .07, η_p^2 = .06].

Table 3.2

Main effects of State, Deviation, Task, and Age Group on recall performance

Main Effect	df	*MSE*	*F*	*p*	η_p^2
State	1, 3	.20	6.01	.015	.03
Deviation	1, 3	.45	17.12	<.001	.08
Task	1, 3	1.48	17.73	<.001	.08
Age Group	3, 193	.15	4.56	.004	.07

Table 3.3

Non-significant interactions between factors State, Deviation, Task, & Age Group

Factors	df	*MSE*	*F*	*p*	η_p^2
State, Deviation, Task, Age Group	3, 193	.03	1.45	.231	.02
State, Deviation, Task	1, 193	.04	1.65	.201	.01
Deviation, Task, Age Group	3, 193	.07	2.49	.061	.04
State, Task, Age Group	3, 193	.06	1.90	.132	.03
State, Deviation, Age Group	3, 193	.01	.53	.659	.01
Deviation, Age Group	3, 193	.01	.30	.826	.01
State, Age Group	3, 193	.01	.28	.843	.004
Deviation, Task	1, 193	< .001	.01	.921	.01
State, Task	1, 193	.02	.55	.461	.003

3.4 Discussion

The aim of this discussion is to provide a cross-sectional view of the effects of irrelevant speech on recall performance in tasks with and without a serial rehearsal component. Children ranging in age from 5 to 11 years old completed a series of tasks in the presence of irrelevant speech and in quiet. The children's performance was contrasted with that of adults aged 18 to 22 years old. Participants in this study completed three recall tasks in quiet and in the presence of irrelevant speech. Two of the tasks—serial recall and probed recall—are thought to require the use of serial rehearsal to assist task performance while the remaining task, the missing-item task, does not seem to utilize the serial rehearsal. The irrelevant speech comprised steady-state, changing-state, and deviant sequences. Mean recall scores in quiet was used as baseline performance.

The irrelevant speech effect, which is the finding that recall performance is poorer in the presence of irrelevant speech compared to quiet, was found in all three tasks. There were, however, mixed findings regarding which age groups were affected by which type of irrelevant speech sequence. Examination of the ISE on serial recall showed that while adults' recall was poorer in all irrelevant speech conditions compared to quiet, the recall performance of 10-11-year-old children was poorer only in CS and CS + *d* speech, and the recall performance of the 7-9-year-old children was lower only in CS + *d* speech when compared to quiet. The scores of the 5-6 year old group in the presence of irrelevant speech were not significantly lower compared to quiet. For the probed recall task, adults had lower recall scores in all irrelevant speech conditions compared to quiet while the 5-6-year-old children experienced a detriment to recall in all irrelevant speech conditions except SS speech compared to quiet. For the oldest children, the presence of the ISE in the probed recall task was manifest as poorer recall only in the presence of SS + *d* speech compared to quiet. The ISE on the missing-item task was present only for 7-9-year-old children where performance in deviant conditions was lower than in Quiet. Performance in the missing-item task in CS and CS + *d* was lower than that in Quiet for the adults.

The CS effect, which has been consistently observed in tasks that require the retention of order (e.g. serial and probed recall; Elliott et al., 2016; Hughes & Jones, 2005), is the finding that serial recall accuracy is diminished to a larger degree by speech and sounds that vary acoustically than by sounds that are constant or steady in nature (Jones et al., 1993). Therefore, it is the difference in recall scores between CS and SS speech. The CS effect is thought to be dictated by the acoustic nature of the irrelevant sounds and the involvement of serial rehearsal in task performance because it is the conflict between order cues from relevant and irrelevant sources that results in poor recall scores (Jones & Macken, 1993; Hughes, 2014; Hughes & Jones, 2005; Tremblay & Jones, 1998). In the present study, as predicted, the CS effect was present only in the serial and probed recall tasks and not in the missing-item task. None of the age groups had a CS effect in the missing-item task while the effect was present for serial and probed recall tasks only for 10-11-year-old children. In addition, the CS effect was present for adults but only when their performance in deviant conditions (i.e. CS + *d* and SS + *d*) was included in the analysis. This is a novel finding and will be addressed shortly.

The deviation effect is best explained as attentional capture by an unexpected element within the auditory sequence that is different from the prevailing sequence of irrelevant sounds (Hughes et al., 2005; Jones et al., 2010; Näätänen, 1990) such as an unexpected male-spoken letter placed in a sequence of female-spoken letters as used in the present study. This deviation effect was noted across all three tasks and shows how this type of disruption manifests regardless of the processes needed for task completion (e.g., Hughes et al., 2005, 2007). Although the developmental differences analysis suggested that the deviation effect was present regardless of age, the individual age group analyses suggested otherwise. The youngest children and the adults did not demonstrate a deviation effect in any of the tasks. In contrast, the 7-9 year old group's recall performance in serial recall and missing-item tasks exhibited the deviation effect while the 10-11-year-old children showed the effect only on the probed recall task.

3.4.1 Developmental differences in the irrelevant speech effect.

Klatte, Lachmann, Schlittmeier et al. (2010) have suggested that while the magnitude of the overall irrelevant speech effect may not show a developmental increase, attentional capture (i.e., the deviation effect) would reduce with increasing age as attentional control improves. However, many researchers have consistently found that children experience larger irrelevant speech effects than adults (e.g., Elliott, 2002; Elliott et al., 2007; Elliott & Cowan, 2005; Elliott et al., 2016; Meinhardt-Injac et al., 2015). The most recent work from Elliott and colleagues (2016) has suggested that disruption by irrelevant speech in children is driven by their underdeveloped rehearsal acting as an additional attentional load. Children's already limited attentional abilities (which reduce their capacity to inhibit irrelevant stimuli) could be further exacerbated by poor rehearsal ability in the presence of irrelevant auditory material thereby preventing them from accurately recalling items from the focal task. In addition, although Klatte, Lachmann, Schlittmeier et al (2010) did not find a difference in the magnitude of the ISE between adults and children, they observed that children's poorer attentional control made them vulnerable to a wider range of irrelevant sounds compared to adults in the study. The youngest children's recall performance was disrupted by classroom noise while none of the older children and adults were affected by it. These results suggested that children were more vulnerable to distraction and memory performance suffered because of irrelevant noises in their learning environment – regardless of whether the noises had a changing-state pattern or not.

The present results concerning the ISE in serial recall were contrary to those of Elliott (2002), Elliott et al. (2016) and Klatte et al. (2010). The present study showed that the ISE was present for adults and children aged 7-9 and 10-11 years old but not for children aged 5-6 years old. These results suggest two implications: First, developmental improvements in memory strategies and attentional control—which result in memory span improvements—do not necessarily translate into greater resilience to the ISE (Elliott & Cowan, 2005). Second, the rehearsal strategy used to complete a span task in quiet may prove detrimental when used in the presence of irrelevant speech (Elliott & Cowan, 2005). In fact, the results suggest that those age-groups considered to have better rehearsal and attentional control were more susceptible to distraction. Perhaps the increased disruption with age is a reflection of the task design – longer lists for adults than children. Since adults had to remember eight items and children only five, it could be argued that adults were exposed to irrelevant speech for a greater duration than the children and as a consequence show greater disruption by irrelevant speech than children. In terms of the dose of irrelevant speech, this would suggest that individuals who received a higher dose of irrelevant speech (adults) experienced greater disruption to serial recall than those who had a lower dose (children). However, since this comparison is across age groups it is not possible to separate whether the difference seen here was in fact a result of increased dose or rather an effect of age. Therefore, in Study III, the dose of irrelevant speech is varied to ascertain whether children and / or adults are affected by exposure to different amounts of irrelevant speech within a fixed period of time. As will become clear in Study III, the variation in dose did not have an effect on serial recall within and between age groups (see section 4.3). Therefore, in the present context, it would appear that the differences are age-related and not due to a higher dose of irrelevant speech for older children and adults.

From a practical perspective, it was commonly observed that schools and classrooms were noisy. Although there is research to show that noise in classrooms has a negative impact on children’s speech and listening comprehension, reading abilities, and long-term recall (Belojevic, Evans, Paunovic, & Jakovljevic, 2012; Hygge, 2003; Klatte, Lachmann, & Meis, 2010; Maxwell & Evans, 2000;), it may be the case that children are more accustomed to working in such environments than adults. Nevertheless, the overall pattern of results here do suggest that children and adults perform better in quiet than in the presence of irrelevant speech (e.g., Colle & Welsh, 1976; Elliott, 2002).

It was also surprising that the youngest group of children did not exhibit an ISE on serial recall while there was an effect for children aged 7 to 11 and for the adults. It must be noted that the performance of the youngest children was generally lower than the older children and adults; and, the lack of an ISE could be attributed to possible floor effects because baseline scores and performance in irrelevant speech were too low to allow for a differentiation between them. The task for the youngest children was adapted by replacing digits with colour patches, as they were not sufficiently familiar with digits. It is possible that this task modification could have contributed to the lack of effects within this group and lack of developmental difference between this group and others. The study by Klatte and colleagues (2010) has been criticized on the grounds of not placing sufficient demands on rehearsal and attention which in turn reduced possible distraction effects (Elliott et al., 2016). This may have been in the case presently as well – the use of colour patches may have not placed sufficient demands on rehearsal and attention and hence led the absence of an effect.

The ISE on probed recall and missing-item tasks reflected poorer recall in all irrelevant speech conditions except steady-state speech compared to quiet. This effect was present regardless of age group and is indicative of how irrelevant speech can affect recall on a variety of tasks. The only other study to date to contrast the ISE in probed recall and missing-item tasks among children was Elliott et al. (2016) and the results in the present case are contrary to their findings. In the study by Elliott et al. (2016), children had poorer recall in steady- and changing-state speech compared to quiet (regardless of whether the task necessitated serial rehearsal) while adults showed poorer recall only in steady-state speech versus quiet. This vulnerability of the children to irrelevant speech regardless of its nature and across tasks with and without serial rehearsal, suggested that children were more susceptible to auditory distraction in general than adults. The lack of an age effect with regards to the ISE in the present study suggests that performance in the probed recall task and missing-item task was generally poorer in the presence of irrelevant speech (except steady-state speech) compared to quiet regardless of whether serial rehearsal was a likely strategy or not. It is possible that a methodological difference between Elliott et al. (2016) and the present study contributed to contrary results. The missing-item and probed recall tasks used in Elliott’s study were alternated in a blocked fashion (e.g., one block of missing-item followed by one block of probed recall). However, in the present study, each task was completed before moving on to the next (the impact of irrelevant speech in the two task designs are compared in Chapter V). The costs incurred by children in task-switching may have contributed to poorer performance compared to adults (Davidson et al., 2006). However, it is clear from the general pattern of results in this study that some findings may be more difficult to interpret within the existing theoretical framework and literature.

The CS effect.

Serial recall performance is particularly vulnerable to CS speech compared to SS speech (Jones et al., 1992; Jones & Macken, 1993). This effect has been consistently observed in experiments with adults for over four decades and more recently with children as well (Elliott, 2002; Elliott et al., 2016; Hughes et al., 2005; Jones et al., 1993). The effect occurs when two conditions regarding the nature of the task and the nature of the sound are met: the task must involve serial rehearsal and the sound must vary such that each element is different from the preceding one (Jones & Macken, 1993; Jones et al., 1992). Conflict between order information gleaned from automatic processing of sound and order cues generated from deliberate rehearsal of focal task items lead to the CS effect (e.g., Hughes, 2014; Jones et al., 2010; Jones & Macken, 1995b; Jones et al., 1992). Therefore, the presence of a CS effect in serial and probed recall but not missing-item task provides further evidence that serial rehearsal is needed for the effect to occur (Hughes et al., 2007; Jones & Macken, 1993).

Although the CS effect was present in serial recall overall, it was absent for the 5-9 year old children but present for children aged 10-11 years old and for adults but only when a deviant was present (i.e., for adults, CS + d < SS + d). The present lack of a CS effect for children under ten years of age could suggest that their rehearsal abilities are underdeveloped (Flavell et al., 1966; Garrity, 1975) to such an extent that makes them immune to the CS effect. In other words, 5-9 year old children may not be using rehearsal as much compared to older children, and, therefore have less to gain from rehearsal and less to lose because of its disruption by irrelevant speech (Elliott, 2002). It must be noted, however, that the absence of the CS effect for children aged 7-9 years old is contrary to results from Study I. The difference in results may be attributed to the task designs that were used – the 7-9-year-old children in Study I performed much better in the serial recall task that was adjusted to their span compared to children of the same age in Study II who completed a fixed-length version of the task. However, the magnitude of the CS effect in each of these studies was still very low (1% and 2 %, respectively, in Study I and II). This pattern of results suggests that the CS effect is not modulated by task difficulty (Hughes, 2014). A comparison between Study I and II is addressed later in the thesis to show how task design may influence distraction effects (see Chapter V).

The difference between CS + *d* and SS + *d* recall scores for the adults can be addressed in relation to the unitary and duplex accounts (Cowan, 1995; Hughes, 2014). The unitary account predicts greater disruption in the SS + *d* than the CS + *d* condition because there would be more attention-capturing events in the former than the latter and this pattern should prevail regardless of task-type (Elliott, 2002). However, the duplex-mechanism account predicts an equivalence in disruption by deviants in a SS and CS sequence. The argument follows that since CS and SS sequences (without deviants) are not capturing attention, when deviants are added to the sequences they are the only attention-capturing elements in the sequence. Therefore, so long as the deviants are equivalent, the amount of disruption should be the same regardless of the focal task. Given the theoretical predictions, the pattern of disruption to serial recall in the present case is not the result of attention capture. Taken together with the absence of such disruption in the missing-item task, it appears that poorer serial recall in CS + *d* compared to SS + *d* would be best explained as the CS effect. To clarify, the changing-state component of the sequence rather than the deviant element within it is driving the additional disruption in CS + *d* versus SS + *d*.

The CS effect on serial recall for the 10-11-year-old children (8.5%) was larger than that for adults (3.4%; though not a statistically significant difference) and may suggest that while they are engaging in rehearsal to assist task performance it may not be as sophisticated as the adult strategy of cumulative rehearsal leaving more room for it to be disrupted by irrelevant speech (e.g., Jones & Tremblay, 2000). However, the duplex-mechanism account posits that when rehearsal load increases, children may find it more difficult than adults to focus their attention on the focal task (Elliott et al., 2016). This explanation may apply to the present results given that the 10-11-year-old children were given a fixed list length of 6 items to recall and it may have been challenging for them especially if their memory span was lower than six. If the larger effect for children was due to the their general susceptibility to attentional diversion, then it would be expected that children should experience disruption regardless of the type of irrelevant speech used and the focal task demands (Elliott et al., 2016). However, this was not the case as 10-11-year-old children showed poorer performance compared to quiet in fewer irrelevant speech conditions than adults. While this is surprising it may still indicate that differences in rehearsal efficiency may dictate the level of disruption and although the magnitude of the CS effect was not significantly different between children and adults, the numerical pattern does suggest a larger CS effect for children compared to adults; a pattern that has been observed previously (i.e., Elliott et al., 2016). In addition, the trajectory of results among the children show that the magnitude of the CS effect increased with chronological age – 0.47% for 5-6 year old children, 2.6% for 7-9 year old children, and finally 8.5% for the oldest children.

In summary, the CS effect was, as expected, present in tasks thought to involve serial rehearsal (serial and probed recall but not missing-item). This result supports the view suggesting that the CS effect is reliant upon conflicts between order information in the task and the irrelevant sequence. The analysis of developmental differences showed that the effect was present for the 10-11 year old group but absent for those children under the age of 10 years. Although the developmental differences analysis showed there was no CS effect for the adults, this group did in fact have a CS effect but, interestingly, only when deviants were present in the changing- and steady-state sequences. The general pattern of results suggests that children may be more susceptible to the CS effect than adults, however, in the present study this developmental difference was not statistically significant.

The deviation effect.

The deviation effect is a general distraction effect that occurs regardless of processes needed for focal task performance (Beaman & Jones, 1997; Hughes et al., 2007; Marsh et al., 2017; Vachon et al., 2016) and is the finding that recall in the presence of deviants is lower than in their absence (Hughes et al., 2007; Vachon et al., 2016). Distraction occurs through the mechanism of attentional capture by an unexpected element in an otherwise stable irrelevant auditory sequence (Vachon et al., 2012). The only prerequisite for this effect to occur is the involvement of attention in the focal task (Hughes, 2014). Klatte et al. (2010) suggested that developmental change would manifest for the deviation effect but not for the CS effect since attentional abilities improve with age (Elliott, 2002; Wetzel, Widmann, Berti, & Schröger, 2006). Therefore, it would be expected that better attentional control would reduce the likelihood of attention being captured by irrelevant auditory material. From the context of working memory capacity (WMC), it would be expected that that high-WMC individuals would be less prone to attentional capture than those with lower WMC (as has been observed in studies with adults; e.g., Hughes et al., 2013; Sörqvist et al., 2012). This could also be applied to developmental research comparing children and adults as the former would have lower WMC than the latter as their attentional control develops from childhood into adulthood (Cowan et al., 2006; Guttentag, 1997; Hwang et al., 2010; Lane & Pearson, 1982). In addition, it would be expected that older adults would have lower WMC than younger adults considering the cognitive decline that takes place later on in the lifespan (Hasher & Zacks, 1988; Palladino & De Beni, 1999;

Verhaeghen, Marcoen, Goossens, 1993). Therefore, there is an expectation of greater attentional capture among older adults compared to younger adults. However, research with young (18-30 years) and old adults (60-85 years) have found equivalent levels of attentional capture for the two cohorts even when individual ability was taken into account to adjust sound intensity and task difficulty (Bell & Buchner, 2007; Röer et al., 2015). Although WMC was lower for older adults, this did not relate with greater attentional capture (Röer et al., 2015). Perhaps the difference between the present findings and that of Röer et al. (2015) stems from the use of different deviants – in the present study the deviant was a voice change compared to an item change that was used by Röer et al. (2015).

In the present study, developmental differences analyses suggested that while the deviation effect was present in all three tasks, the presence of the effect did not vary as a function of age. However, this is contrary to individual age-group analyses which showed varied findings regarding the presence (or absence) of the deviation effect. The deviation effect was absent in all tasks for adults and the youngest children. The 7-9-year-old children exhibited a deviation effect on serial recall and missing-item performance while the 10-11 year old group showed a deviation effect in probed recall (but only when deviants were embedded in a steady-state sequence). It is probable that the developmental differences analysis was unable to pick up on subtle differences among the age groups because for each task there were three out of four age groups that did not exhibit a deviation effect – the lack of a deviation effect for a majority of the sample may have prevented the effect of age from being significant overall. There is evidence, however, among young and older adults to suggest an age equivalence in the deviation effect (Röer et al., 2015). Studies 1 and 2 are the first to incorporate deviant speech sequences in irrelevant speech experiments with children and as such there is no previous literature to draw comparisons. Therefore, it may be worthwhile contrasting the deviation effect as seen in Study 1 with the present case.

In the first study, children (aged 7-9 years old) showed a deviation effect in all three tasks. However, adults experienced a deviation effect only in the missing-item task when deviants were in a changing-state sequence. In contrast, the deviation effect in Study II was absent for adults and 5-6-year-old children while it was present for 7-9-year-old (in serial recall and missing-item tasks) and 10-11-year-old children (in probed recall). In Study 1, list lengths for recall were adjusted to individual span scores to ensure that each participant received a recall task matched to their memory span. However, in the present study, span was pre-determined and each age group of participants received a fixed list length for recall. Despite this methodological difference, children in both studies experienced a deviation effect. A direct comparison of 7-9-year-old children from the two studies showed that children in Study I exhibited a deviation effect on all three tasks – the effect was present regardless of sequence context for the probed recall task but for serial recall and missing-item tasks the effect manifested only if the deviant was in a changing-state context. However, in the latter study, they exhibited a deviation effect only in the serial recall and missing-item task, regardless of sequence context. The adults in Study 1 were immune to the deviation effect in serial and probed recall tasks while exhibiting an effect in the missing-item when deviants were in a changing-state sequence. However, in Study II, they did not show a deviation effect at all.

In Study I, it was suggested that task engagement in the form of rehearsal may have shielded adults from the deviation effect in serial and probed recall tasks (Hughes et al., 2013; Sörqvist et al., 2012). An important distinction between Study I and II was the use of span-adjusted list lengths in the former compared to fixed list lengths in the latter. Presumably, this resulted in greater task difficulty in the latter study. In Study I, the majority of adult participants received 6 TBR items in the recall tasks but in Study II all adult participants were tested with 8 items. Greater task-engagement through the increase in perceptual load (Hughes et al., 2013) or task difficulty (Sörqvist et al., 2012) has been shown to attenuate the deviation effect (but not the CS effect) because individuals engage in higher levels of concentration and attentional focus to complete the task (Sörqvist & Marsh, 2015). In contrast, the CS effect does not attenuate when task difficulty is greater because it is the very act of task engagement (in the form of rehearsal) that underpins this type of distraction (Hughes et al., 2013). It could be the case that participants in Study II needed to exercise greater task engagement to complete the tasks with 8 items, thus making them less susceptible to the deviation effect.

If the above holds true for adults, then it is fair to expect a similar pattern of results for the children too. However, children's limited attentional control must also be considered as this could influence the pattern of results that emerge. Surprisingly, the deviation effect was absent for the youngest group of children but given that this group exhibited smaller differences between performance in the presence and absence of deviants (and smaller differences in irrelevant speech versus quiet), it may be the case that effects were suppressed because of overall low performance. The 7-9 year old children in this study exhibited a deviation effect in serial recall and missing-item task only while the oldest children showed a deviation effect in the probed recall task only. The pattern of results for these two age groups suggests greater susceptibility to attentional capture for the younger children. In terms of task engagement (rehearsal) and attentional control, the results suggest that younger children may be more susceptible to distraction because of their poorer attentional control and this may be exacerbated when rehearsal acts an additional attentional load (Elliott et al., 2016). The older children exhibited a deviation effect only in the probed recall task which employs rehearsal and may have proved more challenging than the missing-item and serial recall tasks – the use of rehearsal and the added task of recalling which item followed another in the list may have exacerbated their attentional control. In comparison to the children, the adults did not show a deviation effect in any of the tasks. Overall, the pattern of results is similar to that in Study I – children may be more susceptible to attentional capture than adults as evidenced by the deviation effect in more tasks for children than adults. For children, whose attentional control is still developing and less efficient than adults, greater task engagement in the form of rehearsal may exacerbate their poor attentional control and result in attentional capture. This explanation sits well with findings by Elliott and colleagues (2016) who suggest that children are more susceptible to attentional diversion than adults because of their limited attentional control. In contrast, adults who have better rehearsal abilities and attentional control may be less susceptible to attentional capture in serial and probed recall tasks because greater task-engagement shields them from distraction while better attentional control makes them less likely to have their attention captured in the missing-item task (Hughes et al., 2013).

Task comparisons: Probed recall vs. missing-item.

The comparison of recall performance between these two tasks in the presence of irrelevant speech provided an opportunity to assess the role of rehearsal and attention in determining disruption. The addition of a developmental aspect into the analysis allowed for an examination of how rehearsal and attention can influence distraction effects in children and adults. Through a similar analysis, Elliott et al. (2016) identified that children were generally more susceptible to disruption by any type of sound compared to adults and while the CS effect was present in the probed recall task it was absent in the missing-item task. This latter finding is crucial when distinguishing between the two effects because the distinction undermines the unitary account which suggests that the CS effect is the result of attention capture by each successive token in the sequence (e.g., Chein & Fiez, 2010; Cowan, 1995; Bell et al., 2012).

In the current study, the deviation effect was evident in both tasks. Statistical analyses with Task as a factor showed the CS effect was present regardless of task, however, earlier analyses considering performance in each task separately showed that the CS effect was only present in probed recall and not missing-item. Recall performance was generally higher in the missing-item task compared to probed recall but only for the youngest children in the study. All other age groups performed comparatively in the missing-item task as they did in probed recall.

The key finding from this analysis is that the deviation effect manifested regardless of the processes involved in the task, that is, whether or not serial rehearsal was involved. Secondly, the CS effect was present only in the probed recall task when serial rehearsal is thought to be used (Elliott et al., 2016; Hughes et al, 2007). The differentiation between these two effects is a crucial step in determining the underlying mechanisms that govern these forms of distraction. It appears that rehearsal underpins the CS effect while attentional capture is responsible for the deviation effect for children and adults, in line with the duplex-mechanism account (Hughes et al., 2007; Hughes, 2014; Vachon et al., 2016). The evidence from this analysis provides support for the duplex-mechanism account by clearly differentiating between the two forms of distraction.

Concluding summary.

The results from this study run contrary to previous developmental work comparing children and adults’ susceptibility to the irrelevant speech effect. While previous literature suggested that the ISE decreases with age, the present study showed a larger ISE for adults compared to children. The CS effect was noted on serial and probed recall tasks, however, the CS effect on serial recall was only present for the oldest children and adults (but only when deviants were present) and the children had a larger CS effect than the adults which is in line with previous findings in this regard. Presence of the CS effect in probed recall and not missing-item is also in keeping with previous work which have shown a CS effect manifests only in tasks where serial rehearsal is thought to be deployed to complete the task (e.g., Beaman & Jones, 1997; Hughes et al., 2007; Jones & Macken, 1993). The deviation effect was evident for children but not adults and may reflect children's poorer attentional control making them more vulnerable to attentional capture (Elliott et al., 2016)

While the results do not fully conform to findings in the existing literature, they do lend support to the duplex-mechanism account by differentiating between the CS and deviation effects on the basis of serial rehearsal involvement in task completion. The finding that adults had a larger ISE than children is surprising but could be indicative of a greater reliance on rehearsal to support recall which in the presence of irrelevant speech may actually be more detrimental given the vulnerability of rehearsal to irrelevant speech (Elliott & Cowan, 2005). The CS effect being present for older children and not younger ones is also explained with recourse to rehearsal because the younger children may not have been engaging in rehearsal as much as the older ones or the adults which effectively immunizes them against the CS effect. The presence of the deviation effect across all three tasks is in keeping with previous findings that attentional capture is possible regardless of task type or processes involved. However, a more in-depth analysis incorporating individual differences in working memory capacity and attentional control may serve to elucidate any developmental differences that were not identified in this study. As a final note, floor effects may have affected the developmental findings with regard to the youngest children in the study (5-6 years old). These children struggled the most with the tasks and required a great deal of assistance during testing to ensure that instructions were fully understood. Perusal of the raw data of some of the participants revealed that although they could articulate the task demands back to the Experimenter they seemed unable to consistently perform the task. This may have been due to an inability to pay attention for long periods of time, lack of familiarity with the equipment, or an inability to work without being constantly supervised. Working with this group of children is essential to understand the effects of distraction at the pre-rehearsal age, however, care needs to be taken to ensure that testing procedures are adhered to and that the tasks are age-appropriate. When testing young children, it may be beneficial to work with them on a one to one basis to avoid distraction from other children that would generally arise in a group setting. Finally, ensuring that the tasks and procedure used are suitable for the age group is paramount. In the present study, for example, children were asked whether they were familiar with the use of a mouse and only some were accustomed to it. Therefore, on some occasions, the Experimenter had to intervene and click the mouse while the children pointed (or said aloud) the colours they wanted to put in response boxes. The task also had to be modified to suit this age group since they were not sufficiently familiar with digits.

CHAPTER IV

EMPIRICAL STUDY III: A DEVELOPMENTAL TAKE ON THE EFFECTS OF TOKEN-SET SIZE AND DOSE OF IRRELEVANT SPEECH ON RECALL PERFORMANCE.

Abstract

This study uses token-set size and dose effects to explore what developmental differences can tell us about the underpinnings of distraction. The token-set size effect is the finding that disruption to serial recall increases when token-set size increases from one to two tokens but no further (Tremblay & Jones, 1998). This non-monotonic relationship suggests that there is a changing-state effect present when token-set size increases from one to two tokens. The absence of additional disruption when token-set size increases beyond two emphasises that disruption will occur if there is change from one token to the next but that the type of change is not important. The dose effect refers to the finding that serial recall is worse when the dose of irrelevant sounds is higher – i.e. disruption is greater when, for example, 30 tokens are heard across a trial compared to 20 tokens. Higher doses are thought to be more disruptive than lower doses because there is more changing-state information present in a high dose sequence than in low dose (Bridges & Jones, 1996). The above pattern of results aligns with the duplex-mechanism account of distraction. The contrasting unitary account, however, suggests there will be a monotonic relationship between set-size and disruption; and higher doses will be less disruptive because of greater opportunity for habituation of the orienting response (physiological and psychological effects as a result of unexpected stimuli) to take place (Cowan, 1999). A task comparison – serial recall vs. missing-item – is used to adjudicate between the two accounts – if the effects are attentional based, they will manifest in the same way for both tasks. If disruption is underpinned by rehearsal, then

there will be no effects in the missing-item task – a task devoid of serial rehearsal. In the present study, children aged 5-11 years old ($N = 109$) and adults aged 18-22 years old ($N = 34$) completed these tasks in the presence of irrelevant speech consisting of either one, two, or five tokens and varying in dose as follows – high dose of 30 tokens and low dose of 20 tokens. Children and adults showed a CS effect on serial recall (recall in 2 tokens $<$ 1). Contrary to predictions by the duplex-mechanism account, children aged 7-11 years old and adults exhibited additional disruption when token-set size increased from 2 to 5 tokens. Children under 7 years of age did not show additional disruption when token-set size increased from 2 to 5 tokens. There was no effect of dose on serial recall for children and adults. There were no effects of token-set size and dose on missing-item performance for any age group. The results suggest that both children and adults are vulnerable to distraction of the interference-by-process type: the changing-state effect was present when serial rehearsal was deployed in the task. The additional disruption to serial recall (but not missing-item) performance caused by increase in token-set size from 2 to 5 could suggest some additional role for attention capture. However, when considered together with the missing-item task the results are confounding and do not fully support the attentional explanation. The pattern of results will be discussed with reference to the two accounts of distraction.

4.1 Introduction

For the purpose of clarity, this chapter will begin with an outline of key terms before addressing the rationale of the study. Token-set size refers to the number of unique tokens that comprise an irrelevant sound sequence while token-dose is the absolute number of tokens it contains (e.g., "*A-B-A-B*" has a token-set size of two and a token-dose of four; Bridges & Jones, 1996). A non-monotonic relationship has been found between token-set size and disruption to serial recall wherein disruption increases when the token-set size increases from one to two tokens but any further increase in the set-size (e.g., from two to five and seven tokens) does not correspond with additional disruption (Bridges & Jones, 1996; Campbell et al., 2002; Tremblay & Jones, 1998). The relationship between token-dose and disruption is straightforward - when dose increases so does disruption (Bridges & Jones, 1996; Campbell et al., 2002). This dose effect is unique to changing-state sequences and shows that greater disruption occurs when the amount of changing-state information per trial is high. The distinction between high and low doses of changing-state sequences was further strengthened by results from the study by Campbell et al. (2002) which showed that at low doses, there was no difference between the disruptive potential of two and five tokens. However, at higher doses, five-token sequences were more disruptive than two-token sequences. The dose effect is not observed with steady-state sequences because variations in dose for steady sequences do not add any changing-state information to the sequence (Campbell et al., 2002; Tremblay & Jones, 1998).

The present study built upon previous work by comparing the token set-size and dose effects on serial recall between children and adults. This study also incorporated a comparison between serial recall and the missing-item task to identify whether the token-set size and dose effects could be the result of attentional capture (the mechanisms of such disruption are described shortly). This study is the first to consider developmental differences and to use such a task comparison in the context of token-set size and dose effects. This study also involved the use of complex span measures to provide a measure of working memory capacity (WMC; or attentional control) for the adults that could potentially reveal a link between attentional control and one’s susceptibility to distraction specifically to token-set size and dose effects.

The purpose of this study was to exploit the typical patterns observed in relation to token-set size and dose to determine whether rehearsal and / or attention underpin distraction among children in the same way as in adults. The use of a missing-item task (alongside serial recall) adds a novel aspect to the research by enabling an examination of the effects in a task thought to be devoid of serial rehearsal (Hughes et al., 2007; Morrison et al., 2016). In doing so, this study will evaluate whether the unitary or duplex accounts are more suited to explain developmental differences in the token set-size and dose effects. The relative importance of rehearsal and attention in underpinning distraction at different points in the life span will also be addressed. The addition of WMC measures provides an additional means of testing the involvement of attention in determining distraction.

Previous work has shown that when the token-set size increased from one to two, the disruption to serial recall also increased (which demonstrates the changing-state effect) but any further increase beyond two tokens did not reliably increase disruption further (Tremblay & Jones, 1998; however, see also Campbell et al., 2002). Although initially it may seem that disruption from two tokens is the result of attentional capture, the lack of further disruption when tokens increase from two to five suggests this cannot be the case. If tokens in the irrelevant sequence cause distraction by capturing attention then greater attentional capture should take place when there are a greater number of tokens. According to the habituation hypothesis of the embedded processes model (Cowan, 1995, 1999), the rate of habituation is an inverse function of the number of tokens – habituation would occur at a higher rate when there are fewer tokens (e.g., 2 tokens) than when there are several (e.g., 5 tokens). Therefore, this non-monotonic pattern observed in the literature is contrary to the unitary account of distraction which predicts that disruption should increase monotonically with token-set size (Cowan, 19995; Elliott, 2002). The non-monotonic pattern is more suitably explained by the interference-by-process account which proposes that the disruption reflects the CS effect. The lack of disruption when set-size increases beyond two tokens speaks to the nature of the CS effect in that disruption will occur so long as there is change between successive items and that a sequence with two tokens is equivalent in its disruptive potential to one with five tokens (Hughes, 2014; Tremblay & Jones, 1998).

The existing pattern of results seen in the dose effect are also in line with a changing-state explanation than the unitary account (Tremblay & Jones, 1998). According to the unitary account, habituation would be faster in a high dose compared to low dose sequence because of greater exposure to the tokens during the course of a trial (Bridges & Jones, 1996; Cowan 1995, 1999). According to Tremblay and Jones (1998), at higher doses, the neural model would be formed faster causing the orienting response (Sokolov, 1963) to become habituated. The results thus far, however, have shown that with increase in dose there is an increase in disruption (Bridges & Jones, 1996; Tremblay & Jones, 1998). The changing-state hypothesis, however, is able to account for these results – at higher doses (regardless of the number of tokens) there is a greater amount of changing-state information or order cues which will disrupt serial recall to a larger extent than low dose irrelevant sequences. The evidence from the effects of token set-size and dose lean towards the interference-by-process account a great deal more than they do with the unitary account (Bridges & Jones, 1996; Tremblay & Jones, 1998).

To date, research in this area has considered the effects of token set-size and dose on serial recall only (e.g., Campbell et al., 2002; Hughes & Jones, 2005). This is the first study to examine these effects in the missing-item task. Unlike serial recall, the missing-item task is thought not to require serial rehearsal to assist in recall with participants often using a checklist or grouping strategy to identify the missing item (Morrison et al., 2016). The present study capitalizes on this difference in processing as an additional means to show how distraction effects can vary on account of the processes that are deployed in the focal task. If the non-monotonic function between token set-size and disruption is a reflection of the CS effect (and the disruption to rehearsal) then, according to the duplex-mechanism account there should be no CS effect for the missing-item task. Likewise, differences in dose should have no bearing upon this task if they are the result of changing-state disruption (Bridges & Jones, 1996; Tremblay & Jones, 1998). If the token set-size and dose effects were purely attentional-based, it would be expected to manifest in the missing-item task in a similar fashion as in the serial recall task (as is often seen with the deviation effect; Beaman & Jones, 1997; Hughes et al., 2007; Vachon et al., 2016). In the study by Elliott et al. (2016), the serial recall versus missing-item task comparison revealed that children's susceptibility to auditory distraction (whether steady- or changing-state) was underpinned by their poorer attentional control and not inchoate rehearsal. Without foreshadowing the results from the present study, the findings from Elliott et al. (2016) appear to suggest a different pattern of results may emerge in the present study.

It is hypothesised that if poor attentional control underpins children's greater distractibility compared to adults (Elliott et al., 2016), then, a monotonic relationship between token-set size and disruption will be observed; in addition, a low dose sequence will be more disruptive than a high-dose sequence because of a faster habituation in the latter compared to the former (Bridges & Jones, 1996; Cowan 1995, 1999). Furthermore, if distraction is solely underpinned by attentional control (Elliott, 2002; Elliott & Briganti, 2012) then a similar pattern of disruption should occur regardless of task type (cf. Hughes, 2014). Alternatively, if distraction is underpinned by rehearsal (e.g., Hughes et al., 2007; Macken et al., 1999) then the following should be expected to emerge: a non-monotonic relationship between token-set size and disruption (Tremblay & Jones, 1998) and no difference between disruption caused by high and low doses (cf. Bridges & Jones, 1996). Moreover, this pattern of disruption would be expected to occur only in the serial recall task (Hughes & Jones, 2005; Tremblay & Jones, 1998).

4.2 Method

4.2.1 Participants.

Thirty-five undergraduate students aged 18-22 years old (26 females, *M* = 20.31 years, *SD* = 1.19) from the University of Central Lancashire participated in this study. However, data from one participant was removed on account of a score of zero in the baseline (Quiet) condition of the missing-item task. Therefore, only data from the 34 remaining participants were used in the analyses (25 females, *M* = 20.32 years, *SD* = 1.24). One hundred and nine children from primary schools in Lancashire and Caerphilly also participated in this study. The children were categorised into three groups based on their age: 5-6-year-old children (*N* = 29; 12 females, *M* = 6.45 years, *SD* = .26), 7-9-year-old children (*N* = 40; 13 females, *M* = 8.6 years; *SD* = .77), and 10-11-year-old children (*N* = 40; 17 females, *M* = 11.03; *SD* = .39). Children were not grouped based on the school they attended but rather based on their age. Therefore, each age group consisted of children from different schools.

All adult participants reported normal hearing and normal or corrected-to-normal vision. Parents of children were instructed to refuse consent if their child had known hearing and/or vision difficulties. In addition, children's teachers were consulted before testing began. The university students received course credit or a £10 shopping voucher for their participation and the children were given stickers at the end of testing.

4.2.2 Apparatus, materials, and procedure.

To-be-ignored sequences.

Five letter names were chosen that were phonologically different from each other: *Q, B, J, N,* and *I.* These were digitally recorded in an even-pitched female voice at a sampling rate of 44.1 KHz with a 16-bit resolution using Sony Sound Forge Pro 11 (Sony Creative Software). Each letter-name was edited to span 250ms. The sequences were differentiated by the number of sound tokens – one, two, or five tokens – and the dose on each trial –high dose of 30 tokens or low dose of 20 tokens. The onset of the irrelevant sequence was simultaneous with that of the visual TBR items. Each item in the irrelevant sequence lasted 250ms with an inter-stimulus interval (ISI – offset to onset) of 133ms and 325ms for high and low dose variants, respectively. The length of the sequences was the same for adults and children (11.5 s) to ensure that both groups were exposed to the same dose of irrelevant speech (whether high or low) per trial regardless of the number of TBR items they received.

The one-token sequence was the letter *B* repeated 20 or 30 times, depending on dose. The two-token sequence consisted of the letters *J* and *Q* while the five-token sequence consisted of the letters *Q, B, J, N, I,* varied by dose.

To-be-remembered material.

The TBR items comprised digits sampled without replacement from the set 1 to 9 for the adults and 1 to 6 for all children aged seven years and above. Children under seven years old had to remember a series of colour patches and, in addition to those used in Study II (*Black, Blue, Green, Pink, Red*), the colour *Brown* (Mean Age of

Acquisition rating was 4.2 years; Kuperman et al., 2012) was added to make a total of five colours that were used for the recall tasks. Each TBR item appeared on the screen for 1000ms with an ISI of 500ms for the adults and 1625ms for the children. There were eight TBR items for the adult participants and five TBR items for the children but the variation in ISI ensured that each trial lasted 11.5 s regardless of the number of TBR items (see Figure 14).

	1000ms	ISI	1000ms
		500ms	
TBR item	8	-	6

		ISI		ISI			ISI		ISI…	...ISI	
	250ms	133 ms	250 ms	133 ms	234 ms	16ms	133 ms	250ms	133ms		250ms
									101 ms	32 ms	
TBI item	Q	-	B	-	J…	...J	-	N	-…	...-	I

Figure 14. Schematic representation of the onset and offset of TBI and TBR items in a high dose trial for adult participants.

Tasks.

Serial recall and missing-item tasks were used for all age groups. The adults received eight digits for recall while children received five digits or colour patches. Each task took approximately 30 min for both age groups. Adults also completed three complex span measures prior to the memory tasks. The span tasks took approximately 45 min. The consent and administration procedures were the same as in Study I and II.

Shortened versions of the complex span tests (Foster et al., 2015) were used with the adult participants only and they completed one out of three blocks of each span test. The decision to use one block of each span task was based on the finding that it predicted 91% of the overall variance in fluid intelligence with the benefit of cutting down on administration time when compared to administering three blocks of all three tasks (Foster et al. 2015).

In these tasks, participants are given a sequence of items to remember in order and also complete a distractor task between the presentations of each to-be-remembered item (see Figure 15). For all the span tasks, the scores were calculated by summing the number of TBR items (letters, square locations, or arrows) that were correctly recalled in the correct order – also known as a partial score (Turner & Engle, 1989). The span tests were as follows:

Operation span.

Letters were used as the to-be-remembered items and simple math problems as the distractor task (Kane, Hambrick, & Conway, 2005) for Operation span (OSpan). After solving each math problem, participants were presented with a letter to remember. The span task was designed such that the math-letter sequences varied unpredictably from three to seven items on each trial. Once all the math tasks and letters for each trial were presented, a recall screen was displayed for participants to click on the letters in the order they were presented.

Symmetry span.

The method used for Symmetry Span (SymSpan) was similar to the OSpan but with three main differences. The TBR item in this task was the location of a red square presented in a 4 × 4 grid and the distractor task was to judge whether the displayed shape was symmetrical along its vertical axis. The symmetry-location pairs varied from two to five times per trial.

Rotation span.

In the Rotation Span (RotSpan) task, participants had to remember the size and direction of arrows in the sequence they were presented. The distractor task involved judging whether rotated letters were presented normally or as a mirror image of the letter. The letter-arrow sequence was repeated two to five times per trial and the number of items varied unpredictably.

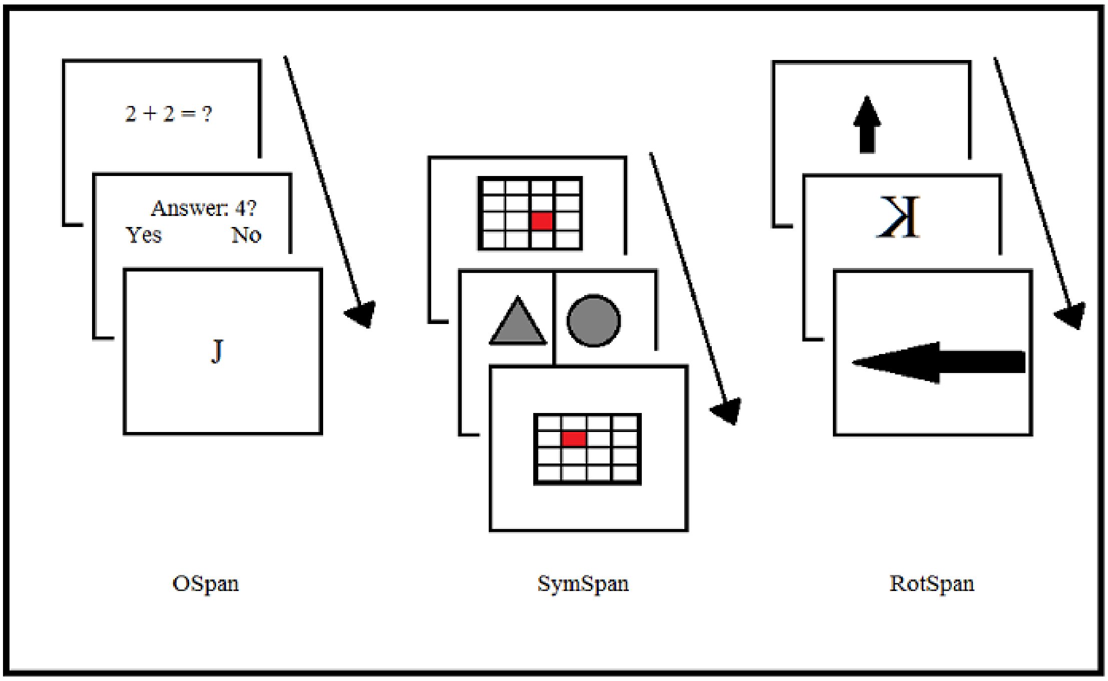


Figure 15. Diagram showing progression of Operation span, Symmetry Span, and Rotation Span.

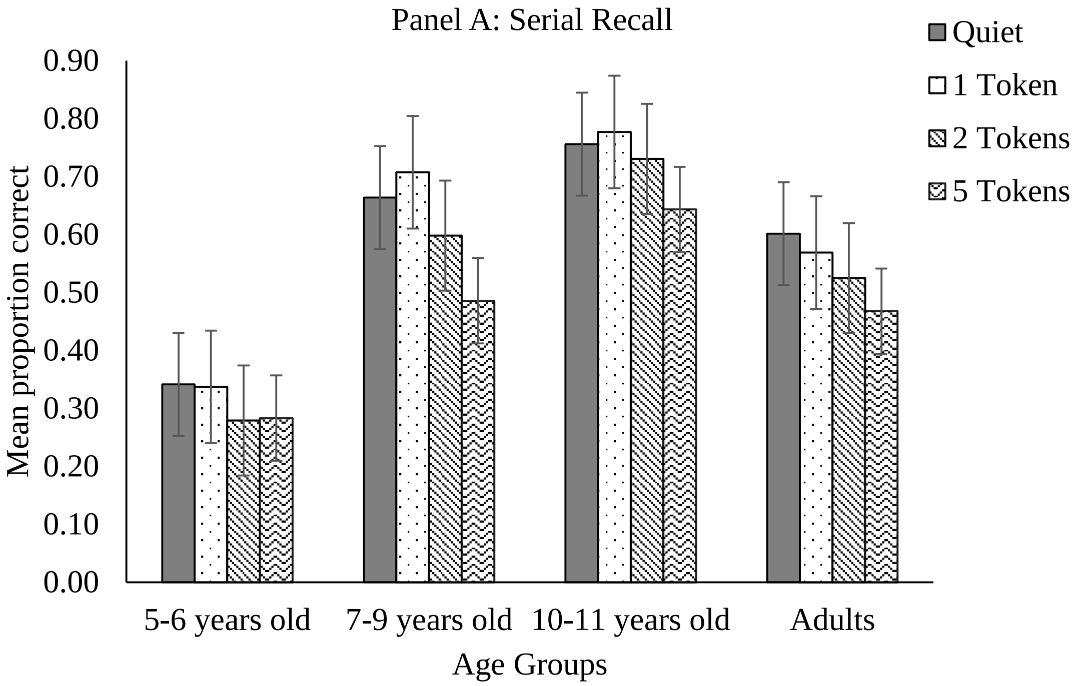
4.2.3 Design.

A 4 (Age Group) × 2 (Task Type) × 3 (Tokens) × 2 (Dosage) mixed design was used. The between-participants factor, Age Group, had four levels: 5-6 years old, 7-9 years old, 10-11 years old, and adults aged 18-22 years. There were three within-participant factors, Task-Type, Token set-size, and Dose. Serial Recall and Missing Item tasks were used with trials that had either one, two, or five irrelevant speech tokens that were presented at a high dose of 30 tokens or a low dose of 20 tokens. Adults completed the span tasks in one of six order permutations so that each task order was used roughly an equal number of times across the sample. The order of the serial recall and missing-item tasks was also counterbalanced across participants. Adults completed 64 trials while children completed 48 trials for each memory task.

4.3 Results

Outliers were observed in the data, however, they were retained in the analyses because the pattern of results remained the same even when they were removed. There were three outliers in serial recall baseline data for 10-11 year old children, two of which were also outliers in the missing-item task. There was one outlier in serial recall data for the adult group and one outlier in missing-item task data for the 5-6 year old group. Figure 15 shows the mean recall performance for all age groups in Quiet, one token, two token, and five token irrelevant speech sequences. Figure 16 shows mean recall performance for each task as a function of dose and age group.

Analysis of Variance was used to assess the effect of irrelevant speech on recall performance in both tasks. In cases where Mauchly’s Test of Sphericity was significant, a Greenhouse-Geisser correction was applied. The initial one-way repeated measures ANOVA examined the effect of Sound Condition on recall by comparing recall performance in quiet versus in the presence of steady-state (1 token) and changing-state (2 and 5 tokens) irrelevant speech sequences. The subsequent two-way repeated measures ANOVA examined the effect of token-set size and dose by comparing recall performance in 1, 2, and 5 tokens across high and low dose conditions (3 Token-set Sizes × 2 Doses). Proportion correct scores for serial recall were calculated as described in Chapter II (see Section 2.3.1).



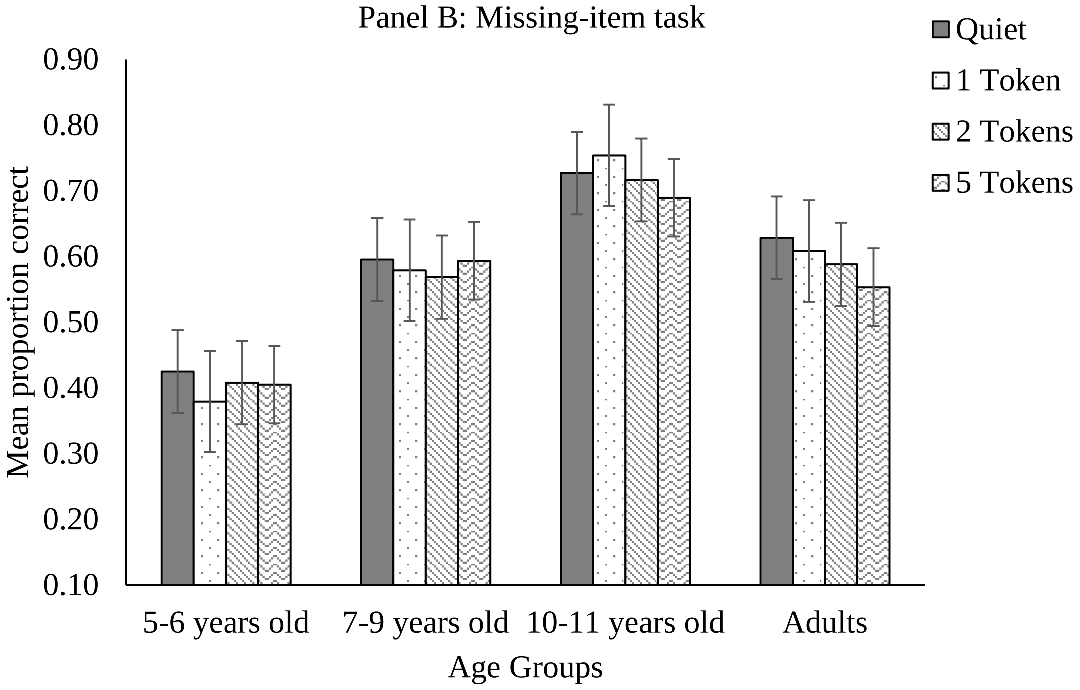


Figure 16. Panel A: Mean serial recall performance for each age group and sound condition. Panel B: Mean recall performance in the missing-item task for each age group and sound condition. Error bars represent standard error of the mean.

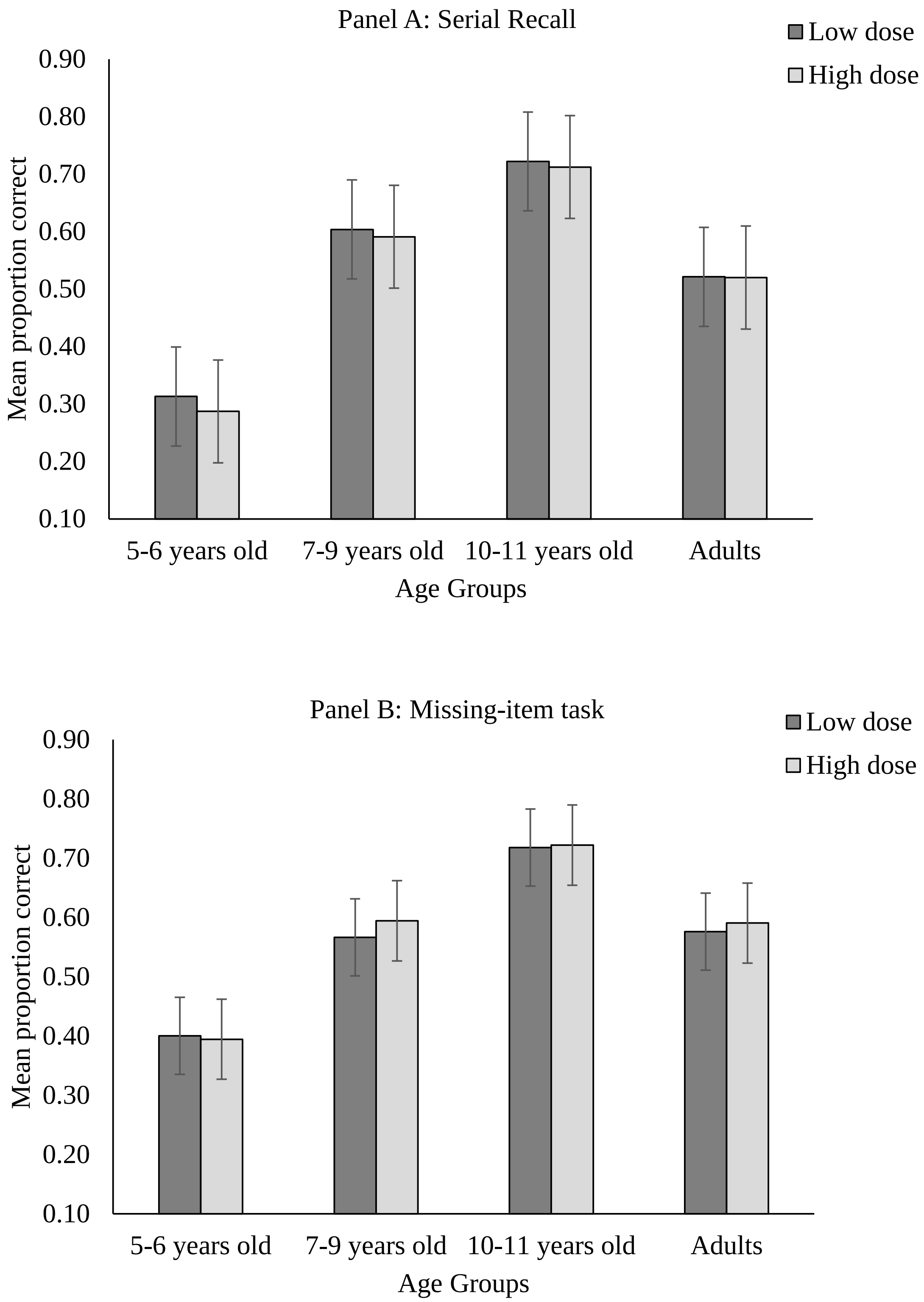


Figure 17. Panel A: Mean serial recall performance at low and high doses. Panel B: Mean recall performance in missing-item task at low and high doses Error bars represent standard error of the mean.

4.3.1 Children.

Five to six-year-old children.

An ANOVA incorporating all four Sound Conditions (Quiet, 1, 2, and 5 tokens) showed a significant main effect of Sound Condition on serial recall performance, *F*(2.20, 61.62) = 4.31, *MSE* = .04, *p* = .015, η_p^2 = .13. Following this, planned contrasts indicated that serial recall performance in the presence of two (*M* = .28; *SD* = .08) and five tokens (*M* = .28; *SD* = .08) was significantly lower than in Quiet (*M* = .34; *SD* = .14; *p* = .023 and *p* = .041, respectively). There was no significant difference between recall performance in the one token condition (*M* = .34; *SD* = .10) versus quiet (*p* = .873). The subsequent ANOVA showed a significant main effect of Token-set Size on serial recall performance, *F*(2, 56) = 6.08, *MSE* = .06, *p* = .004, η_p^2 = .18. Pairwise comparisons indicated that recall performance in the one token (steady-state) condition (*M* = .34; *SD* = .10) was significantly higher than in two tokens (*M* = .28; *SD* = .08; *p* = .001) and five tokens (*M* = .28; *SD* = .08; *p* = .018) conditions. There was no significant difference between recall scores in two versus five token conditions (*p* = .832). The main effect of Dose was not significant, *F*(1, 28) = 3.66, *MSE* = .03, *p* = .066, η_p^2 = .12, and neither was the interaction, *F*(2, 56) = .21, *MSE* = .002, *p* = .807, η_p^2 = .01.

The ANOVA incorporating all four sound conditions (Quiet, one, two, and five tokens) showed a non-significant main effect of Sound Condition on missing-item performance, *F*(3, 84) = .47, *MSE* = .01, *p* = .705, η_p^2 = .02. Similarly, the subsequent ANOVA showed that there were no significant main effects of Token-set Size, *F*(2, 56) = .40, *MSE* = .01, *p* = .670, η_p^2 = .01, or Dose, *F*(1, 28) = .06, *MSE* = .001, *p* = .807, η_p^2 = .002, nor a significant interaction, *F*(2, 56) = .08, *MSE* = .003, *p* = .926, η_p^2 = .003, in the missing-item task.

Seven to nine-year-old children.

The initial ANOVA showed a significant main effect of Sound Condition on recall performance, *F*(2.43, 94.62) = 33.68, *MSE* = .46, *p* < .001, η_p^2 = .46. Planned contrasts revealed that serial recall performance in the presence of two token (*M* = .60; *SD* = .20; *p* = .008) and five token sequences (*M* = .48; *SD* = .19; *p* < .001) were significantly lower than in Quiet (*M* = .66; *SD* = .20). On the other hand, contrasts showed that serial recall performance in the steady-state 1 token sequence (*M* = .71; *SD* = .20; *p* = .020) was significantly *higher* than that in Quiet. The second ANOVA showed a significant main effect of Token-set Size on serial recall performance, *F*(1.66, 64.66) = 43.96, *MSE* = 1.19, *p* < .001, η_p^2 = .53. Pairwise comparisons revealed that recall performance in the presence of irrelevant speech with two tokens (*M* = .60; *SD* = .20; *p* <.001) and five tokens (*M* = .49; *SD* = .19; *p* <.001). Recall in the two token condition was also significantly higher than that in five tokens (*p* < .001). Neither the main effect of Dose on serial recall performance, *F*(1, 39) = .82, *MSE* = .01, *p* = .372, η_p^2 = .02, nor the two-way interaction, *F*(2, 78) = 1.97, *MSE* = .03, *p* = .146, η_p^2 = .05, were significant.

Mean recall performance in the missing-item task was similar across quiet and irrelevant speech conditions and the initial ANOVA comparing performance across conditions showed a non-significant main effect of Sound Condition, *F*(3, 117) = .37, *MSE* = .01, *p* = .772, η_p^2 = .01. The second ANOVA showed that there was no significant main effect of Token-set Size on missing-item task performance, *F*(2, 78) = .35, *MSE* = .01, *p* = .706, η_p^2 = .01. Similarly, the main effect of Dose [*F*(1, 39) = .2.44, *MSE* = .05, *p* = .127, η_p^2 = .06] and the interaction were not significant [*F*(2, 78) = .32, *MSE* = .001, *p* = .729, η_p^2 = .01].

Ten to eleven-year-old children.

The results from the first ANOVA confirmed a significant main effect of Sound Condition, *F*(3, 117) = 13.43, *MSE* = .14. *p* <.001, η_p^2 = .26, with planned contrasts showing that recall performance in the presence of irrelevant speech with 5 tokens (*M* = .64; *SD* = .22) was significantly lower than that in Quiet (*M* = .76; *SD* = .19; *p* < .001). There was no significant difference between recall performance in the other two irrelevant speech conditions versus quiet (both *p*s > .05). There was a significant main effect of Token-set Size on serial recall performance, *F*(1.69, 65.99) = 17.7, *MSE* = .44, *p* < .001, η_p^2 = .31. Pairwise comparisons showed that serial recall performance in the presence of two tokens (*M* = .73; *SD* = .20; *p* = .011) and five tokens (*M* = .64; *SD* = .22; *p* < .001) were significantly lower than in one token sequences (*M* = .78; *SD* = .19). Recall performance in the presence of two alternating tokens was also significantly higher than in five tokens (*p* = .001). The main effect of Dose, *F*(1, 39) = .38, *MSE* = .006, *p* = .543, η_p^2=.01, and interaction between Token-set Size and Dose, *F*(2, 78) = .76, *MSE* = .009, *p* = .473, η_p^2 = .02, were not significant.

The initial ANOVA incorporating all four sound conditions showed a non-significant main effect of Sound on recall performance in the missing-item task, *F*(3, 117) = 1.76, *MSE* = .03, *p* = .159, η_p^2 = .04. Similarly, the main effects of Token-set Size [*F*(2, 78) = 2.32, *MSE* = .07, *p* = .105, η_p^2 = .06] and Dose [*F*(1, 39) = .04, *MSE* = .001, *p* = .836, η_p^2 = .001] on missing-item task performance were not significant. The interaction between Token-set Size and Dose was not significant, *F*(2, 78) = .104, *MSE* = .005, *p* = .902, η_p^2 = .003.

4.3.2 Adults.

As previously mentioned, data from one participant was excluded on account of a score of zero in the Quiet condition of the missing-item task. Inclusion of this participant's data did not change the outcome for serial recall results but it did render the main effect of Sound Condition on missing-item task performance marginally non-significant [$F(3, 102) = 2.65$, $MSE = .03$, $p = .053$, $\eta_p^2 = .07$].

The initial ANOVA assessing the effect of Sound Condition on serial recall performance showed a significant main effect of Sound Condition, $F(2.39, 78.90) = 21.88$, $MSE = .14$, $p < .001$, $\eta_p^2 = .40$. Planned contrasts showed that recall in Quiet ($M = .60$; $SD = .17$) was significantly higher than in one ($M = .57$; $SD = .16$; $p = .024$), two ($M = .52$; $SD = .17$; $p < .001$), and five token conditions ($M = .47$; $SD = .13$; $p < .001$). The subsequent 3 (Token Set-Size) × 2 (Dose) ANOVA showed there was a significant main effect of Token-set Size on serial recall, $F(2, 66) = 17.66$, $MSE = .17$, $p < .001$, $\eta_p^2 = .35$. Pairwise comparisons further clarified that mean recall in the one token condition ($M = .57$; $SD = .16$) was significantly higher compared to two tokens ($M = .53$; $SD = .17$; $p = .008$) and five tokens ($M = .47$; $SD = .13$; $p < .001$). Furthermore, recall in the presence of two tokens was significantly higher than in the presence of five tokens ($p = .001$). There was no significant main effect of Dose, $F(1, 33) = .01$, $MSE < .001$, $p = .906$, $\eta_p^2 < .001$, and no significant interaction between the two factors, $F(2, 66) = .73$, $MSE = .01$, $p = .487$, $\eta_p^2 = .02$.

Mean recall performance in the missing-item task in irrelevant speech conditions was lower than in Quiet. The initial ANOVA confirmed a significant main effect of Sound Condition on recall performance, $F(3, 99) = 2.90$, $MSE = .04$, $p = .039$, $\eta_p^2 = .08$. Planned contrasts showed that recall in Quiet ($M = .63$; $SD = .21$) was significantly higher than in the presence of five tokens (*M* = .55; *SD* = .23; *p* = .017). Recall performance in the other two irrelevant speech conditions were not significantly lower than Quiet (both *p*s > .05). The second ANOVA showed that the main effect of Token-set Size [$F(2, 66) = 2.05$, $MSE = .05$, $p = .136$, $\eta_p^2 = .06$] and Dose [$F(1, 33) = .493$, $MSE = .01$, $p = .488$, $\eta_p^2 = .01$] were not significant. Likewise, their interaction was not significant, $F(1.66, 54.92) = .19$, $MSE = .007$, $p = .788$, $\eta_p^2 = .01$.

4.3.3 Correlations with working memory capacity.

Adults' serial recall scores in quiet and in all irrelevant speech conditions were significantly positively correlated with their working memory capacity. Missing-item performance in all conditions except 2 tokens with low dose was also significantly positively correlated with working memory capacity. Of particular interest were any correlations between the magnitude of the dose effect and the token-set size effect with working memory capacity (see Table 4.1). The dose effect was calculated as the difference between performance in low dose and high dose for each task, collapsed across token-set size. Token-set size effects were split into two parts: the difference between performance in one versus two tokens – which is, in essence, the magnitude of the CS effect; and, the difference between performance in two versus five tokens which indicates whether disruption increased when token-set size increased from two to five.

Among these effects, only one significant correlation was found – a moderate positive correlation between the magnitude of the dose effect in serial recall and the mean working memory score (*R* = .37, *p* = .024).

Extreme group analysis.

Participants were categorised into high and low WMC based on the scores that fell in the upper and lower quartile of the whole sample (*N* = 34). A total of 16 participants were included in the analysis – 8 in the low WMC category and 8 in high

WMC category. A mixed ANOVA with Token Dose (High or Low) as the within factor and WMC category (High or Low WMC) as the between factor to assess whether the effect of dose varied with WMC. Results showed a significant interaction between Dose and WMC category for serial recall performance, $F(1, 14) = 10.79$, $MSE = .01$, $p = .005$, $\eta_p^2 = .44$. Simple main effects analyses showed that the effect of Dose was significant for the high WMC group, $F(1, 7) = 20.19$, $MSE = .01$, $p = .003$, $\eta_p^2 = .74$, who performed better in the presence of low dose ($M = .66$; $SD = .12$) compared to high dose ($M = .61$, $SD = .13$). This result is in line with the earlier correlation showing a moderate positive correlation between the magnitude of the dose effect and WMC. There was no significant effect of dose for the low WMC group, $F(1, 7) = 1.29$, $MSE = .002$, $p = .294$, $\eta_p^2 = .16$, showing that performance in low dose ($M = .41$, $SD = .13$) was not significantly different from high dose ($M = .43$, $SD = .14$). This pattern of results suggests that high WMC individuals experienced greater disruption to recall when the dose of irrelevant speech was high. This is contrary to prior evidence from dichotic listening tasks which showed that low WMC individuals were more likely to hear their own name in an irrelevant sequence than their high WMC counterparts (Conway et al., 2001). This pattern of results is also contrary to those within the irrelevant sound paradigm that have shown poorer performance (i.e., greater disruption by irrelevant speech) for low-WMC-individuals compared to high-WMC-individuals (Beaman, 2004; Hughes et al., 2013; Marsh et al., 2017; Sörqvist, 2010a; Sörqvist et al., 2015). However, given the small sample size used in the present study these results may be limited in their generalizability.

Table 4.1

Pearson's product moment correlations between recall performance in each sound condition and working memory capacity

	SR	MIT
Sound condition and magnitude of effect	*R*	*R*
Quiet	.58 **	.41 *
1 token	.46 **	.43 **
2 tokens	.54 **	.42 *
5 tokens	.65 **	.35 *
Low Dose	.64 **	.38 *
High Dose	.50 **	.46 **
1 token-low	.50 **	.36 *
1 token-high	.38 *	.42 *
2 tokens-low	.56 **	.27
2 tokens-high	.44 **	.49 **
5 tokens-low	.65 **	.35 *
5 tokens-high	.53 **	.24
Magnitude of the dose effect (Low-High Dose)	.37 *	-.08
Magnitude of token-set size effect: 1 token - 2 tokens	.08	-.02
Magnitude of token-set size effect: 2 tokens - 5 tokens	.01	.11

Note: SR – Serial recall; MIT – Missing-item task. * = $p < .05$; ** = $p < .001$

4.3.4 Developmental differences.

Two mixed ANOVAs were conducted with Age Group – 5-6 year-old, 7-9 year-old, 10-11 year-old children, and 18-22 year-old adults – as the between-participants factor in each. For the initial ANOVA, Auditory Condition (Quiet, One, Two, and Five tokens) was the within-participants factor. The second ANOVA consisted of Token-set Size (One, Two, and Five tokens) and Dose (High and Low) as the within-participants factors.

The first ANOVA showed a significant main effect of Auditory Condition, $F(2.65, 7.34) = 56.56$, $MSE = .56$, $p < .001$, $\eta_p^2 = .29$, which was further clarified by a significant interaction with Age, $F(9, 417) = 4.15$, $MSE = .04$, $p < .001$, $\eta_p^2 = .08$. The Token-set Size × Dose × Age Group ANOVA revealed a significant main effect of Token-Set-Size on serial recall performance [$F(1.73, 5.19) = 69.39$, $MSE = 1.32$, $p < .001$, $\eta_p^2 = .33$] and a significant interaction with Age Group [$F(6, 278) = 5.97$, $MSE = .01$, $p < .001$, $\eta_p^2 = .11$].

Following the significant interactions of Auditory Condition with Age Group and Token set-size with Age Group, post hoc analyses using Gabriel’s procedure showed that the youngest children performed significantly lower in quiet and irrelevant speech conditions than all other age groups of children and adults (all *p*s < .001). The 7-9 year-old group performed significantly better than adults in the 1 token condition ($p = .004$) but performed significantly worse than the 10-11 year-old group in the presence of two ($p = .006$) and five tokens ($p <.001$). Recall performance of the 10-11 year-old children was significantly better than the adults in quiet ($p = .002$) and in all irrelevant speech conditions ($p < .001$). All groups of children and the adults had poorer recall in the presence of two tokens compared to one token; but, while recall in five tokens was significantly lower than two tokens for adults and children aged 7-11 years old, it was not the case for the youngest children (see Section 4.3.1 & 4.3.2).

The main effect of Dose was not significant [$F(1, 3) = 3.10$, $MSE = .03$, $p = .08$, $\eta_p^2 = .02$]. In addition, the interaction between Token-set Size and Dose [$F(2, 6) = 1.86$, $MSE = .02$, $p = .158$, $\eta_p^2 = .01$] and the three-way interaction (Token-set Size × Dose × Age Group) were not significant [$F(6, 278) = .71$, $MSE = .008$, $p = .639$, $\eta_p^2 = .01$].

The main effect of Sound Condition on recall performance in the missing-item task was not significant, $F(3, 417) = 1.76$, $MSE = .03$, $p = .154$, $\eta_p^2 = .01$, and neither was the interaction with Age Group, $F(9, 417) = 1.01$, $MSE = .02$, $p = .428$, $\eta_p^2 = .02$. However, planned contrasts did show that mean recall (across age groups) in the presence of five tokens ($M = .57$; $SD = .24$) was significantly lower than in quiet ($M = .61$; $SD = .24$; $p = .037$). The main effect of Token-set Size on recall performance in the missing-item task was not significant [$F(1.91, 5.73) = .74$, $MSE = .02$, $p = .473$, $\eta_p^2 = .005$] and neither was the main effect of Dose, $F(1, 3) = .995$, $MSE = .02$, $p = .320$, $\eta_p^2 = .01$. The two-way interactions, Token × Dose [$F(2, 6) = .25$, $MSE = .01$, $p = .775$, $\eta_p^2 = .002$], Token × Age [$F(6, 278) = 1.25$, $MSE = .04$, $p = .280$, $\eta_p^2 = .03$], Dose × Age [$F(3, 139) = .49$, $MSE = .01$, $p = .690$, $\eta_p^2 = .01$], were not significant. Finally, the three-way interaction was also not significant, $F(6, 278) = .118$, $MSE = .004$, $p = .994$, $\eta_p^2 = .003$.

Two one-way between-groups ANOVAs were conducted to assess age differences in the magnitude of the token-set size effects. The magnitude was calculated as the difference between recall scores in one token versus two tokens and subsequently two tokens and five tokens. The results showed a significant main effect of Age Group when the token-set size increased from one to two tokens, $F(3, 139) = 2.68$, $MSE = .05$,

p = .049, η_p^2 = .05, and pairwise comparisons showed that the 7-9 year old had the greatest magnitude of disruption (M = .11; SD = .11) compared to other age groups and this was significantly higher than the magnitude experienced by the 10-11-year-old children (M = .05; SD = .11) and the adults (M = .02; SD = .20) only. The magnitude of the effect for the 5-6-year-old children (M = .06; SD = .10) was not significantly different from the other children or the adults. The main effect of Age Group was also significant when the token-set size increased from two to five tokens, F(3, 139) = 2.99, MSE = .08, p = .033, η_p^2 = .06, and pairwise comparisons showed that serial recall performance of the 5-6-year-old children was better when the token-set size was five as opposed to two (M = -.004; SD = .08) and this was significantly lower than the effect experienced by 7-9 year old (M = .11; SD = .16) and 10-11-year-old children (M = .09; SD = .16). There were no other significant age differences in the magnitude of disruption when token-set size increased from two to five tokens. The pattern of means suggests that 5-6-year-old children experienced a positive effect of the increase in token-set size from two to five while the 7-9-year-old children were the most disrupted by the increase. The magnitude of disruption declined steadily with age (although the difference was not significant) and the adults showed the least disruption (M = .06; SD = .22).

Similar ANOVAs were conducted with missing-item data although given that earlier ANOVAs showed no significant main effect of Token-set size on performance no effect was expected. The results were clear-cut and showed no significant main effect of Age Group on the magnitude of disruption when token-set size increased from one to two, F(3, 139) = .96, MSE = .03, p = .413, η_p^2 = .02, and from two to five, F(3, 139) = .78, MSE = .03, p = .508, η_p^2 = .02.

4.3.5 Task comparisons: Serial Recall versus Missing-Item.

A 3 (Token-Set-Size) × 2 (Dose) × 2 (Task Type) × 4 (Age Group) mixed ANOVA was conducted which compared performance in the serial recall and missing-item tasks across the various age groups and sound conditions.

The main effect of Token-set Size and its interaction with Age were significant which was also noted in the preceding analyses. Of particular concern is the effect of Task Type and any interactions of this with other factors. The main effect of Task was significant, $F(1, 139) = 6.94$, $MSE = .567$, $p = .009$, $\eta_p^2 = .05$, and planned contrasts showed that performance in the serial recall task was significantly lower than in the missing-item task. The two-way interaction between Token-set Size and Task was significant, $F(1.87, 5.62) = 17.59$, $MSE = .45$, $p < .001$, $\eta_p^2 = .11$, which is in line with results from earlier analyses that showed a significant main effect of Token-set Size on serial recall performance but not on missing-item performance. In addition, the Token-set Size × Age interaction, $F(3, 139) = 3.49$, $MSE = .28$, $p = .018$, $\eta_p^2 = .07$, was also significant. Finally, the three-way interaction (Token-set Size × Task × Age) was also significant, $F(6, 278) = 3.42$, $MSE = .08$, $p = .003$, $\eta_p^2 = .07$, and is corroborated by individual group and task analyses in the preceding section which showed a significant main effect of token-set size for all age groups in the serial recall task but a non-significant main effect of token-set size for the missing-item task.

4.4 Discussion

The results showed that serial recall of the children and adults was poorer in the presence of irrelevant speech compared to quiet. Serial recall performance for all children and adults was poorer in the presence of two tokens compared to one – further evidence for the changing-state effect (Jones et al., 1992). The youngest children in this study showed no additional decline to recall performance when the token-set size increased from two to five. However, for 7-9 year-old children, 10-11 year-old children, and the adults, serial recall performance diminished when token-set size increased from one to two (again, presence of the changing-state effect) and declined further when set-size increased from two to five. The effects of dose in this study were non-significant – generally, performance levels in high and low dose conditions were similar among children and adults.

Performance in the missing-item task was not as affected by irrelevant speech as the serial recall task. For the adults, there was a difference between recall in quiet and in the five-token irrelevant sequence only, while recall in all other irrelevant speech conditions was similar to levels in Quiet. For the children, there was no significant difference between recall in Quiet and irrelevant speech conditions. There was also no token-dose effect on recall performance in the missing-item task for children and adults. In the missing-item task, neither the children nor adults experienced a detriment to recall when token-set size increased from one to two which is contrary to the serial recall task and lends support to the assertion that the changing-state effect occurs only when serial rehearsal is involved (e.g., Hughes et al. 2007; Perham et al., 2007)

The irrelevant speech effect (characterized by poorer recall in irrelevant speech conditions compared to quiet) on serial recall was observed for the children but not adults. In addition, the children did not experience an irrelevant speech effect on recall in the missing-item task while the adults did. Furthermore, the presence of the changing-state effect for children and adults in serial recall (but not missing-item) suggest that both were engaging in serial rehearsal for task completion. Taken together, this pattern of results suggests that serial rehearsal is particularly vulnerable to distraction among both adults and children. In addition, when the task demands the use of serial rehearsal, children are more likely than adults to be disrupted even by steady-state (one token) sounds. Thus, it would appear that greater task demands (as seen in the serial recall task) made children more vulnerable to distraction. More specifically, the requirement of rehearsal for task completion may have exacerbated their already poorer attentional control making them vulnerable to distraction by a wider range of sounds than adults. Similar results have been observed by Elliott et al. (2016) – children were more distracted by irrelevant speech when the rehearsal load increased within the context of serial recall. The pattern of results in the Elliott et al. (2016) study suggested that increasing rehearsal load acted as an additional attentional load for the children making them more vulnerable to distraction.

Children and adults were susceptible to the classical changing-state effect in serial recall as demonstrated by lower recall performance in two- compared to one-token irrelevant sequences. This aspect of the results is in agreement with previous work (e.g., Bridges & Jones, 1996; Campbell et al., 2002; Tremblay & Jones, 1998) and suggests a similarity in the mechanism of changing-state disruption across children and adults. Presumably, the two-token sequence was more disruptive of serial recall performance than the steady-state one-token sequence because there were seriation cues in the former sequence which interfered with the rehearsal of those order cues stemming from the visual TBR items (e.g., Elliott et al., 2016; Macken et al., 1999). Further support for the interference-by-process account comes from the finding that a similar token-set size effect was not seen in the missing-item task in this study. Although recall performance in the missing-item task was poorer in the presence of irrelevant speech compared to quiet (specifically recall in 5 tokens > Quiet for the adults), there was no effect of increased token-set size on recall scores.

The distinction in the way token-set size effects manifest in each task provides more evidence to suggest that first, serial rehearsal is particularly vulnerable to disruption by changing-state sounds (Beaman & Jones, 1997; Hughes et al., 2007; Jones

& Macken, 1993) and second, that the changing-state effect occurs only in tasks with a serial rehearsal component (Hughes, 2014; Hughes et al, 2007). This is an important finding as not only does it show the unitary account to be untenable but it also highlights the role played by rehearsal in determining distraction. If the predictions of the unitary account were correct, a token-set size effect should have occurred in the missing-item task in a similar manner as in the serial recall task. In addition, this result is also important from a developmental perspective because it shows that even though children may have poorer attentional control than adults, they are still vulnerable to distraction underpinned by rehearsal in a similar fashion to adults.

The results of token-set size effects on serial recall beyond two tokens (i.e., when token-set size was increased from 2 to 5 tokens) are mixed – children aged seven to eleven years old and adults experienced an additional disruption to serial recall performance when the number of tokens increased from two to five; but, 5-6 year-old children experienced a disruption only when token-set size increased from one to two and no further disruption from two to five tokens. This additional disruption to serial recall undermines the changing-state explanation of the token effects which is based on the assumption that the only necessary condition for changing-state disruption to arise is the occurrence of change between immediately adjacent sounds (Hughes, 2014; Tremblay & Jones, 1998). On the interference-by-process account, the nature of the change is not important and a sequence, ‘A-B-A-B’, for example, would be as disruptive as ‘A-B-C-D’ because change occurs between each successive token in both cases – a finding supported by results observed in Experiment 5 of Tremblay and Jones’ study where the levels of disruption caused by a 2-token sequence were not significantly different than that caused by 6-tokens (Tremblay & Jones, 1998).

An interference-by-process account of token-set size effects is provided in a study by Hughes and Jones (2005, Experiment 2) who assessed the effect of token-set size in conjunction with order incongruence between the irrelevant auditory sequence and the visual TBR sequence (i.e., the order of items in the irrelevant sequence was either congruent – e.g., 6, 1, 5, 2, 7, 3, 8, 4 – or incongruent – e.g., 7, 4, 2, 5, 3, 1, 8, 6 – with the items in the TBR sequence – e.g., 5, 2, 7, 3, 8, 4, 6, 1). The prediction of the interference-by-process account in this regard was that there would be a difference between token-set sizes (above two tokens) only when increasing the token-set size also meant greater order-incongruence. The results of Experiment 2 of Hughes and Jones' study (2005) confirmed that serial recall performance was depressed in the presence of 8 digits compared to 2 digits but only when the order of the tokens was incongruent with that of the TBR material. The predictions of the interference-by-process account in this case and the results from Hughes and Jones (2005) are similar to the findings of the present study which showed a significant decline in serial recall performance in five tokens compared to two tokens (for children aged 7 to 11 and for adults).

The additional disruption when token-set size increased from two to five tokens is more readily explained with reference to the habituation hypothesis of the embedded-processes model (Cowan 1995, 1999). It would be easier to construct a neural model of the incoming stimuli when there are only two tokens (versus five) and as each incoming stimulus in the two-token condition would be a good fit for the existing model, habituation would soon follow. This would lead to suppression of the OR and associated attentional capture at a much faster rate. The converse is true for the five-token condition – the process of developing the neural model would be slower thereby slowing down the rate of habituation, allowing the OR to endure for a longer period, and resulting in lower performance in the five-token condition compared to two tokens. The results for the older children and adults, although contrary to previous work (Tremblay & Jones, 1998), are similar to those seen in a study by Campbell et al. (2002; Experiment 3B). In that study, disruption increased along with the increase in token-set size from one to two and two to five while the dose at each token-set size was kept constant at 30 tokens per trial. By contrast, it is likely that a similar result was noted here because of the dosage that was used (high dose – 30 tokens and low dose – 20 tokens). It is intriguing that the youngest group of children, aged 5 and 6 years old, were immune to a significant effect of token-set size when it increased beyond two tokens. It must be noted, however, that this group of children had a modified version of the serial recall task which utilized colour patches instead of digits as the TBR items. Therefore, one possibility is that the difference in the results between this and other groups is a reflection of this difference in task stimuli. However, the initial pattern of serial recall results (recall in 1 token > 2 tokens) indicate that the changing-state effect is present for this group which suggests that even at age five and six they are already using serial rehearsal strategies to complete the task.

The token-dose effects on recall performance in the missing-item task have not been assessed prior to this study. The results are clear cut – while adult performance in this task was depressed in the presence of five-token irrelevant sequence when compared to quiet; there was no effect of token-set size or dose on the levels of performance. At the outset, it would appear that while this task is not immune to disruption by irrelevant speech, it is still left relatively unscathed by irrelevant auditory material compared to serial recall. Given the differences between missing-item and serial recall on the grounds of response demands, order retention, and use of rehearsal (Morrison et al., 2016), it is reasonable to assume that the token-dose effects (so far only noted in serial recall tasks) would manifest differently or not at all on the missing-item task. A clear difference emerged (which was also noted in Study 1 and 2) between the two tasks in that performance in the two-token condition was significantly lower than in the one-token condition for serial recall but not missing-item and again points to the role played by order information in determining disruption. Serial order cues are absent in the missing-item task and this is supported by the finding that individuals often utilize a checklist strategy (Morrison et al., 2016) instead of serial rehearsal to complete this task.

If the token set-size and dose effects were purely attentional-based, the pattern of disruption should have been the same for serial recall and missing-item task (e.g., Vachon et al., 2016). Instead, it is clear that the changing-state effect is only present on the serial recall task and not the missing-item task. In addition, the irrelevant speech effect on missing-item performance is completely absent for the children and only present for the adults when the irrelevant sequence consists of five tokens. A possible explanation for the absence of the irrelevant speech effect comes from experiments by Bell et al. (2012) who found that when participants had pre-exposure to the auditory distractors without a task-induced concurrent working memory load, they were better able to habituate to auditory distractors during task performance. Their experiments showed that pre-exposure to auditory distractors attenuated the irrelevant sound effect on serial recall. Although the methodology in the present study did not consist of a pre-exposure period, it may be the case that the missing-item task imposed a lower working memory load on participants compared to serial recall and therefore resulted in the complete absence of an irrelevant speech effect for the children and an attenuation of the effect for the adults (they were still susceptible to the irrelevant speech effect but only when five tokens were used in the irrelevant speech sequence). The pattern of results for the missing-item task is in line with those in Study I and II, and with extant evidence that shows the missing-item task is immune to the CS effect but not the deviation effect (Beaman & Jones, 1997; Elliott et al., 2016; Hughes et al., 2007; Vachon et al., 2016). In the present study, the missing-item task did not show an increase in disruption when token set-size increased from one to two tokens and above. The only disruption observed was when adults’ performance in quiet was compared to that in five tokens suggesting an irrelevant speech effect was present (which was also the case in Study I and II).

Taken together with the habituation hypothesis of the embedded-processes model (Cowan, 1988, 1995; Elliott & Cowan, 2001), these results suggest that habituation is more likely to occur if attentional resources are not occupied with focal task processing (Bell et al., 2012) or higher working memory load (Berti & Schröger, 2003; SanMiguel et al., 2008). In this case, the visual missing-item task may have been easier for participants to complete and allowed a greater amount of attentional resources to be allocated to developing the neural model of the distractors. The rate of habituation is also dependent on the irrelevant sequence itself – habituation is slower for more complex auditory sequences (e.g., Cowan 1995). Therefore, although adult participants were immune to the irrelevant speech effect when one and two tokens were used, they may have taken longer to develop the neural model for the five-token sequence and thus the OR will have endured for a longer period resulting an irrelevant speech effect only when this sequence was used.

The effect of dose on serial recall and missing-item task performance was negligible. Children and adults had similar recall scores across high and low doses which is contrary to previous findings (Bridges & Jones, 1996; Campbell et al., 2002; Tremblay & Jones, 1998). Through a series of five experiments, Bridges and Jones (1996) built up a body of evidence to show that the dose effect on serial recall was independent of the number of phonemes and syllables in the irrelevant sequence. Therefore, it is unlikely that differences between the results of the present study and the previous ones are the result of using different distractors (i.e., words or letters). By contrast with Campbell et al. (2002) whose study utilized thirty tokens as high dose and two tokens as low dose, high dose in the current study was thirty tokens per trial while low dose was twenty tokens. Perhaps a larger difference between the doses would have accentuated differences between recall performance in high and low dose akin to those seen previously. However, the pattern of the results in this study are justifiable with reference to the interference-by-process account (Hughes et al., 2005; Marsh et al., 2009) and the feature model (Neath, 2000). Both accounts predict no difference in the disruption when levels of dose are varied. From the perspective of interference-by-process, disruption is dependent on the interference with rehearsal by changing-state information, therefore, whether the dose is high or low is inconsequential because as long as there is a change from one irrelevant token to the next and rehearsal is employed, a disruption will occur (Hughes et al., 2005; Marsh et al., 2009). The lack of a dose effect in the missing-item task is also explained through the interference-by-process account – rehearsal is an unlikely strategy in this task, therefore, disruption by changing-state speech whether in high or low dose will have no effect. In the feature model, this is because an increase in dose (for a given token-set-size) does not add any new features to the search set and therefore the chances of a feature mismatch are not increased (Neath, 2000). An increase in disruption will occur only when there are a greater number of different or unique irrelevant items in the search set and this is observed when the token-set size and not dose is increased (Campbell et al., 2002).

CHAPTER V

AN ANALYSIS OF DISTRACTION EFFECTS ACROSS EXPERIMENTAL DESIGNS AND EMPIRICAL STUDIES

Three sets of analyses are described in this chapter. The first two explore the effects of varying experimental design on distraction effects and any developmental differences in the magnitude of distraction. The differences in distraction effects when list length for recall was varied by span versus when it was fixed; and, the impact of alternating tasks as opposed to administering them separately were assessed. The third analysis considers distraction effects across all three empirical studies to provide an overview of distraction effects in a large sample of children aged 5 to 11 years old (*N* = 274) and adults aged 18 to 22 years old (*N* = 124).

5.1 The Effect of Task Design on Distraction

5.1.1 Varied vs fixed list length for recall.

Data from Study I and Study II were jointly analysed to contrast performance when list length was varied as opposed to fixed. The age of the children and adults in each study was the same (7-9 and 18-22 years old, respectively), therefore, any differences that emerge are likely to reflect differences in task design.

The first group of children and adults completed tasks in which the to-be-remembered (TBR) lists were adjusted to their individual span scores (Study I). Digit span was used to ascertain participants' short-term memory capacity and the highest set size that was correctly recalled was taken as their digit span score (Baddeley, 2015; as cited in Baddeley et al., 2015). The list length for recall in Study I was set at each participant's final digit span to ensure that the number of TBR items was equated to individual short-term memory capacity. Children in Study I had an average span of 4 items while adults had a span of 7 (Table 5.1 shows the number of participants with each digit span). In Study II, however, the number of TBR items was fixed at one item more than the average span for each age group as assessed in Study I – five TBR items for children and eight items for adults. Equating task difficulty to each person's upper limit for short-term retention may have rendered the task easier than when list length was fixed arbitrarily in the subsequent study. In Study II, if the list length was higher than a person's span they may have found the task harder than those for whom the list length was lower (or the same as) their memory span. However, it must be noted that since span was not assessed in Study II, it is not possible to identify whether the number of items in the TBR list (five and eight items) was in fact higher (or lower) than each participant's digit span.

To anticipate, the CS effect will be larger in Study II compared to Study I if rehearsal was placed under a higher demand when list length was fixed at five or eight items rather than at each individual's digit span. Greater reliance on rehearsal would increase participants' vulnerability to distraction of the interference-by-process type – this could be the case especially for children given that their rehearsal abilities are developing and not as efficient as adults (Elliott et al., 2016). When rehearsal is poor, the transitional links between cues of the TBR items will also be poor and leave them open to disruption from cues obligatorily yielded from the irrelevant sequence. In addition, evidence shows that as the load on rehearsal increases so does the disruption to serial recall (Elliott et al., 2016; Macken et al., 1999). As such, for those individuals for whom the list was longer than their memory span, the load imposed would have increased as the list progressed and could have resulted in greater interference-by-process than when the list length was adjusted to their span. Finally, disruption caused by CS sounds is thought to be a negative function of the efficiency of rehearsal (Jones et al., 1996). This would imply that children should show a greater vulnerability to the CS effect than adults because their rehearsal was not as efficient as that of adults. The empirical studies described thus far have consistently shown that the CS effect was restricted to tasks with a serial rehearsal component (serial and probed recall but not missing-item; Study I, II and III), therefore suggesting that this effect among children is not driven by attentional capture. Following from these findings, the CS effect is only expected to manifest in the serial and probed recall tasks but not in the missing-item task.

The deviation effect was observed in the preceding empirical studies regardless of task. The analysis in this section will also consider whether the magnitude of the deviation effect varied as a function of age and as a function of the list length manipulation. It is expected that the deviation effect will be larger for children than adults as a reflection of their poorer attentional control in the face of distraction by irrelevant deviants in the auditory stream. There has been no investigation of the deviation effect among children prior to the empirical studies in this thesis. It is hoped that the results described in this section will provide a better understanding of children’s susceptibility to attentional capture.

Table 5.1

Frequency table showing number of children and adults in each span category in Study I

Span	Children	Adults
3	13	-
4	19	-
5	5	1
6	2	22
7	1	11
8	-	3
9	-	2
Total	**40**	**39**

Results and discussion.

Data from eighty-nine children and eighty-nine adults were included in this analysis: forty children and thirty-nine adults from Study I; forty-nine children and fifty adults from Study II. A 2 (State: Changing or Steady) × 3 (Task: Serial recall, Probed recall, and Missing-item) × 2 (Study: Variable or Fixed length) × 2 (Age Group: Children and Adults) repeated measures ANOVA was conducted. State and Task were within-participant factors while Study and Age Group were between-participants factors. Of key interest for present purposes is the effect of Study and any interactions with Study that will help clarify differences in performance as a consequence of the variable and fixed list lengths used.

The main effect of Study was significant, $F(1, 174) = 89.61$, $MSE = 2.47$, $p < .001$, $\eta_p^2 = .34$, with overall mean performance (collapsed across tasks) being significantly higher when list length was varied by span (*M* = .74) rather than fixed (*M* = .51, *MD* = .24). This suggests that participants performed better when the list length was adjusted to their short-term memory capacity as assessed by the digit span task. The interactions between the different factors and Study are presented in Table 5.2.

Although the effects of State did not vary across Study I and II there was a significant main effect of State [*F*(1, 174) = 18.63, *MSE* = .26, *p* < .001, η_p^2 = .10]. The interaction between State and Task was significant, *F*(1.83, 319.70) = 2.94, *MSE* = .05, *p* = .028 (one-tailed), η_p^2 = .02. Further analysis of the interaction showed that the effect of State was present only in those tasks requiring serial rehearsal – serial recall and probed recall but not missing-item task. Data from both age groups and studies were collapsed and paired-samples *t*-tests showed that scores in CS were significantly lower than in SS speech conditions for serial recall [*t*(177) = -2.97, *p* = .003] and probed recall tasks [*t*(177) = -4.13, *p* < .001] but not for the missing-item task [*t*(177) = -.89, *p* = .376].

The main effect of Age Group was not significant, *F*(1, 174) = 3.43, *MSE* = .10, *p* = .066, η_p^2 = .02, but it was further clarified by a significant interaction between Age Group and Study (see Table 5.2). In Study I, children performed slightly better than adults ($M_{Children}$ = .75 vs M_{Adults} = .74), however, a one-way ANOVA showed this difference was not significant, *F*(1, 77) = .23, *MSE* = .01, *p* = .631. In Study II, however, the difference between children's and adults' performance ($M_{Children}$ = .45 vs M_{Adults} = .56) was significant, *F*(1, 97) = 9.08, *MSE* = .29, *p* = .003, showing that adults performed better than children in this study. Furthermore, one-way ANOVAs showed that children, *F*(1, 87) = 63.70, *MSE* = 1.98, *p* < .001, and adults, *F*(1, 87) = 27.74, *MSE* = .67, *p* < .001, had significantly poorer performance when list length was arbitrarily fixed rather than adjusted to individual span.

Table 5.2

Interactions between factors State, Task, and Age with Study

Factors	df	*MSE*	*F*	*p*	η_p^2
State, Task, Age Group, Study	1.84, 319.70	.01	.64	.526	.004
State, Task, Age Group	1.84, 319.70	.01	.60	.534	.003
State, Task, Study	1.84, 319.70	.02	1.66	.191	.01
State, Age Group, Study	1, 174	<.001	.001	.981	<.001
Task, Age Group, Study	2, 348	.01	.20	.823	.001
Task, Study	2, 348	.09	2.55	**.020**	.01
Task, Age Group	2, 348	.02	.49	.613	.003
State, Study	1, 174	.01	.52	.518	.002
State, Age	1, 174	< .001	<.001	.994	<.001
Study, Age Group	1, 174	.17	6.20	**.014**	.03

The absence of a significant four-way interaction between the factors suggested that there was no significant difference in performance across irrelevant speech conditions in any of the tasks as a function of age or list length differences. However, the significant main effect of Study showed that overall performance was better when the tasks were adjusted to each participant’s memory capacity. In addition, while the main effect of Age Group was not significant, there was an interaction with Study. When the list length was adjusted to individual span, there was no developmental difference in performance levels between children and adults. However, when the task was made more difficult by fixing the list length at one item more than the average span for each age group (five and eight items, respectively), clear developmental differences emerged in that children's performance was significantly lower than that of adults. This pattern of results suggests that when task difficulty or demands are greater, developmental differences are more likely to emerge which may be an indication of working memory capacity differences between children and adults (Cowan, Morey, AuBuchon, Zwilling, & Gilchrist, 2010; Elliott et al., 2016).

Finally, the significant main effect of State and (crucially) its significant interaction with Task concur with existing findings on the CS effect which have shown consistently that this effect manifests only when rehearsal is involved in the focal task (e.g., Hughes et al., 2005; Hughes et al., 2007; Jones, 1994; Jones et al., 2010; Jones & Macken, 1993). This not only highlights the indomitable nature of changing-state disruption but also provides additional evidence for the vulnerability of rehearsal to distraction by irrelevant changing-state sounds. The absence of an interaction between State and Study also speaks to the nature of the CS effect which has previously been shown to be immune to task difficulty (Hughes et al., 2013; Hughes, 2014).

Variability in the magnitude of changing-state and deviation effects due to task design and age.

The magnitude of the CS effect and deviation effect were compared across varied and fixed length studies; and, across age groups. The magnitude of the effects was calculated for each task: the difference between performance in SS speech and CS speech was the magnitude of the CS effect while the difference between performance in CS speech and CS + *d* speech was the magnitude of the changing-state deviation effect. Performance in SS speech and SS + *d* speech was not included in this analysis because the SS + *d* in Study I and II were not equivalent – there were deviations on two dimensions (voice and item deviations) in Study I but only one deviation in Study II (voice deviation only).

A two-way ANOVA with Study (Varied or Fixed length) and Age Group (Children and Adults) as between-groups factors showed that the magnitude of the CS effect in each task did not differ as a function of Study or Age Group (see Table 5.3). There was also no significant interaction. These results suggest that magnitude of the CS effect was not affected by whether the list length was varied or fixed. The magnitude of the CS effect also did not differ with age.

A two-way ANOVA assessing the age- and study-related differences in the magnitude of the Changing-state deviation effect for each task showed there was a significant main effect of Age Group for the deviation effect in the serial recall task only (results are presented in Table 5.4). There was also a significant main effect of Study but only in the probed recall task. These results suggest that children ($M = .05$) experienced a greater changing-state deviation (CS + *d*) effect in the serial recall task than adults ($M = .01$; $p = .032$). The results also showed that magnitude of the CS + *d* effect in the probed recall was greater when list lengths were varied ($M = .07$) than when it was fixed ($M = -.002$).

The pattern of results has provided some insight that may be useful for developmental research. Developmental differences in performance were more pronounced when task difficulty was increased, therefore, it may benefit researchers to ensure that tasks are challenging to such an extent that they tease out potential developmental differences but do not result in floor effects on account of being too difficult. The foregoing analyses also show the vulnerability of rehearsal to changing-state irrelevant sounds and how irrelevant changing-state sounds can affect recall regardless of task difficulty. This finding would be useful for practical settings such as schools and other learning spaces as it shows that even if individuals are engaged in a less challenging task, they may still be vulnerable to distraction by irrelevant sounds so long as rehearsal is a dominant strategy for focal task completion. Developmental differences analyses showed that the CS effect did not differ between children and adults, however, the deviation effect in serial recall (in a changing-state context) did vary as a function of age. The results suggest that while the magnitude of distraction underpinned by rehearsal did not vary with age and task difficulty, disruption as a result of attentional capture was greater for children than adults and greater when tasks were adjusted to individual span rather than arbitrarily fixed. Therefore, it would appear that task difficulty modulates the deviation effect and not the CS effect: attentional capture (but not interference-by-process) occurred to a larger extent when tasks were easy rather than difficult. This pattern of results aligns with the notion that greater task engagement (which can be facilitated through increasing task difficulty) can shield against distraction (Hughes et al., 2013; Sörqvist & Marsh, 2015) — in the present study, task difficulty was increased by fixing the list length of the tasks rather than adjusting list length to each participant's memory span.

Table 5.3

Results from a two-way ANOVA assessing the differences in the magnitude of CS effect as a function of Study (Varied or Fixed length) and Age Group (adults and children)

Factors	Task	df	*MSE*	*F*	*p*	η_p^2
Study	SR	1, 174	<.001	.01	.929	< .001
	PR	1, 174	.02	.54	.463	.003
	MIT	1, 174	.09	2.37	.125	.01
Age Group	SR	1, 174	.02	1.15	.286	.01
	PR	1, 174	.02	.50	.480	.003
	MIT	1, 174	< .001	.01	.921	< .001
Study, Age Group	SR	1, 174	.01	.43	.512	.002
	PR	1, 174	.02	.81	.371	.01
	MIT	1, 174	.01	.15	.697	.001

Note. SR – Serial Recall; PR – Probed Recall; MIT – Missing-item task.

Table 5.4

Results from a two-way ANOVA assessing the differences in the magnitude of the CS + d effect as a function of Study (Varied or Fixed length) and Age Group (adults and children)

Factors	Task	df	*MSE*	*F*	*p*	η_p^2
Study	SR	1, 174	.003	.24	.623	.001
	PR	1, 174	.22	4.34	**.039**	.02
	MIT	1, 174	.01	.31	.580	.002
Age Group	SR	1, 174	.06	4.70	**.032**	.03
	PR	1, 174	.003	.06	.800	< .001
	MIT	1, 174	.002	.04	.844	< .001
Study, Age Group	SR	1, 174	.002	.14	.710	.001
	PR	1, 174	.04	.84	.361	.01
	MIT	1, 174	.001	.02	.876	< .001

Note. SR – Serial Recall; PR – Probed Recall; MIT – Missing-item task.

5.1.2 Effects of task switching on task performance and distraction.

A subset of 7-9-year-old children from Study II (*n* = 32) also completed an additional version of the missing-item and probed recall tasks wherein the two tasks were alternated during the testing session — one block of missing-item task followed by a block of probed recall (or vice versa; Elliott et al., 2016). The following section describes a comparative analysis of performance when tasks were completed in alternating blocks versus when they were completed in separate testing sessions (as in Study II). The comparison will show whether task-switching had an effect on performance levels and on the disruption by irrelevant speech.

Results and discussion.

A repeated measures ANOVA incorporated Sound Condition (Quiet, CS, and SS speech), Task (Missing-item and Probed recall), and Design (Alternating Blocks and Separate Tasks) as factors. There was a significant main effect of Sound Condition, $F(2, 62) = 8.08$, $MSE = .19$, $p = .001$, $\eta_p^2 = .21$, whereby performance collapsed across task and design in CS ($M = .37$; $SD = .14$) and SS speech ($M = .41$; $SD = .14$) differed significantly from each other ($p = .041$) and were significantly lower than performance in Quiet ($M = .44$; $SD = .16$; ps = .001 & .036, respectively). There was also a significant main effect of Design, $F(1, 31) = 16.83$, $MSE = 2.13$, $p < .001$, $\eta_p^2 = .35$, and performance was lower when tasks were administered in alternating blocks ($M = .33$; $SD = .12$) than separately ($M = .48$; $SD = .20$). The interaction between Sound Condition and Design was also significant, $F(2, 62) = 4.61$, $MSE = .07$, $p = .014$, $\eta_p^2 = .13$, and upon further analysis revealed a significant main effect of Sound Condition in the alternating design, $F(2, 62) = 13.53$, $MSE = .12$, $p < .001$, $\eta_p^2 = .30$, but no significant effect when tasks were completed separately, $F(2, 62) = 1.36$, $MSE = .01$, $p = .264$, $\eta_p^2 = .04$. There were no other significant main effects and interactions (see Table 5.5).

Table 5.5

Non-significant main effects and interactions from Sound Condition × Task × Design ANOVA

Factors	df	*MSE*	*F*	*p*	η_p^2
Task	1, 31	.08	1.76	.194	.05
Sound, Task	2, 62	.02	1.10	.338	.03
Design, Task	1, 31	.05	1.45	.238	.04
Sound, Design, Task	2, 62	.001	.09	.918	.003

A subsequent 2 (State: Changing or Steady State speech) × 2 (Task: Missing-item and Probed recall) × 2 (Design: Alternating Blocks and Separate Tasks) ANOVA showed a significant main effect of State, $F(1, 31) = 4.57$, $MSE = .10$, $p = .041$, $\eta_p^2 = .13$, wherein performance in CS speech ($M = .37$) was significantly lower than in SS speech ($M = .41$). This difference reflects the presence of the CS effect. There was also a significant main effect of Design, $F(1, 31) = 22.11$, $MSE = 1.99$, $p < .001$, $\eta_p^2 = .42$, reflecting again that performance was lower when tasks were alternated than administered separately. There were no other significant main effects and interactions (See Table 5.6).

Table 5.6

Non-significant main effects and interactions from State × Task × Design ANOVA

Factors	df	*MSE*	*F*	*p*	η_p^2
Task	1, 31	.03	1.06	.311	.03
State, Task	1, 31	.03	1.65	.208	.05
State, Design	1, 31	<.001	.002	.962	<.001
Task, Design	1, 31	.03	.94	.341	.03
State, Task, Design	1, 31	.002	.12	.732	.004

To assess whether the magnitude of the CS effect was affected by the differences in task design (and presumably task difficulty), paired samples *t*-tests were used to compare the magnitude of the CS effect when tasks were alternated versus administered separately. The results showed that there was no significant difference in the magnitude of the CS effect for probed recall, *t* (31) = -.23, *p* = .822, or the missing-item task, *t* (31) = .32, *p* = .752, as a function of task design.

An additional comparison of performance in Quiet versus steady-state speech in each task led to the conclusion that children but not adults were susceptible to sounds regardless of the nature of the sounds and the type of task (Elliott et al., 2016). This was based on the finding that children's recall performance in the missing-item and probed recall tasks were significantly lower in steady-state speech compared to quiet. A similar analysis was conducted here to assess whether performance in SS speech was lower than in quiet when the tasks were administered separately. The difference between scores in SS speech and quiet were calculated for each task and then compared between the two task designs in a paired-samples *t*-test. The difference (Quiet - steady-state speech) between the two designs for the missing-item task was nearing significance, *t*(31) = 1.96, *p* = .059, and an inspection of the means showed that steady-state disruption was greater in the alternated design (*M* = .10, *SD* = .17) than when tasks were administered separately (*M* = .01, *SD* = .18), though not significantly so. The difference between the two designs for probed recall was not significant, *t* (31) = 1.43, *p* = .163, but the pattern of the means again showed greater steady-state disruption in the alternated design (*M* = .05, *SD* = .18) compared to separate tasks (*M* = -.01, *SD* = .20).

To summarize, the results showed that performance was better when children completed each task separately compared to alternated blocks. This difference may reflect the costs incurred during task-switching: the process of revaluating task rules (find the missing item or identify which item followed the probe) each time a switch took place may have had a negative influence on recall accuracy (Liefooghe, Barouillet, Vandierendonck, & Camos, 2008). However, the task switching design did not influence the level of changing-state disruption experienced by the children – as evidenced by the magnitude of the CS effect being roughly the same whether tasks were alternated or administered separately. Although the steady-state disruption in the missing-item task and probed recall were not significantly different across designs, these results do suggest that children may be more distractible if the task is alternated in blocks rather than completed separately. Furthermore, if the task switching design constituted a greater cognitive load then it is reasonable to expect greater distraction would take place in this situation compared to separate administration (Lavie, 2005). In addition, this could be expected to be particularly prominent for children and those individuals with low working memory capacity or poor attentional control (Elliott, 2002; Elliott et al., 2016).

5.1.3 A combined analysis of data from the empirical studies.

A joint analysis of data from Study I, II, and III was conducted with three aims: first, to identify if the patterns of disruption varied across tasks and age groups. Second, to compare the magnitude of the CS effect across age groups. Finally, assess whether children and / or adults show a general susceptibility to distraction by any sort of sound by comparing their performance in Quiet versus SS speech. Performance in serial recall and missing-item tasks were chosen for this analysis since these tasks were used across all three empirical studies.

Results and discussion.

Data from 398 participants were included in the analysis: 54 children aged 5-6 years old, 130 children aged 7-9 years old, 90 children aged 10-11 years old, and 124 adults aged 18-22 years old. An initial mixed ANOVA – 3 (Sound Condition: Quiet, CS, and SS speech) × 2 (Task: Serial recall and Missing-item task) × 4 (Age Group: 5-6, 7-9, 10-11-year-old children, and 18-22-year-old adults) was conducted.

There was a significant main effect of Sound $F(2, 788) = 19.57$, $MSE = .30$, $p < .001$, $\eta_p^2 = .05$. Overall performance in CS speech ($M = .55$) was significantly lower than that in SS speech ($M = .58$; $p < .001$) and Quiet ($M = .60$; $p < .001$) while the latter two conditions were not significantly different from each other ($p = .061$). The main effect of Task was also significant, $F(1, 394) = 9.99$, $MSE = .41$, $p = .002$, $\eta_p^2 = .03$, reflecting better performance in the missing-item task ($M = .59$) compared to serial recall ($M = .56$). There was also a significant main effect of Age Group, $F(3, 394) = 19.42$, $MSE = .74$, $p < .001$, $\eta_p^2 = .13$, and 5-6-year-old children had significantly lower performance compared to other age groups of children and adults (all ps < .001). There were no other significant differences among age groups (all ps > .05).

There was a significant interaction between Sound Condition and Task, $F(1.95, 767.03) = 4.79$, $MSE = .07$, $p = .009$, $\eta_p^2 = .01$, which showed that serial recall performance in CS speech ($M = .56$) was significantly lower than in Quiet ($M = .61$; $p < .001$) and SS speech ($M = .61$; $p <.001$) while there was no significant difference between the latter two conditions *(p* = .560). In contrast, performance in the missing-item task in CS speech ($M = .60$) and SS speech ($M = .60$) were significantly lower than that in Quiet ($M = .63$; both *p*s < .05) while CS and SS speech conditions did not significantly differ from one another ($p = .273$).

The foregoing results show that the CS effect was present in the serial recall task and not the missing-item task: performance was significantly lower in the presence of CS speech compared to SS speech in the serial recall task but not the missing-item task. The results also show that missing-item task performance in SS speech was lower than that in Quiet. When the missing-item task results are considered with those from the serial recall task (where there was no significant difference between performance in SS speech and quiet), it would appear that the steady-state disruption in the missing-item task may be attributed to attentional capture. The serial recall and missing-item task vary in the extent to which serial rehearsal is employed in task performance. If the use of rehearsal encouraged greater task engagement in the serial recall task, this may have shielded individuals from disruption through attentional capture (Hughes et al., 2013). In contrast, the missing-item task does not necessarily require rehearsal (e.g., Morrison et al., 2016), and therefore, lower task engagement may increase individuals' vulnerability to distraction by any sort of sound in this task.

There were two significant interactions with Age Group: Task × Age Group, $F(3, 394) = 2.89$, $MSE = .12$, $p = .035$, $\eta_p^2 = .02$, and Sound Condition × Age Group, $F(6, 788) = 2.11$, $MSE = .03$, $p = .050$, $\eta_p^2 = .02$. The three-way interaction among the factors, *F*(6, 788) = .54, *MSE* = .01, $p = .777$, $\eta_p^2 = .004$, was not significant. Analysis of the interaction between Task and Age Group indicated that performance in the serial recall task was significantly lower than in the missing-item task for 5-6-year-old children ($M_{\text{Serial recall}} = .38$; $M_{\text{Missing-item}} = .46$; $p < .001$) and adults only ($M_{\text{Serial recall}} = .64$; $M_{\text{Missing-item}} = .68$; $p = .020$). There was no significant difference in performance between the two tasks for the other age groups (both *p*s > .05). In addition, there was a significant main effect of Age Group on serial recall performance, *F*(3, 397) = 21.23, *MSE* = .91, $p < .001$, $\eta_p^2 = .14$, wherein 5-6-year-old children's performance was significantly lower than the other age groups of children and the adults (all *p*s < .001). There were no significant differences among the two older age groups of children and adults (*p*s > .05). Overall performance in the missing-item task was also significantly different across age groups, *F*(3, 397) = 12.97, *MSE* = .61, $p < .001$, $\eta_p^2 = .09$, and the pattern of the differences was the same as for the serial recall task.

Analysis of the interaction between Sound Condition and Age Group showed that levels of performance (collapsed across tasks) in Quiet (*M* = .43), CS speech (*M* = .41), and SS speech (*M* = .42) were not significantly different for the 5-6-year-old children (all *p*s > .05). However, there were significant differences between conditions for 7-9-year-old (*M* = .63, .59, & .62) and 10-11-year-old children (*M* = .64, .59, & .63), and adults (*M* = .69, .63, & .66, for Quiet, CS, & SS speech, respectively). The pattern of disruption was the same (for the most part) for the latter three groups: performance in CS speech was significantly lower than that in Quiet and SS speech (all *p*s < .05). There was one crucial point of difference, however, in that adults (but not children) had significantly poorer performance in SS speech (*M* = .66) compared to Quiet (*M* = .69; $p < .001$).

Although this pattern of results for the adults was unexpected, it has been observed previously – adults had lower scores in SS speech compared to quiet in the missing-item task in the study by Elliott et al. (2016). However, the overall pattern of results in that study suggested that in comparison to adults, children had a greater susceptibility to distraction regardless of the nature of sounds (Elliott et al., 2016). In the present experimental series, this does not appear to be the case because the disruption by SS and CS speech compared to Quiet was greater for adults than for children (see Figure 17). In addition, while children did not show a detriment to recall in SS speech compared to quiet, adults did.

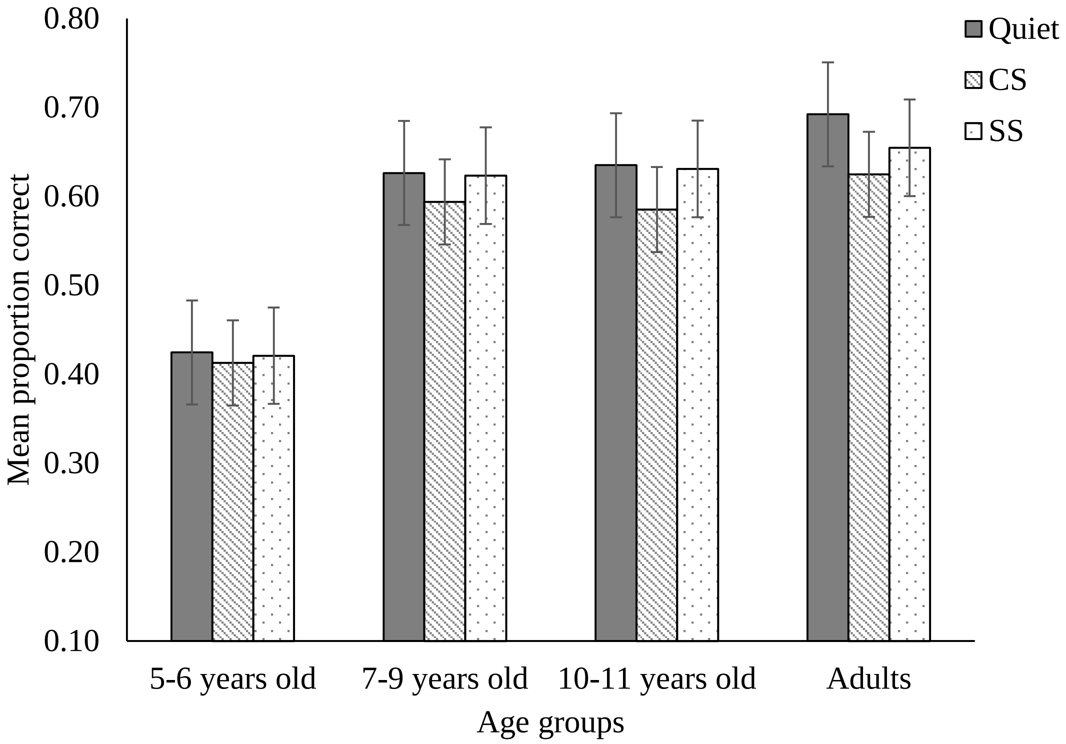


Figure 18. Performance of each age group collapsed across serial recall and missing-item tasks in Quiet and irrelevant speech conditions.

The final analysis considered whether the magnitude of the CS effect on serial recall differed across age. A One-Way ANOVA, with the magnitude of the CS effect as the dependent variable and Age Group as the between-groups factor, was conducted.

The results showed that the magnitude of the CS effect on serial recall was not significantly different across age groups in this study, *F*(3, 397) = 1.18, *MSE* = .02, *p* = 318.

To summarize, performance in serial recall and missing-item tasks were affected by irrelevant speech. Children and adults performed poorly in the presence of irrelevant speech compared to quiet. The CS effect was present in the serial recall task but not missing-item task which is line with existing research that shows the CS effect will occur only if the irrelevant sounds fluctuate and if the task involves serial rehearsal (e.g., Hughes et al., 2005; Jones & Macken 1993). Performance levels in Quiet, CS and SS speech for the youngest children were similar and could be the result of floor effect and / or the use of different TBR stimuli in the tasks compared to older children and adults. Children aged 7-11 years old and adults experienced a CS effect on serial recall performance, however, the magnitude of the effect did not vary with age. The comparison of performance in Quiet versus SS speech was meant to identify whether children and / or adults were generally more susceptible to distraction by any sort of sound. The disruption by steady-state sounds was surprisingly observed only for adults in this experimental series.

CHAPTER VI

GENERAL OVERVIEW AND IMPLICATIONS OF RESULTS

The current experimental series extends knowledge about the developmental differences in the detrimental effects of auditory distraction on memory performance. To summarize, recall performance suffered as a result of irrelevant speech. When compared to quiet, performance in irrelevant speech was poorer for adults and children and regardless of the task used. When children’s data were examined by age group (i.e., 5-6, 7-9, and 10-11 years old) a more detailed picture of the results emerged. Performance in serial recall and probed recall was lower in irrelevant speech compared to quiet for all groups of children. However, performance in the missing-item task was lower in irrelevant speech compared to quiet only for 7-9-year-old children.

The CS effect which is characterized by poorer recall of order information in the presence of changing-state sounds compared to steady-state was observed for all participants in the present experimental series. Crucially, the effect was present only when serial rehearsal was deployed in the tasks resulting in a CS effect in serial and probed recall tasks but not the missing-item task (Elliott et al., 2016; Hughes et al., 2007; Jones & Macken, 1993). This vulnerability of serial rehearsal to changing-state disruption was observed among adults and children in all three empirical studies. However, while the adults exhibited a CS effect on serial and probed recall tasks across all three empirical studies, there was some variation for the children in that it manifested in some empirical studies but not others. When the serial recall task was used, the CS effect occurred for the youngest children in Study III, the 7-9 year old group in Study I and III, and the oldest children in Study II and III. The CS effect within the probed recall task was observed only for the 7-9-year-old children in Study I only.

Disruption by attentional capture (the deviation effect) varied across age groups and empirical studies. Adults were the least affected by this type of distraction and exhibited a deviation effect in the missing-item task in Study I but only when the deviant was embedded in a changing-state sequence. Surprisingly, the youngest children who were expected to show greater disruption by attentional capture than older children and adults did not exhibit a deviation effect at all. The 7-9-year-old children in Study I, however, showed a deviation effect in all three tasks when the deviant was in a changing-state context. In Study II, this group exhibited a deviation effect in serial recall and missing-item tasks regardless of the sequence context. The oldest children exhibited a deviation effect only in the probed recall task when the deviant was in a steady-state context (Study II).

Results regarding the token-set size and dose effects provided additional evidence for the vulnerability of serial rehearsal to changing-state disruption. When token-set size increased from one to two tokens, children and adults showed a detriment to serial recall (but not missing-item) performance. The additional increase in token-set size from two to five tokens, had a further detrimental impact on serial recall for adults and children aged 7 to 11 years old but an unexpected positive effect on recall performance for the 5-6-year-old children.

6.1 Developmental Differences in the Susceptibility to Auditory Distraction

6.1.1 The irrelevant speech effect.

The irrelevant speech effect (ISE) refers to the finding that recall performance in the presence of irrelevant speech is lower than in quiet (Beaman & Jones, 1997; Colle & Welsh, 1976). The detrimental impact of auditory distraction on serial recall has been widely studied among adults (Colle & Welsh, 1976; Hughes & Jones, 2003, 2005; Jones & Macken, 1993; Salamé & Baddeley, 1982) and recently the effects of auditory distraction among children have been assessed as well (Elliott, 2002; Elliott & Cowan, 2005; Elliott et al., 2016; Klatte et al., 2010). The findings from previous work together with present results show that memory for serial order is especially vulnerable to disruption by irrelevant sounds.

In this experimental series, the ISE was present among children aged 5 to 11 years old and among young adults aged 18 to 22 years old. The ISE was especially robust on serial recall and probed recall tasks compared to the missing-item task, suggesting that these tasks and the processes that underlie them may be particularly susceptible to disruption by irrelevant speech. Of the four age categories, only the 7-9-year-old children and adults exhibited an ISE on missing-item performance. This was in contrast to the presence of the ISE on serial and probed recall tasks for all the children and adults.

The youngest children did not consistently show an ISE on serial recall across empirical studies – the ISE was present for this group in Study III but not Study II. This inconsistency appears to be the result of task differences between the two studies. The serial recall task used in the two studies were similar in that colour patches were the to-be-remembered (TBR) stimuli, the number of trials was the same, and irrelevant speech was in the presentation phase. However, there were two changes made in Study III: five TBR items instead of four and the addition of an inter-stimulus interval (ISI; 500ms) between each TBR item. Speculatively, these modifications may have resulted in the ISE in Study III but not Study II. Although the addition of an ISI slowed down the presentation rate, children still had to recall five colour patches instead of four, which would have imposed a greater rehearsal load than four items. Elliott et al. (2016) found that children (and adults) showed greater disruption by irrelevant speech when the rehearsal load was higher (i.e., later on in the presentation phase); additionally, children’s recall was significantly poorer compared to quiet when irrelevant speech was presented during the latter half of the retention phase. Taken together, the results suggested irrelevant speech was most disruptive at higher levels of rehearsal demands. This finding as applied to the present results would suggest that rehearsing five TBR items posed a greater rehearsal load than four items therefore resulting in an ISE on the former (Study III) but not the latter serial recall task (Study II). Although the task varied slightly for the 7-11 year old children and adults (addition of ISI and fewer number of TBR items for 10-11-year-old children in Study III), it may have still been challenging enough to elicit the ISE.

Although there was an ISE in the probed recall task (for children and adults individually) in Study I, there were no effects of age suggesting that the ISE was equivalent for children and adults in this study. However, in Study II, there was an effect of age and the ISE was present for the youngest and oldest children and adults but not the 7-9-year-old children. In Study I, list length was adjusted to individual digit span which may have made the task much easier than when list length was fixed. The majority of children in Study I had spans of 3 and 4 items and the average span for the age group was 4 items. In study II, list length was fixed at 5 items for 7-9-year-old children and it may have resulted in floor effects. As a result, any effects of irrelevant speech on performance may have been masked by overall low scores in Study II. Mean performance in Study I versus II (see Figure 4 and Figure 12) supports this explanation of the results.

Prior to this, only one study has investigated the effects of irrelevant speech on the missing-item task among children (i.e., Elliott et al., 2016). While the results from the missing-item task can be considered alone, they are better explained in contrast with a task (or tasks) that involves serial rehearsal (i.e., probed and/or serial recall) to show the different patterns of disruption that emerge in tasks with and without serial rehearsal. Elliott et al. (2016) found that children’s performance in the missing-item task was lower in steady-state speech and changing-state speech compared to quiet and the magnitude of this disruption was larger for children than adults. In the probed recall task, there was no effect of age and performance in changing- and steady-state conditions were lower than in quiet. This suggested that children (but not adults) were vulnerable to disruption by irrelevant sounds in general, that is, regardless of the changing- or steady-state nature of the sounds and the processes involved in the task. Results from empirical Study I and II showed the opposite – there were age-related differences in the disruption to probed recall performance (in Study II) but the effects of age on the missing-item task were absent in both studies. In addition, the observation in Elliott et al. (2016) that children were more susceptible to distraction in general was not observed in these two studies. In Study I, children and adults showed significant disruption by steady-state speech with and without deviants in the missing item task but were susceptible to all irrelevant speech conditions except steady-state speech in the probed recall task. For participants in Study II, missing-item task performance was lower in all irrelevant speech conditions except steady-state speech. Adults' probed recall scores in Study II were significantly lower in all irrelevant speech conditions compared to quiet, performance in steady-state deviant speech was lower than in quiet for 10-11 year old children, and 5-6 year old children showed disruption to performance in all irrelevant speech conditions except steady-state speech compared to quiet. There was no difference between probed recall performance in irrelevant speech conditions and quiet for the 7-9 year old group.

Compared to the older children and adults, the five and six year old children had lower levels of performance on all three tasks and the lack of a difference between performance levels in quiet and irrelevant speech conditions may reflect floor effects. In addition, task stimuli for the five and six-year-old children were colour patches instead of digits. The general protocol when using the missing-item task is to use stimuli that are part of a well-learned and finite set (e.g., digits from 0-9; Beaman & Jones, 1997; Jones & Macken, 1993; Murdock & Smith, 2005). All but one item from the set are presented for the participant to identify the missing item. However, in Study II and III, the missing-item task consisted of five and six colour patches, respectively. Prior to the commencing the task, cards with the colour patches, that were to be used in the computerized task, were shown to the children. The aim of this procedure was to familiarize them with the set of colours being used (i.e., create the notion of a finite set) and to explain how the task would work. The missing-item task was demonstrated using these colour cards by showing the children all but one of the cards and asking them to identify which colour was missing. Therefore, although colours do not form part of a finite set, the procedure followed in this study ensured that the children would expect in the task only those five or six colours that the experimenter had presented. Nevertheless, it is not possible to rule out the effect of this task design in influencing the results.

In contrast to the youngest children, the 7-9 and 10-11-year-old children in Study I and II had lower missing-item performance in deviant speech conditions compared to quiet. For a better understanding of these results, a comparison with serial and probed recall may be beneficial. Unlike children in the study by Elliott et al. (2016), children in the present three studies did not show lower levels of performance in steady-state speech compared to quiet in any of the tasks. Instead, the general pattern for all the children in serial and probed recall was a disruption by changing-state and changing-state deviant speech compared to quiet. The 7-9 and 10-11-year-old children who participated in Study II were the only groups to show a lower level of performance in the presence of steady-state deviant speech compared to quiet, in the missing-item and probed recall task, respectively. In Study III, there was no ISE in the missing-item task for any of the children. Therefore, regardless of whether the task involved serial rehearsal, children were most often disrupted by deviant sequences which are generally assumed to cause disruption through attentional capture (Hughes et al., 2013; Hughes et al., 2005; Parmentier et al., 2008). Adults' recall performance in the missing-item task was also different from that observed by Elliott et al. (2016) – the pattern of results here suggested that adults were susceptible to more types of irrelevant speech than children. In Study I, adults' recall performance in the missing-item task was significantly lower in all irrelevant speech conditions compared to quiet and in Study II they had significantly lower scores in all irrelevant speech conditions except steady-state speech compared to quiet. In Study III, missing-item recall in the 5-token changing-state sequence was lower than in quiet. Similar results were observed in the serial and probed recall tasks – lower levels of recall in all irrelevant speech conditions compared to quiet (in all three studies) with the exception of serial recall in steady-state speech (Study I) not being significantly lower than quiet.

The pattern of developmental results in the missing-item task versus serial and probed recall indicated that children and adults were especially susceptible to changing-state speech regardless of task type. Aside from the two instances where adults' recall in steady-state speech was poorer compared to that in quiet, the general pattern indicated that steady-state speech did not cause a great deal of disruption to recall performance for adults or children. The vulnerability of children's recall to the ISE was specific to changing-state and deviant speech conditions while the ISE for the adults was generalized to all irrelevant speech conditions (with the exception of steady-state speech on two occasions). These results indicated a developmental difference in the ISE but in a pattern that was qualitatively different to that observed in the study by Elliott et al. (2016) since children (and not adults) in their study were affected by a wider range of irrelevant speech.

6.1.2 The changing-state effect.

The Changing-state effect (CS effect) was present in the serial recall task for all children and adults in the experimental series (the effect presented among 5-6-year-old children in Study III, 7-9-year-old children in Study I and III, 10-11-year-old children in Study II and III, and for adults in all three studies). The CS effect on probed recall, however, was present among adults (Study I and II) and 7-9-year-old children (Study I). As expected, there was no CS effect on missing-item task performance. The results concerning the CS effect are clear-cut – the effect is present in tasks with a serial rehearsal component and absent in the one without serial rehearsal consistent with the pattern observed in the literature (Beaman & Jones, 1997; Elliott et al., 2016; Jones & Macken, 1993; Perham et al., 2007).

There is a considerable amount of literature that shows the presence of a CS effect in serial recall across a wide range of young (18-35 years old; e.g., Beaman & Jones, 1997; Hughes, Tremblay, & Jones, 2005; Hughes et al., 2005, 2007) and old adults (60 years and above; Röer et al., 2015) and among children too (Elliott, 2002; Elliott et al., 2016). The CS effect manifests as lower recall in the presence of changing-state sounds compared to steady-state sounds (e.g., Elliott et al., 2016; Elliott, 2002; Jones et al., 1992; Jones & Macken, 1993). Although at the outset, it appears that CS effect is simply the evocation of an orienting response (OR: Sokolov, 1963) to each different sound token in the CS sequence (Cowan, 1995; Elliott, 2002; Elliott & Cowan, 2001; Lorch, Anderson, & Well, 1984) there is strong evidence to suggest otherwise. For example, the CS effect does not habituate over trials or experimental sessions (Hellbrück et al., 1996; Jones, Macken, & Mosdell, 1997; Tremblay & Jones, 1998; but see Banbury & Berry, 1997). In addition, if the CS effect were attentional based, it would not be able to account for the non-monotonic relationship observed between token-set size and disruption because an attentional view would suppose a monotonic relationship instead (Bridges & Jones, 1996; Tremblay & Jones, 1998; but see Campbell et al., 2002; and results from Study III). Lastly, if the CS effect were an attentional form of distraction then it would be expected it to manifest on any task and not just in those with a serial rehearsal component (Beaman & Jones, 2004; Hughes et al., 2005; Elliott et al., 2016; see also Study I, II, and III).

The presence of the CS effect in tasks invoking serial rehearsal shows the link between this effect and the specific process that support recall. The interference-by-process account (e.g., Hughes, 2014), therefore, posits rehearsal processes directed towards the focal task are disrupted by the obligatory processing of auditory to-be-ignored material (Hughes, 2014; Jones et al., 2010; Jones & Macken, 1993; Macken et al., 2009). In the present series, the CS effect was reliably observed across all three studies and only in the serial and probed recall tasks. In the present experimental series, the evidence for developmental differences is mixed – in Study I, there was no developmental difference in the CS effect in the serial and probed recall tasks, but in Study II, there was a developmental difference. In Study II, the developmental differences analysis showed that the CS effect was present only for 10-11-year-old children. However, individual age-group analyses showed a CS effect was also present for adults but only when deviant trials were included in the analysis (i.e. disruption in CS + *d* > SS + *d*). This novel finding will be addressed shortly. In Study III, a developmental difference in the token-set-size effect was present but may actually reflect a developmental difference in the additional disruption when tokens increase from two to five because all age groups experienced a CS effect (recall in 1 token > 2 tokens).

Before discussing the CS effect noted in the probed and serial recall tasks, it would be worthwhile to mention here that the three studies provide unequivocal evidence for the absence of a CS effect in the missing-item task – which further undermines the attentional account of the CS effect.

Overall, the CS effect was present across all age groups in those tasks thought to involve serial rehearsal (Hughes et al., 2005; Elliott et al., 2016). However, the effect was sometimes absent in one task or the other for some age groups across empirical studies – put simply, the CS effect did not always manifest in the serial and probed recall tasks for some age groups (e.g., it is present for 5-6-year-old children in Study III but not in Study II). From a developmental perspective, the interference-by-process account would suggest that the CS effect would be larger for those groups that have poorer rehearsal abilities (Elliott et al., 2016). On the one hand, adults who use a cumulative rehearsal strategy would be less vulnerable to irrelevant speech effects because disruption by seriation cues from the irrelevant sequence would be less likely to disrupt co-articulation of TBR items during rehearsal (e.g., Jones et al., 1996). On the other hand, children who tend to label items or repeat a single item several times more than using cumulative rehearsal (a pattern observed among children aged 8-10 year old; Lehmann & Hasselhorn, 2007) may be more vulnerable to cues from irrelevant sounds disrupting the seriation process. Another perspective, however, was proposed by Elliott (2002) which was if children have poorer rehearsal or do not rely on rehearsal as much as adults, then they should be less vulnerable to distraction by interference. However, as Elliott et al. (2016) points out, the latter possibility would mean smaller distraction effects among children than adults and this has not been observed.

While the developmental difference in the CS effect on serial recall was absent in Study I, it was present in Study II and III when a larger number of children aged 5 to 11 years old participated. The children in Study I were seven to nine years old – an age where rehearsal is thought to be present but still developing (Flavell et al., 1966; see also Gathercole, 1998). Therefore, children like adults would have been susceptible to interference-by-process when rehearsing TBR items in the presence of changing-state speech (but not steady-state speech; Hughes et al., 2007; Jones et al., 2010). In Study II, the CS effect, as indexed by poorer recall in CS speech versus SS speech, was observed only in the 10-11 year old group. Interestingly, the CS effect was present for adults but only when comparing performance in the deviant trials – performance was poorer in CS + *d* condition compared to SS + *d*. The finding of a CS effect on serial recall among the 10-11-year-old children is in line with results from Elliott (2002). However, the developmental pattern of results between the present study and that of Elliott (2002) vary. A developmental difference was observed in Elliott’s study (2002) which showed disruption by irrelevant speech decreasing with age. The youngest children were most susceptible to disruption by changing-state words (in particular) and tones. The results were interpreted in light of Cowan’s model (1995) which suggested that changing-state sounds were more disruptive because their changing-state nature would give rise to several deviations from the memory model and would capture attention. This coupled with children’s poor attentional control suggest a greater likelihood for children’s attention to be captured than adults’ (Elliott, 2002). The opposite pattern was observed in the present Study II – the youngest children and 7-9-year-old children did not show a CS effect on serial recall while the 10-11 year old group and adults (only with deviants) did. The pattern seen here suggests that as children develop and rehearsal improves, a larger CS effect emerges. However, this result is by no means conclusive because slightly different results were obtained in Study III.

In Study III, there was a developmental difference in the effect of token-set size which at the outset seemed to indicate a difference in the CS effect (as indexed by recall in the two tokens condition being lower than recall in the one token condition). However, upon closer examination, the developmental difference was not present for the CS effect but instead reflected a developmental difference in the disruption when token-set size increased from two to five. The results concerning the CS effect show that all age groups experienced a CS effect on serial recall. The lack of a developmental difference again contradicts results from Elliott (2002) but also does not align with results from Study II. At this stage, a comparison between the two studies and groups of participants may help to understand the discrepancy in results.

For the youngest children, the task in Study III may have been more challenging since there were five items rather than four to rehearse. This additional item may have placed greater demands on their rehearsal. In a challenging task like serial recall in the presence of irrelevant speech, the children may have had to rely greatly on their attentional control abilities to complete the focal task in the presence of irrelevant speech. It is likely that for the five-item task, the load on cognitive control was higher and resulted in greater distractor processing (Lavie, 2005) and consequently a CS effect on serial recall.

From the viewpoint of rehearsal development, the presence of a CS effect for the youngest children could provide a line of support for the quantitative development view of rehearsal (Hitch, Halliday, Dodd, & Littler, 1989; Hulme, Silvester, Smith, & Muir, 1986). This view suggests, contrary to the notion that children start rehearsing around age six or seven, that children as young as four may be rehearsing. There is evidence that shows the word-length effect is present (if material is presented aloud) and correlations are present between articulation rate and span – both signs that children as young as four years old may already be rehearsing (Hitch et al., 1989; but see also Jarrold, Baddeley, & Hewes, 2000). Interestingly, though, the CS effect was not present for this age group in the probed recall task. The presence of the CS effect among these children can be considered indirect evidence for the involvement of rehearsal among them; however, some caution is needed since the effect was not consistently present in the probed recall task that presumably also relies on order retention. That being said, performance in the probed recall task has generally been lower (when compared to the missing-item task; Elliott et al., 2016; Beaman & Jones, 1997; Hughes et al., 2007; see Study I, II, and III) and perhaps lower performance masked a potential CS effect in this group. Probed recall has also been associated with strong recency effects (in studies of word length; Jarrold, Cocksey, & Dockerill, 2008). In the present context, since the lists used with the children were quite short, it may have restricted the extent to which the CS effect would manifest. Finally, this group of children completed a different version of tasks to the other groups and the differences in the results for this group can be a reflection of task differences.

The CS effect among adults in Study I and III was in keeping with previous findings (e.g., Jones & Macken, 1993; Jones et al., 1993; Hughes et al., 2005) and shows how robust the interference-by-process is when serial rehearsal is involved. Although the CS effect was present for adults in Study II, further analysis showed that the effect was present only for CS + *d* vs SS + *d* sequences. Initially, this was thought to be an attentional effect but if that was the case, the SS + *d* sequence would be expected to have more attention-capturing power than the CS + *d* sequence (Elliott, 2002), however, this was not apparent. Indeed, if this was attentional capture, it would be expected in a task devoid of serial rehearsal too – but again this was not the case. An examination of scores in the missing-item task showed no difference in the disruption caused by CS + *d* and SS + *d* sequences. Additionally, the duplex-mechanism account predicts that deviants will have as much impact regardless of whether they are in a steady- or changing-state sequence (Hughes et al., 2007). Therefore, it would appear that the changing-state characteristic of the sequence (or CS effect) rather than the deviant element is driving the disruption in in CS + *d* versus SS + *d*.

6.1.3 The deviation effect.

The assessment of the deviation effect among children and subsequent comparison with adults has not been addressed before. The developmental research comparing young and old adults and their susceptibility to the deviation effect has shown an age-equivalence in the effect (e.g., Röer et al., 2015; Rouleau & Bellville, 1996; cf. Andrés et al., 2006). Additionally, although working memory capacity was lower for the older adults, this did not always associate with greater attentional capture (Sörqvist, 2010a; Sörqvist et al., 2013). In the present experimental series, the developmental differences analyses for the deviation effect (in Study I and II) were clear-cut – there was no difference between children and adults with regards to the deviation effect. In addition, there was no relation between the deviation effect and working memory performance as assessed by complex span tasks such as operation span, symmetry span, and rotation span (Foster et al., 2015; Unsworth et al., 2005).

Therefore, the pattern of results observed here is in line with previous findings of an age-equivalence between young and old adults in the deviation effect (Röer et al., 2015; Rouleau & Bellville, 1996; Sörqvist et al., 2013). The lack of a relationship between the deviation effect and working memory capacity is also similar to results observed with adults (Sörqvist, 2010a; Sörqvist et al., 2013). Therefore, although children may have lower working memory capacity it may not necessarily lead to greater attentional capture compared to adults who have higher working memory capacity. Factors such as task design may have an impact on the developmental differences. For example, research in the oddball paradigm with young and old adults has shown a greater susceptibility to deviant sounds among older adults (e.g., Andrés et al., 2006). Therefore, one could conjecture that a developmental difference may also emerge between children and adults in such a paradigm rather than in the irrelevant sound paradigm. The oddball paradigm is different to irrelevant sound experiments in that the irrelevant sounds generally precede a focal task item rather than being heard concurrently with the task (e.g., Parmentier, Elsley, Andrés, & Barceló, 2011). It may be this difference between the two paradigms that leads to developmental differences being observed in one but not the other.

6.1.4 Insights from cross-experimental analyses.

Of the three cross-experimental analyses that were conducted, two were aimed at identifying potential differences in distraction effects on account of task design and the third was a large-scale evaluation of developmental differences in distraction among children and adults (see Chapter V).

The comparison of performance in Study I versus Study II showed that while developmental differences in performance levels are more likely to emerge when tasks are difficult (Cowan et al., 2010), there was no difference in the CS effect as a function of task difficulty. Previous studies have shown that the CS effect is immune to task difficulty (unlike the deviation effect; Hughes et al., 2013) and therefore, the present results concur with extant findings in this respect. Furthermore, the CS effect was absent in the missing-item task across both studies showing that rehearsal is essential for this type of distraction to occur (Beaman & Jones, 1997; Hughes et al., 2007; Jones & Macken, 1993). As was observed in the individual empirical studies, there was again no effect of age on the occurrence of the CS effect and also no effect on the magnitude of disruption by the CS effect — in other words, children and adults did not differ in their susceptibility to disruption through interference-by-process (Elliott et al., 2016).

Two important findings regarding attentional capture (i.e. the deviation effect) were highlighted in the cross-experimental analyses. First, children were more susceptible to attentional capture by deviants in a serial recall task than adults. This age-related finding is in line with previous studies that have shown children can be more susceptible to distraction because of poorer attentional control (Elliott, 2002; Elliott et al., 2016). Second, a greater deviation effect was present (albeit, only in the probed recall task) when list-lengths were varied rather than fixed. When these results are considered together with evidence that greater task difficulty shields against attentional capture (Hughes et al., 2013), it shows that the fixed length task may have encouraged greater task engagement on account of its higher difficulty which in turn shields cognitive performance from distraction by attentional capture (Hughes et al., 2013; Sörqvist & Marsh, 2015).

In the comparison between the design of Study II (separate testing sessions) and the task-switching design used in the study by Elliott et al. (2016), a striking difference was observed with regards to children's performance levels while more subtle differences were present in the distraction effects. Children had significantly lower performance in the task-switching setting compared to separate testing sessions — a 15% decline in performance was observed. This difference in performance could reflect greater task difficulty created by the task-switching design. The costs associated with task switching are strongly related to the similarity between the tasks such that a greater similarity between the tasks results in higher alternation costs (Jersild, 1927). In addition, switch costs are greater when only one aspect of a task is switched rather than all aspects (Davidson et al., 2006) and this has been observed among children and adults (Crone, Van Der Molen, & Ridderinkhof, 2006; Mayr, 2001). While there are other factors that affect task-switching (for a review, see Monsell, 2003), the two factors mentioned above are relevant for the present discussion. In the study by Elliott et al. (2016), children were asked to perform two very similar tasks — the probed recall and missing-item task — which involve the presentation of digits and requirement of a single response but differ in their requirement of order retention (Hughes et al., 2007). The only difference between the tasks is during recall wherein children have to either click on the item that followed the probe or identify the missing item. Therefore, the costs incurred as a result of having to change mind-sets and reconfigure stimulus-response associations (from ‘which followed *x*?’ to ‘Which item was missing?’) may have been quite difficult for the children (Brass et al., 2003). Nevertheless, the inclusion of practice trials and clear on-screen instructions to inform of the switch between task blocks should have reduced at least some of the switch costs (Monsell, 2008). However, the overall pattern of results once again indicate that in difficult task settings, differences are more likely to emerge (Cowan et al., 2010).

Since the same children completed the tasks when they were alternated in blocks and administered separately, the difference in performance cannot be attributed to group or individual differences and thus must be a reflection of the design used. Furthermore, although the irrelevant speech used in the study by Elliott et al. (2016) and Study II did not contain the same content, they did match in terms of their acoustic nature (i.e. steady- and changing-state). Given that the acoustic nature of sound and not its content determines disruption to short-term memory tasks (Jones et al., 1992; Jones & Macken, 1993), it can be said with more confidence that the observed difference in performance is the result of task design adopted.

The ISE, which is the difference between performance in quiet and irrelevant speech conditions, was present in the task-switching design but absent in the separate-task design for both probed recall and missing-item tasks. The CS effect, however, was present in both designs but the magnitude of the effect did not vary between the two designs. This pattern shows again that the CS effect is not influenced by task difficulty (Hughes et al., 2013; Sörqvist et al., 2012). The results from Study II (in section 3.3.1) for the 7-9 year old age group (as a whole) showed that the ISE and CS effect were absent in the probed recall task while only an ISE was present in the missing-item task. Children’s performance in the probed recall task was generally low in Study II which may have obscured differences across sound conditions; and, the ISE observed in the missing-item task was attributed to a difference between performance in quiet and deviant speech only. That the deviant condition was not included in the cross-design analysis explains why there was no ISE when compared to the task-switching design.

The cross-experimental analyses compared the CS effect when list lengths were fixed versus varied and when tasks were administered separately versus in alternating blocks. These two foregoing analyses have shown that the CS effect, an example of interference-by-process, is not dependent upon task difficulty modulated through the use of different list lengths or through a task-switching design. This finding is in line with previous research showing that task difficulty (induced by increase in perceptual load) did not modulate the CS effect (Hughes et al., 2013). Of particular relevance in developmental research, the results showed that when task difficulty was high, developmental differences were more likely to emerge (Cowan et al., 2010). In addition, when the same group of children completed the memory tasks in a task-switching setting and in separate testing sessions, differences in performance emerged. This highlights the general importance of selecting suitable experimental designs for research.

The overall analysis comprising data from all three empirical studies showed that adults' and children's performance (collapsed across age and serial recall and missing-item tasks) was significantly poorer in the presence of changing-state speech compared to quiet and steady-state speech while there was no difference between the latter two conditions. The steady-state disruption observed for children in the study by Elliott et al. (2016) was not replicated in present results. In fact, in the present series, adults demonstrated disruption by steady-state speech regardless of task-type. This aspect of the results stands in contrast to developmental studies that have consistently shown children to be more distractible than adults regardless of the nature of the sounds

(Elliott, 2002; Elliott et al., 2016; Klatte et al., 2010; Klatte et al., 2007; Meinhardt-Injac et al., 2015). The pattern also contradicts findings from individual empirical studies in the thesis which showed that children were susceptible to the deviation effect in more tasks than adults (Study I and II). However, in Study III, a slightly different pattern emerged wherein older children and adults showed additional disruption to serial recall when token-set size increased from two to five. This was attributed to slower habituation to the irrelevant sequence on account of a concurrent working memory load being imposed by the focal serial recall task (Bell et al., 2012). This interpretation was suggested since there was no effect of token-set size (disruption did not increase with increase in token-set size) in the missing-item task. This task is assumed to be devoid of rehearsal (Beaman & Jones, 1997) and may also impose a lower working memory load than serial recall which would allow a faster rate of habituation since attentional resources are not engaged with high working memory load (Berti & Schröger, 2003; SanMiguel et al., 2008). As such, perhaps these results need to be treated with caution.

Elliott et al. (2016) concluded that because the steady-state disruption was present in probed recall and missing-item tasks for the children and not adults that it represented a general susceptibility to distraction among children. They also showed that when the load on rehearsal increased, the disruption exhibited by children was greater than for adults. This combination of results suggested that children were more susceptible to distraction because of their poorer attentional control which was exacerbated by rehearsal acting as an additional attentional load. The present finding that adults (and not children) exhibited a steady-state disruption regardless of task type should be treated with some caution because the weight of evidence suggests that children are more susceptible to distraction regardless of its acoustic nature than adults (Elliott, 2002; Elliott et al., 2016; Klatte et al., 2010; Klatte et al., 2007). Several studies have also shown very minimal steady-state disruption or none at all (e.g., Bridges & Jones, 1996; Hughes et al., 2005; Jones & Macken, 1999).

The finding of a steady-state disruption for the adults regardless of task type suggests that the effect may have been attentional-based. Nevertheless, this interpretation should be treated with some caution because in individual analyses of empirical studies, the pattern of results was in line with the duplex-mechanism account. In addition, the finding of a steady-state disruption does not cohere with predictions by the feature model (Neath, 2000) and in turn shows the inability of the feature model to explain distraction effects. Neath (2000) suggests that steady-state disruption occurs through the process of feature adoption, however, the attentional parameter to simulate this disruption is much higher than that for changing-state disruption. The modification in the attentional parameter is to account for the fact that steady-state sounds are easier to ignore than changing-state sounds (Neath, 2000). When applied to the present results, the attentional parameter should have been quite high to accommodate the nature of steady-state sounds and adults' superior attentional control. Therefore, it would seem that the feature model would predict less steady-state disruption for adults. Thus the feature model predictions and the steady-state disruption for adults stand at odds with one another. The discrepancy in predicting results shows the feature model to be untenable and highlights the arbitrary nature of the attentional parameter (Jones & Tremblay, 2000).

The overall analysis of study I, II, and III therefore confirm that the CS effect was present for children and adults only when serial rehearsal was deployed in the tasks. The absence of an effect of age is in line with other studies suggesting developmental differences are more likely to emerge when distraction is underpinned by attentional control rather than the use and / or efficiency of rehearsal (Elliott, 2002; Elliott et al., 2016; Klatte et al., 2010). In addition, the comparison between Study I and II did show that children were more susceptible to attentional capture by deviants than adults. Furthermore, in Study I and II, children exhibited a deviation effect in more tasks than adults. Taken together, it would appear that differences between children and adults in distraction effects may be underpinned by their differences in attentional control. Finally, differences may become more evident when task difficulty is greater (Cowan et al., 2010).

6.1.5 Concluding summary.

The aim of this thesis was to identify differences in susceptibility to distraction among children and adults. School-age children (aged five to eleven years) and young adults (aged 18 to 22 years) completed three short-term memory tasks – serial recall, probed recall, and missing-item – in the presence of irrelevant speech. While both children and adults showed a detriment to recall by irrelevant speech, developmental difference did not always emerge. The classical Irrelevant Speech Effect and Changing-state effect were present for all children and adults. The ISE was noted in all three memory tasks while the CS effect only emerged on tasks with a serial rehearsal component. The presence of the CS effect in tasks with serial rehearsal and its absence on tasks devoid of serial rehearsal is empirical evidence for the vulnerability of serial rehearsal to disruption by irrelevant speech. An additional distraction effect – the deviation effect – was more prevalent for children but the overall developmental difference analysis suggested the effect did not differ as a function of age. The deviation effect was also observed in tasks regardless of whether serial rehearsal was involved. The CS effect occurs when changing-state sounds interfere with rehearsal processes that are used to complete short-term memory tasks while the deviation effect represents a more domain-general type of distraction that operates through the mechanism of attentional capture (Hughes, 2014; Hughes et al., 2005, 2007).

Contrary to previous findings by Elliott (2002) and Elliott et al. (2016), the present study did not find that children were more susceptible to distraction than adults. In fact, the CS effect was more prominent among older children and adults than younger children suggesting that as rehearsal improved, distraction effects became stronger. It was proposed that while rehearsal is a good strategy for maintaining items in memory in quiet, the mechanism of the CS effect disruption makes this strategy less effective in the presence of irrelevant speech (Elliott & Cowan, 2005). The results from Elliott et al. (2016) suggested that as rehearsal load increased, children and adults experienced greater disruption by irrelevant speech. In addition, children were found to be vulnerable to any type of sound (steady or changing) even in the missing-item task (Elliott et al., 2016). The pattern of results suggested that children's underdeveloped rehearsal exacerbated their limited attentional control and made them more susceptible to distraction not by interference-by-process but by attentional diversion (Elliott et al., 2016). It is not entirely clear why in the present study an opposite pattern of results were observed. However, this opens up possibilities for future research. Specifically, an assessment of longitudinal effects of distraction would be beneficial to understanding how distraction effects change as one gets older. A longitudinal study among children would be particularly informative in light of the cognitive changes that take place from childhood into adolescence with regards to rehearsal, attentional control, and memory storage. The developmental differences in distraction could also be considered within other paradigms (oddball tasks, for example) and with the use of different task designs within the irrelevant sound paradigm (e.g., use of alternating blocks instead of separate task administration).

The results from the empirical studies provide support for a duplex-mechanism account of distraction (Hughes et al., 2007) by showing that distraction can be distinguished on the basis of rehearsal and attention (cf. Körner et al., 2017). The CS effect was consistently present for children and adults in tasks with a serial rehearsal component and did not manifest in the missing-item task which is assumed to be devoid of rehearsal (Beaman & Jones, 1997). The deviation effect manifest regardless of task type (Hughes et al., 2007) for children and adults across the three studies. From a developmental perspective, the statistical interaction with age was not always significant, however, on a task-level analysis, the pattern of results indicated that children were susceptible to distraction more frequently than adults. In addition, the overall analyses showed that the deviation effect (but not CS effect) interacted with age: the deviation effect was greater for children (in serial recall) than for adults. This finding sits well with others that have suggested a greater susceptibility among children because of their poorer attentional control (Elliott, 2002; Elliott et al., 2016), developmental differences are more likely to emerge as a function of attention rather than rehearsal (Klatte et al., 2010), and attentional capture is more likely to occur for low WMC individuals than high-WMC individuals (Hughes et al., 2013; Sörqvist, 2010a; Sörqvist & Marsh, 2015). Although the links between WMC and distraction effects were not consistently observed, the general pattern was that of a correlation between the deviation effect and WMC but no relationship between the CS effect and WMC for children and adults. The correlation between the dose effect and WMC (in Study III) suggested that high WMC adults exhibited greater disruption when the dose of irrelevant speech was increased. Although this pattern may seem contrary to the duplex-mechanism account, it does cohere with the idea that disruption will be greater when there are more order cues that can disrupt serial recall performance (Marsh et al., 2009). In addition, the interference-by-process explanation suggests that a greater reliance on rehearsal in the presence of changing-state irrelevant sounds will increase the disruption that occurs. The lack of a difference in the dose effect for low WMC individuals may be an indication that they were engaging in rehearsal to a lesser degree than their high-WMC counterparts. Thus, there are three lines of evidence in this thesis that support the premise of the duplex-mechanism account: interference-by-process occurred only in the presence of changing-state sound and rehearsal engagement while attention capture took place regardless of processes in the task; the deviation effect varied between children and adults but no differences were observed with regards to the CS effect; and, the dose effect manifested only for high-WMC individuals who may are presumed to engage in rehearsal to a larger extent than low-WMC individuals; thus making them more susceptible to interference-by-process.

It is clear from this discussion of the results fit within the framework of the duplex account. In doing so, the unitary account of distraction (Cowan, 1995; Elliott, 2002) is severely undermined. The parsimonious explanation that CS and deviation effects are the result of attentional capture cannot be explained by the pattern of results here. However, there was only aspect of results for which an explanation through attentional means was deemed appropriate: the monotonic relationship observed among 7-11 year old children and adults in Study III (Campbell et al., 2002; cf. Tremblay & Jones, 1998).

An important theoretical implication of the results in this thesis is that they undermine the feature model proposed by Neath (2000) and the unitary account of distraction that proposes attentional-based distraction alone. The feature model predicts larger disruptive effects in situations where the attentional parameter, a, is small. This parameter is a scaling variable that sets the amount of attention available based on the individual’s attentional control, the nature of the task, and nature of the irrelevant sounds (Neath et al., 2003). Therefore, for children in this study, the model should have not only predicted a greater deviation effect but also a greater CS effect since both types of distraction would disrupt through feature adoption. However, the pattern of results showed that the children did not always exhibit a deviation effect, and, there was no difference in the magnitude of the CS effect between children and adults in any of the studies. This finding casts doubt on the rationale behind the attentional parameter and shows its inability to account for the present results. On a similar note, the steady-state disruption in these studies was minimal (with the exception of adults in the combined analysis) and children did not show a steady-state driven disruption. That the disruption was minimal and that adults (but not children) exhibited steady-state disruption when data were combined contradict the predictions of the model. In the feature model, the attentional parameter will be set high for steady-state speech because it is easy to ignore and would presumably be higher when accounting for adults' superior attentional control. Therefore, the model would predict some steady-state disruption to still occur (which was not always the case in Study I, II, and III) and that children should show a steady-state disruption because they have poorer attentional control than adults. Yet again, the model is unable to account for the pattern of results.

The feature model assumes that disruption, whether by changing-state speech or deviant speech, should lead to feature adoption. Therefore, a logical prediction would be that the effects of distraction should be the same regardless of task type. However, this prediction must be discounted since the pattern of results shows that the CS effect occurred only in serial and probed recall tasks while the deviation effect was present regardless of task type. That the deviation effect occurred regardless of task type should not be construed as evidence to support the feature model. If feature adoption is the underlying mechanism of distraction then there should be no differences between the CS effect and deviation effect since each token in the changing-state and deviant sequences will generate similar modality-independent features. The presence of a deviant in the form of a voice change would be coded within memory as a modality-dependent feature and as such would not have a bearing upon the feature adoption process and resulting distraction (Neath, 2000). The model also fails to account for the non-monotonic function in the token-set size effects and disruption for 5 and 6-year-old children together with the monotonic token-set size effect for the older children and adults. The feature model would predict the opposite pattern of results — that is, the youngest children should show a monotonic function while the older children and adults should exhibit a non-monotonic function. This prediction would be based on adjustments to the attentional parameter to account for less attention among the youngest children and more attention for the older children and adults. Therefore, the youngest children should show a greater disruption as the token set-size increases but the adults and older children should not. Finally, the lack of dose effects cannot be explained by the model either because according to the feature model, disruption will be greater when there are a greater number of features in memory. When there are a greater number of features in the search set within memory, there is a greater opportunity for mismatch to occur between relevant and irrelevant items and so an increase in dose should, in theory, cause more disruption to recall.

A final theoretical consideration in light of the findings is related to the automatization of rehearsal hypothesis. It was suggested that children's rehearsal will improve as a function of their language skill and that around 6 or 7 years of age, children are likely to begin using rehearsal to facilitate recall (Bebko et al., 2014; Lehmann & Hasselhorn. 2012). Since the process of rehearsal is not yet fully automatized among children and continues to undergo changes until late childhood, many children demonstrate utilization deficiencies in the initial use of rehearsal as a memory strategy and rehearsal becomes a dominant strategy in recall only around 10 years of age (Clerc et al., 2014; Lehmann & Hasselhorn, 2007, 2012). The hypothesis in relation to distraction was that children's underdeveloped rehearsal and tendency not to engage in rehearsal all the time may result in a lower susceptibility to interference-by-process in the serial and probed recall tasks. For adults, however, greater interference-by-process (in the form of the CS effect) would be observed because although their rehearsal is fully automatized and more efficient than children, it is the act of engaging in rehearsal, in the presence of changing-state sounds, that produces the CS effect (Hughes, 2014; Marsh et al., 2009). With regards to the deviation effect, the automatization hypothesis predicts that in serial and probed recall tasks, children's immature rehearsal acts as an additional attentional load presumably because the process of engaging in rehearsal is more deliberate than automatic and requires monitoring in order to maintain its use (Clerc et al., 2014). This additional attentional load coupled with already poor attentional control will increase the likelihood of attention capture by deviants. In the absence of rehearsal (i.e. in the missing-item task) attention capture is due to poor attentional control. Among adults, fully automatized rehearsal may be a protective factor in the face of attention capture because, unlike for children, it does not place additional demands on cognition.

The pattern of results in the empirical studies are in line with the automatization hypothesis to some extent. There was no difference between children and adults to suggest a greater interference-by-process for adults (Elliott et al., 2016), however, the results did show that children (and not adults) were susceptible to attentional capture when the tasks required serial rehearsal. This is in keeping with the notion that rehearsal can act as an additional load thereby increasing the likelihood of distraction. The absence of an age effect in the CS effect is somewhat problematic for this account but given the small effect sizes for many of the effects in this study, perhaps the results are a reflection of statistical methods rather than a suggestion that there are no differences at all. The results pertaining to rehearsal disruption fit well the duplex account and the automatization hypothesis because they show that rehearsal is required for disruption to occur. The CS effect was absent in the missing-item task and also did not consistently emerge for children under the age of seven (children in Study III exhibited a CS effect but those in Study II did not). The ambivalence in the occurrence of the CS effect for children could reflect that children under the age of seven are rehearsing some of the time but that they do not consistently use the strategy as do older children and adults. In fact, this explanation also holds true for children aged up to nine years of age because in Study II, the CS effect only emerged for children aged 10-11 years old and adults. This pattern could suggest, as Lehmann & Hasselhorn (2007, 2012) have found, that rehearsal is a more dominant strategy only from the age of ten. In addition, that rehearsal was a dominant strategy for adults is also proven in the fact that the CS effect was consistently present when serial and probed recall were used.

In terms of attentional control, the combined analyses showed that there was greater attentional capture for children than adults in the serial recall task. The role played by rehearsal as an attentional load can be inferred from this finding. Furthermore, there was no relation between age and the deviation effect for the missing-item task in any of the empirical studies suggesting that rehearsal may have a role to play in attentional-based distraction. This suggestion seems feasible given that Elliott et al. (2016) found a greater susceptibility to distraction as a result of poorer attentional control among children.

To conclude, the impact of this empirical series is as follows: distraction effects can be separated on the basis of attention and rehearsal (Study I, II, and III); however, these cognitive processes do not act in isolation because children’s underdeveloped rehearsal can impose an additional attentional load, increasing the likelihood of attentional capture for children (Chapter V). More generally though, children’s lack of efficient attentional control makes them more vulnerable to distraction regardless of the task type (Elliott et al., 2016). In contrast, adults appear to enjoy a shield against distraction when performing difficult tasks (i.e. serial recall) — it was suggested that performing more difficult tasks fostered greater task engagement and a more steadfast locus of attention towards the focal task (Hughes et al., 2013; Sörqvist & Marsh, 2015; Sörqvist & Rönnberg, 2014). This suggestion was supported by the finding that while adults’ attention was not captured in serial and probed recall tasks, it was vulnerable to attentional capture in the missing-item task. In addition, the efficiency of rehearsal as a function of age did not modulate the magnitude of disruption that was exhibited by different age groups. However, it appears that interference-by-process occurs more reliably among groups that are consistently using rehearsal as a strategy for recall. Interference-by-process was observed for children aged 7-9 in two out of the three empirical studies they participated in compared to 10-11 year old children and adults who showed a consistent CS effect in all participated studies. Similarly, the 5-6 year old children in Study III exhibited a CS effect while the same age group in Study II did not. The ambivalence of the CS effect suggests that young children do not always rely on rehearsal to support memory (and findings may reflect variability in strategy use among young children; Schneider, Kron, Hünnerkopf, Krajewski, 2004). Therefore, the pattern of results suggests that an account that incorporates the interaction of rehearsal and attention in determining disruption is needed. This is especially important for interpreting developmental results which may, as in this series, present complex patterns of results. In addition, future research may benefit from including measures that tap children’s degree of language (and rehearsal) automatization (e.g., speed of naming task; Bebko et al., 2014) alongside a measure for rehearsal (e.g., serial recall) to assess how the interaction between the two can modulate distraction effects.

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APPENDIX A

Ethical approval for research project

11 July 2014

John Marsh /Tanya Joseph
School of Psychology

University of Central Lancashire

Dear John / Tanya

Re: PSYSOC Ethics Committee Application Unique Reference Number: PSYSOC 149

The PSYSOC ethics committee has granted approval of your proposal application **'The effects of noise on memory: How children are distracted by noise and what can we do about it in schools'**. Approval is granted up to the end of project date or for 5 years from the date of this letter, whichever is the longer. It is your responsibility to ensure that

- the project is carried out in line with the information provided in the forms you have submitted
- you regularly re-consider the ethical issues that may be raised in generating and analysing your data
- any proposed amendments/changes to the project are raised with, and approved, by Committee
- you notify roffice@uclan.ac.uk if the end date changes or the project does not start
- serious adverse events that occur from the project are reported to Committee
- a closure report is submitted to complete the ethics governance procedures (Existing paperwork can be used for this purposes e.g. funder's end of grant report; abstract for student award or NRES final report. If none of these are available use e-Ethics Closure Report Proforma).

Yours sincerely

C Sullivan

Cath Sullivan

Chair

PSYSOC Ethics Committee

APPENDIX B

Information sheet and consent refusal forms for parents

Re: The effects of noise on memory: How children are distracted by noise and what can we do about it in schools

Dear Parent/Guardian,

My name is Tanya Joseph and I am a PhD student in the School of Psychology at the University of Central Lancashire. I am currently working on a research project that aims to assess the negative impact that noise (e.g.: noise from computers, chatter in the classroom, etc.) has on children's memory and their ability to recall information and provide suggestions to reduce this impact.

This study has been approved by the Ethics Committee at UCLan. I have also spoken with the Head Teacher at your child's school and explained the study in detail. The teacher is interested in this research and has agreed to allow pupils to participate. We hope to develop a clear understanding of how noise affects children ranging from 4 to 12 years old. This will help us to compare how younger and older children are affected by noise.

The study involves conducting three computer-based memory tasks while distracting noises are played over headphones. Overall, this will take roughly 60-70 minutes to complete and will be done over three separate sessions. Studies show that when children are faced with such distraction, their memory gets impaired and they're unable to recall some of the information. This happens even when they are asked to ignore the sounds and focus on the task. By using these tasks, we will be able to see how noise affects children's ability to remember numbers that they see in the experiment. It will also help us to find out which type of noise affects their memory the most.

Please note, since our study involves listening to sounds over headphones, we would like that children who participate have normal hearing ability. **If your child has a hearing impairment, they cannot participate in the study.** Thank you for your co-operation.

The data obtained will be used in my PhD thesis and may also be published in academic journals. However, no children's names will be mentioned. The data that is collected from each child will be given a unique code number and any documents which have personal information about your child will be stored in a locked filing cabinet at the University. The data that is collected will be confidential and only available to my research supervisors and me.

If **YOU ARE NOT WILLING** to let your child participate in the study (or if your child has a hearing impairment), **please fill in the refusal form and post it to us in the pre-paid envelope that was provided. We require that the refusal form reach us before …/…/….**

On the other hand, **if you are willing to let your child participate, please do not send the attached refusal form back.** No further action is required on your part. Please retain this information sheet should you wish to refer to it at a later date. Before the study begins, your child will be asked whether they would like to take part or not.

The researchers will ensure that only those children who want to participate and have parental permission will be allowed to take part in this study. In addition, the researchers will ensure that your decision to allow or withhold your child's participation in the study will have no impact on any educational activities or school procedures.

Please be reminded, if you and/or your child do not want to participate in this project you will need to send the refusal form back to make us aware of your decision.

Please note that if you wish to withdraw your child from the study at a later date, you will need to contact me (the lead researcher) or my supervisor via **email or letter**. You will need to tell us whether you want to withdraw your child; their data; or both from the study. Please also note that you have a period of up to **one month** after data has been collected to withdraw. After that time, it will not be possible for us to trace your child's data since it will be filed under a code number and no names will be used. We aim to begin data collection on **…/…/…**

If you would like more information about the project, please feel free to get in touch with the researchers via the contact details on the next page. We will be happy to address any questions or concerns you may have. You may also contact the head teacher for more details on the study. We have provided the teacher with information regarding the aims of the study, the tasks that will be used, and the likely benefits of the study. The head teacher will be glad to share this information with you should you wish to know more about the study.

Your support with this research is greatly appreciated. I hope that it will be a rewarding experience for your child, should you allow them to participate. Thank you for taking the time to read this letter.

Yours sincerely,

Tanya Joseph

You may contact the research team via the contact details below:

Tanya Joseph	**Project Supervisor: Dr. John Marsh**
Room DB 120, Darwin Building. School of Psychology, University of Central Lancashire. PR1 2HE.	Room DB 111, Darwin Building. School of Psychology, University of Central Lancashire. PR1 2 HE.

PARENTAL CONSENT REFUSAL FORM

The effects of noise on memory: How children are distracted by noise and what can we do about it in schools

This form is to be filled in by a parent or guardian who **DOES NOT WANT** their child to take part in the Noise and Memory Study at their child's school.

I **would not like** my child to participate in the study entitled '**The effects of noise on memory: How children are distracted by noise and what can we do about it in schools'**

Please use BLOCK CAPITALS

Child's Full Name...

Child's Date of Birth: …………………………….

Child's School ………………………………………………………………

…………………………………………

Parent/Guardian's Name…………………………………….

Parent/Guardian's Signature…………………………………

Date……………………….

Please return this completed form before .../…/…

Thank you.