Journal of Cognitive Psychology

ISSN: (Print) (Online) Journal homepage: www.tandfonline.com/journals/pecp21

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To cite this article: Zoe Littlefair, Beth H. Richardson, Linden J. Ball, François Vachon & John E. Marsh (11 Sep 2024): Semantic priming by task-irrelevant speech: category-level or item-level processing?, Journal of Cognitive Psychology, DOI: 10.1080/20445911.2024.2395584

To link to this article: https://doi.org/10.1080/20445911.2024.2395584

Published online: 11 Sep 2024.

JOURNAL OF COGNITIVE PSYCHOLOGY
https://doi.org/10.1080/20445911.2024.2395584

Semantic priming by task-irrelevant speech: category-level or item-level processing?

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ABSTRACT
Recent studies show that task-irrelevant speech affects subsequent behaviour. For instance, category-exemplar production is primed if those exemplars were previously auditory distractors that accompanied the presentation of visual digits for serial recall (Röer et al., 2017. Semantic priming by irrelevant speech. *Psychonomic Bulletin & Review*, *24*(4), 1205–1210. https://doi.org/10.3758/s13423-016-1186-3). This study examines semantic organisation as a boundary condition for the semantic priming effect. In a between-participants design, sequences of auditory distractors were either semantically organised (eight exemplars from one category) or random (one exemplar from each of eight categories). Semantic priming was measured by comparing production probability of previously encountered words against a matched unencountered set. Prior research indicates that an unexpected categorical change in task-irrelevant speech disrupts performance, suggesting processing of shared categorical membership enhances semantic priming (e.g. Vachon et al., 2020. The automaticity of semantic processing revisited: Auditory distraction by a categorical deviation. *Journal of Experimental Psychology: General*, *149*(7), 1360–1397. https://doi.org/10.1037/xge000071). Consistent with these findings, semantic priming was found when distractor words were semantically organised but was absent with randomly presented exemplars, offering insight into the semantic processing of background sound.

ARTICLE HISTORY
Received 5 December 2023
Accepted 17 August 2024

KEYWORDS
Auditory distraction; semantic processing; irrelevant speech; semantic priming

Coherent mental performance requires the capacity to remain focussed on the subset of environmental information that is relevant to one's current goals (e.g. reading the words in this text), while simultaneously ignoring task-irrelevant information (e.g. people conversing in the background). However, a balance must be found between the ability to focus and the requirement to remain open to changes in "irrelevant information" should these events require immediate action (e.g. someone in the background suddenly shouting). The selective attention system must therefore be permeable; however, the extent to which it allows the processing of post-categorical properties—such as the semantic, syntactic, and contextual aspects of task-irrelevant speech without focused attention—remains open to debate (Holender, 1986; Lachter et al., 2004).

Recent studies demonstrate that the semantic properties of task-irrelevant sound, although ineffective in disrupting concurrent task processing, nevertheless affect performance in a subsequent, unrelated task (Richardson et al., 2022; Röer et al., 2017). For example, Richardson et al. (2022) found that the presentation of non-dominant homophones (e.g. "thyme" [non-dominant] vs. "time" [dominant]), or their associates (e.g. "herbs", "spices", "flavour"), as task-irrelevant speech during a visual-verbal serial recall paradigm, primed subsequent spelling of the homophones in line with their non-dominant meaning in an "unrelated" task. Although most previous work focusses on the *disruption* that task-irrelevant sound produces to focal task outcomes, few studies have focussed on such *facilitation* associated with task-irrelevant sound. In the current study we attempt to shed light on boundary conditions for these effects of semantic priming from task-irrelevant sound and relate this to the nature of nonconscious semantic processing.

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The irrelevant sound paradigm

A substantial body of work has focussed on understanding auditory selective attention (Arnell & Jolicoeur, 1999; Cherry, 1953; Treisman, 1964). Interest in our study centres on cross-modal selective attention where the focal task is in one sensory modality while distracters are presented in another modality. We utilise the irrelevant sound paradigm wherein participants are presented with to-be-remembered visual-verbal information (lists comprising 6–9 sequentially presented items such as digits, letters, or words) and are required to ignore sounds that are typically presented concurrently with the visual-verbal information or during a retention period prior to the test. The mere presence of task-irrelevant sound disrupts the serial recall of the visual-verbal information (Colle & Welsh, 1976)—a phenomenon coined the "irrelevant sound effect" (Beaman & Jones, 1997). This effect occurs for soft (e.g. 20 dBA) and loud (e.g. 76 dB(A) sounds; Alikadic & Röer, 2022; Colle, 1980; Ellermeier & Hellbrück, 1998; Tremblay & Jones, 1999) and occurs independently of the mere presence of phonology within the task-irrelevant sound or phonological overlap between sequences of to-be-remembered and task-irrelevant items (Jones & Macken, 1995; Marsh, Vachon, et al., 2008; but see Eagan & Chein, 2012).

Crucially, for the current investigation, the semantic characteristics of task-irrelevant sound lack the power to disrupt visual-verbal serial recall. For example, equivalent disruption of visual-verbal serial recall has been observed for English monolinguals exposed to English narrative and Welsh narrative and the narratives played in reverse (Jones et al., 1990; see also Marsh et al., 2009). Thus, the meaningfulness of the task-irrelevant sound to the participant is not a critically important ingredient of disruption. Similarly, task-irrelevant sequences of words are no more disruptive than sequences of non-words (Salamé & Baddeley, 1982) and the semantic similarity between the to-be-remembered items and task-irrelevant items produces little, if any, additional disruption to visual-verbal serial recall (Bridges & Jones, 1996; Buchner et al., 1996; LeCompte et al., 1997; Marsh, Hughes, et al., 2008; Marsh et al., 2009; Neely & LeCompte, 1999). Rather, pre-categorical, acoustic factors related to task-irrelevant sequences appear to drive the effect (Jones & Macken, 1993).

A key empirical signature of the irrelevant sound effect is the changing-state effect (Jones & Macken, 1993), which is the finding that acoustically variable irrelevant sound sequences, such as a stream of changing spoken letters (e.g. t, c, u, g) or tones of varied pitch (e.g. F#, B, C, A), produce greater disruption to serial recall performance than less acoustically variable sequences such as a stream of repeated "steady-state" speech sounds (e.g. g, g, g, g) or tones (e.g. B B B B). Changes within fundamental acoustic characteristics such as pitch and timbre, but not intensity (Alikadic & Röer, 2022; Tremblay & Jones, 1999), promote the additional disruption from changing-state as compared to steady-state sequences. The finding that pre-categorical, but not post-categorical (e.g. semantic) properties of sound drive the irrelevant sound effect, at first glance coheres with the notion that post-categorical properties of sound are filtered out (Broadbent, 1958, 1971), or at least attenuated (Treisman, 1964, 1969), at an early discrete processing stage and are thereby ineffective in contributing to the disruption of serial recall. However, at odds with the notion of early filtering or attenuation, is the increasing evidence that the post-categorical properties of task-irrelevant sound can influence later task performance (Hanczakowski et al., 2017; Richardson et al., 2022; Röer et al., 2017), which demonstrates that they are, in fact, processed.

Semantic interference by process

The finding that the semantic properties of task-irrelevant sound can influence performance on a later task, without disrupting concurrent task performance, gels with the interference-by-process account (Jones & Tremblay, 2000; Marsh et al., 2008, 2009; Meng et al., 2020). According to this account, the automatic seriation of acoustic changes within the task-irrelevant sound, as part of the perceptual streaming process (Bregman, 1990), disrupts the similar, but this time deliberate, process of encoding and maintaining the order of to-be-remembered items through subvocal serial rehearsal (Jones & Tremblay, 2000). This does not mean that the task-irrelevant sound does not undergo complete semantic processing; it may do so, but such post-categorical processing will not clash with the non-semantic vocal-motor seriation processes that underpin task performance, and hence leaves serial recall performance unscathed (Marsh et al., 2009).

The notion that task-disruption is a joint product of the nature of the background sound and the processes underpinning the prevailing focal task is supported by evidence that is accruing for a *semantic* interference-by-process. Here, the obligatory processing of the semantic properties of task-irrelevant sound disrupts performance when the focal task necessitates or encourages semantic processing (e.g. Beaman, 2004; Marsh, Hughes, et al., 2008; Marsh et al., 2009; Martin et al., 1988; Meng et al., 2020; Neely & LeCompte, 1999; Sörqvist et al., 2012; Vasilev et al., 2019). However, compelling evidence for the semantic processing of task-irrelevant sound, even in the absence of semantic processing for the focal task, has been obtained from a recent wave of studies. For example, Vachon et al. (2020) demonstrated that, compared with a sequence without a categorical deviation, the presence of a single categorical change in the content of a task-irrelevant stream of auditory items (e.g. horse, goat, cat, sheep, lemon, dog, tiger, pig) yields additional disruption of visual-verbal serial recall (see also Labonté et al., 2021; Littlefair et al., 2022). In contrast to semantic interference-by-process, this categorical deviation effect can disrupt performance even when the task does not rely on semantic processing (e.g. visuospatial serial recall; Vachon et al., 2020). As detection of a categorical change requires semantic processing of task-irrelevant sound, this finding offers evidence for the nonconscious processing of meaning (Vachon et al., 2020). Furthermore, processing of the shared categorical membership of items within a stream (e.g. the semantic relationship between the items *preceding* the categorical deviant; animals: horse, goat, cat, sheep) is necessary for the change in category to be detected.

The benefits of task-irrelevant sound for task performance

The study of Vachon et al. (2020) demonstrates semantic processing of task-irrelevant sound associated with a disruption to focal task performance. However, there is a small but growing number of studies demonstrating a *facilitation* of cognitive performance due to the presence of task-irrelevant sound (Ball et al., 2015; Hanczakowski et al., 2017; Richardson et al., 2022; Röer et al., 2017). For example, Hanczakowski et al. (2017) demonstrated that the semantic similarity between task-irrelevant items and to-be-remembered items, which usually disrupts free recall performance (Beaman, 2004; Marsh, Hughes, et al., 2015, Marsh, Sörqvist et al. Hughes, 2015; Marsh, Sörqvist & Hughes, 2015), can give rise to improved performance when lists comprising multiple categories (e.g. sheep, whisk, troll, blouse …) are presented and a category-cued recall test is adopted during retrieval. For example, in Experiment 2 of their series, to-be-remembered items were either presented synchronously with a task-irrelevant item drawn from the same category, or from an unrelated category. After list presentation, participants were given a category-cue and asked to produce the corresponding to-be-remembered item from the just-presented sequence. Recall of the to-be-remembered item was superior if it had been paired during study with a task-irrelevant item drawn from the same category, as compared to an unrelated category. This facilitation of task performance due to the semantic similarity between *concurrent* task-relevant and task-irrelevant streams is likely to result from the similarity in the processing characteristics applied deliberately to the to-be-remembered material and automatically to the sound (Hanczakowski et al., 2017). However, there is also important emerging evidence for obligatory semantic processing of task-irrelevant sound in the absence of focal semantic processing, in the form of enhanced production of responses due to earlier presented distractors (Richardson et al., 2022; Röer et al., 2017).

Using a priming paradigm, Richardson et al. (2022) demonstrated semantic priming of homophone interpretation via the processing of task-irrelevant sound (cf. Eich, 1984). In the context of a visual-verbal serial recall task, participants were presented with task-irrelevant sound comprising sequences of associates of the non-dominant meaning of a homophone, wherein the homophone was either presented or not. Furthermore, this task-irrelevant sound was either meaningful (i.e. presented normally) or meaningless (i.e. reversed, thereby rendering the semantic content unintelligible). On a subsequent, ostensibly unrelated, spelling task, homophones were spelt with their non-dominant interpretation if the task-irrelevant meaningful speech comprised associates of the non-dominant homophone regardless of whether the homophone was included. Such priming was absent if the earlier task-irrelevant speech was meaningless. Furthermore, the priming of the non-dominant spelling of homophones following exposure to the task-irrelevant meaningful speech occurred in the absence of self-reported awareness. Given that the priming of the non-dominant homophone interpretation occurred via the presentation of merely its semantic associates, the findings suggest that the activation of task-irrelevant items spreads to other non-presented items, including the non-dominant homophone itself. Thus, the findings of Richardson et al. (2022) cast light on the nature of nonconscious semantic processing and are consistent with the notion that a spreading activation mechanism operates to enable nonconscious processing of sequences of two or more words (cf. Greenwald, 1992).

Relevant to the current study, Röer et al. (2017) presented sequences of eight category-exemplars in a forward direction (meaningful), or a reverse direction (meaningless), in the context of visual-verbal serial recall. The meaningful distracters were no more disruptive than the meaningless ones. However, participants produced previously presented category-exemplars with a higher probability than a matched set of previously non-presented category-exemplars on a category-exemplar production task that the participants were informed was unrelated to the visual-verbal serial recall task. The consistent finding emerging from both Röer et al. (2017) and Richardson et al. (2022) is that, notwithstanding being "task-irrelevant", distracter words are processed semantically despite their failure to disrupt visual-verbal serial recall and, as such, they can influence behaviour on subsequent tasks.

The priming study of Röer et al. (2017) provides strong evidence for the semantic processing of irrelevant sound. Two features of the study, however, need to be addressed. First, only task-irrelevant meaningful speech and quiet trials were presented during serial recall—the comparison between the action of meaningful and meaningless speech was manipulated between-participants. Therefore, the semantic priming observed could be explained by the fact that the task-irrelevant category-exemplars are salient during the serial recall task. Indeed, given that meaningful speech was the only type of auditory stimulation encountered during the experiment, one can assume the contrast with the silent background of quiet trials was greater—hence making it more salient—than when other task-irrelevant conditions (e.g. meaningless speech) are implemented. Such saliency may render the exemplars distinctive (and thus readily accessible) during the category-exemplar production task. Second, whether the semantic priming occurred due to the shared categorical relationship between the category-exemplars within the task-irrelevant sequence, or their specific identities (i.e. individual meanings) could not be determined. Researchers (e.g. Greenwald, 1992) are often sceptical about whether nonconscious processing can occur for multiple word stimuli. On this view, priming at the level of individual word meaning should occur to a similar degree regardless of the semantic context of the task-irrelevant sequence.

A third feature of the study that may cast some doubt over its conclusions is that, for the category-exemplar production task, only the categories from which task-irrelevant exemplars were previously presented were used. It is possible that, combined with the salience of the meaningful speech, participants used explicit retrieval strategies to recall category-exemplars. This would undermine the notion that priming reflects implicit processing related to the earlier nonconscious semantically processing of task-irrelevant speech (Richardson et al., 2022).

If the semantic priming effect observed in Röer et al. (2017) is not produced via explicit retrieval strategies and truly reflects evidence of nonconscious semantic processing, then it would be useful to determine the nature of that processing. One possibility is that the priming emerges due to the post-categorical processing of the identities of each word, thereby increasing their accessibility for retrieval in the category-exemplar production task. On this view, equivalent semantic priming should be observed regardless of whether the items are organised according to semantic categories within task-irrelevant sequences. That is, equivalent priming should be observed from sequences comprised of many items, each of which is drawn from a different category.

On the other hand, semantic priming of responses in the category-exemplar production task may emerge from processing the items and their categorical membership. When attended, there are well-known effects of semantic organisation on recall. For example, unless instructed to process properties of items that are not shared by other list items (item-specific processing), participants will process the dimension common to all items within a list (relational processing; Einstein & Hunt, 1980; Hunt & Einstein, 1981). Further, the blocked-random effect (D'Agostino, 1969) refers to the finding that categorical-clustering (Bousfield, 1953)—the recall of category-exemplars according to their category—for a list of category-exemplars drawn from several categories, is more pronounced when the exemplars are arranged by semantic category during list presentation, as compared to randomly presented. Category-clustering is taken as an index of the use of pre-existing conceptual relationships or semantic associations to guide encoding and retrieval processes (Marsh et al., 2009).

Current study

The present study sought to determine the nature of priming by task-irrelevant sound in a subsequent task involving category-exemplar production. To reduce the overall salience of the task-irrelevant material during the visual-verbal serial recall task, semantic primes were presented as either meaningful or meaningless irrelevant speech. The addition of a meaningless speech condition was assumed to reduce the salience of meaningful speech because meaningful speech was no longer the only type of auditory stimulation to break the silence of quiet trials. Furthermore, the category-exemplar production task required production of exemplars from categories presented as both meaningful and meaningless irrelevant speech. Since meaningless (reversed) speech lacks the intelligibility of language, in this case semantics, it is unlikely that participants will explicitly attempt to retrieve category-exemplars from task-irrelevant sequences that were earlier presented. However, we suggest that the presence of these categories as fillers during the category-exemplar production task may serve to reduce the likelihood of participants noticing a relationship between the category-exemplars presented as distracters in the visual-verbal serial recall context and the category-exemplar production task, and therefore the use of explicit retrieval strategies to deliberately generate earlier presented category-exemplars. The inclusion of filler category-names in the context of the category-exemplar production task serves the purpose of disguising the connection between the two phases (i.e. study and test) of the experiment (Prull et al., 2016).

Nevertheless, as a precaution and to further investigate any potential contamination of "implicit" priming via explicit retrieval processes, we also include questions concerning explicit memory so that we can, at least in part, determine the extent of any such contamination (cf. Mulligan, 2002). Furthermore, insights provided by the questions will give a window onto the extent of irrelevant sound processing, even in the absence of (or only weak evidence for) disruption to visual-verbal serial recall that is attributable to the semantic features of the task-irrelevant material.

Crucial to the current investigation was the aim of providing insight into the nature of the processing of irrelevant sound that underpins semantic priming (Röer et al., 2017). To this end, we manipulated the semantic organisation of the task-irrelevant material: streams were either composed of eight different category-exemplars drawn from one category, or eight different category-exemplars drawn from eight distinct categories. Based on converging evidence from previous work (Bentin et al., 1995; D'Agostino, 1969; Einstein & Hunt, 1980; Masson, 1995; Richardson et al., 2022; Saint-Aubin & Poirier, 1999; Vachon et al., 2020), we predicted that semantic priming would be evident when the presentation of category-exemplars is blocked by semantic category, but attenuated or absent when category-exemplars are randomly presented. However, we contrasted this viewpoint with the notion that nonconscious semantic processing cannot occur for multiword stimuli (e.g. Greenwald, 1992) and that the semantic priming effect observed (e.g. Röer et al., 2017) is attributable to the nonconscious semantic processing of singular lexical-item identities. On this view, semantic priming arising from a task-irrelevant item should be equivalent regardless of the semantic context (the task-irrelevant stream of items) within which it is presented.

Method

Design

A mixed design was adopted for the study. The within-participants component incorporated two phases. In Phase 1, participants completed a visual-verbal serial recall task in quiet or in the presence of meaningful or meaningless irrelevant speech. The meaningful speech condition entailed the presentation of category-exemplars, while the meaningless speech condition involved different exemplars from the same category played in reverse. The between-participants component was whether the meaningful speech comprised category-exemplars drawn from a single semantic category, or one from eight different semantic categories. In summary, the independent variables were thus organisation, which had two levels (blocked vs. random presentation) and was manipulated between-participants, and sound condition, which had three levels (quiet, meaningful speech, meaningless speech) and was manipulated within-participants. The dependent variable was serial recall performance.

Phase 2 involved a category-exemplar production task to measure whether semantic priming occurred from the irrelevant speech that was presented in Phase 1. The dependent variable was semantic priming, as reflected by the frequency of production of category-exemplars arising from those presented in meaningful and meaningless conditions and an unheard set of category-exemplars matched for production frequencies in a prior norming study.

Participants

120 participants were recruited for the current study via opportunity sampling. All participants spoke English as a first language and reported normal, or corrected-to-normal, vision and normal hearing. They received course credits or a small honorarium for completing the study. Sixty participants were allocated to the blocked condition (48 females, 12 males; mean age = 26.12 years, $SD = 8.92$) and 60 participants to the random condition (48 females, 12 males; mean age = 22.03 years, $SD = 6.48$). Ethical approval for the study was granted by the University of Central Lancashire Ethics Committee, which adheres to the British Psychological Society Code of Ethics.

Since the most important effect within the current study related to the priming status by organisation interaction, a sensitivity analysis was performed in G*Power (Faul et al., 2007). Given a sample size (N) of 120 and $\alpha = \beta = 0.05$, 2 groups (blocked vs. random) and 2 measurements (primed vs. unprimed), and assuming a population correlation of rho = 0.5 between the two levels of the repeated measures variable, an effect of size $f = 0.17$ (between small and medium effects according to Cohen's [1988] benchmarks) could be detected.

Apparatus

Auditory sequences were presented via headphones at a sound level of approximately 65 dB[A]. The experiment was executed on a PC running an E-Prime 2.0 program (Psychology Software Tools) that controlled stimulus presentation.

Materials

Auditory task-irrelevant stimuli

A total of 16 exemplars were sampled from each of 16 categories. In each category, the eight most frequently produced exemplars were not sampled to guard against the possibility of ceiling effects in the semantic priming measure (see later). The categories were a subset of categories used in a category-norming study using a UK sample, undertaken by the corresponding author (cf. Van Overschelde et al., 2004). The categories were divided into two sets of eight based on the category potency measure (a single mean for each category computed by taking the total number of responses produced for a category divided by the total number of participants providing responses to that category) reported by Van Overschelde et al. (2004). Set 1 included Fruit, Flowers, Animals, Building Parts, Fish, Weather Phenomena, Natural Earth Formations, and Insects which had a mean category potency measure of 6.13 ($SD = 1.01$). Set 2 included Musical Instruments, Substances for Flavouring Food, Sports, Articles of Furniture, Types of Fabric, Birds, Reading Materials and Vegetables and had a mean category potency measure of 6.26 ($SD = 0.97$). The two sets did not differ on Category Potency, $t(14) = -0.28$, $p = 0.79$, or on the total number of responses generated for each category (computed prior to removing the eight most frequent responses; $M = 74.87$, $SD = 25.75$ for Set 1, and $M = 74.00$, $SD = 14.10$ for Set 2, $t[14] = 0.084$, $p = 0.93$). The 16 category-exemplars chosen for each of the 16 categories were further divided into sets of eight category exemplars to create Set 1A, Set 1B, Set 2A and Set 2B versions. For example, Set 1, Version A contained the category fruit (i.e. melon, peach, blueberry, lemon, cherry, blackberry, satsuma, apricot) and Set 1, Version B also contained the category fruit but with different exemplars (i.e. plum, raspberry, mango, pomegranate, grapefruit, lime, nectarine, lychee).

The two different category sets and versions were matched on the frequency with which an exemplar is given as an example of a category from our UK category-norming study (output dominance; $M = 14.906$, $SD = 6.14$, Set 1A; $M = 14.83$, $SD = 5.98$, Set 1B; $M = 15.23$, $SD = 6.14$, Set 2A; $M = 15.16$, $SD = 6.31$, Set 2B). With version (A vs. B) as the within-participant factor, and Set (1 vs. 2) as the between-participants factor, for output dominance there was no between-participants main effect of Set (e.g. 1 or 2), $F(1, 14) = 0.011$, $MSE = 75.42$, $p = 0.92$, . = 0.001, or version (A vs. B), $F(1, 14) = 1.045$, $MSE = 0.047$, $p = 0.324$, . = 0.069, and the interaction between set and version was also not significant, $F(1, 14) = 1.00$, $MSE = 0.047$, $p = 0.1$, . < 0.001. This statistically supports that the mean output dominance was matched between the two different category sets (Set 1 and 2) and versions (A and B). The two different category sets and versions were also matched on the number of syllables ($M = 2.08$, $SD = 0.48$, Set 1A; $M = 2.09$, $SD = 0.44$, Set 1B; $M = 2.06$, $SD = 0.31$, Set 2A; $M = 2.05$, $SD = 0.26$, Set 2B). This was confirmed via a mixed ANOVA with version (A vs. B) as the within-participant factor and set (1 vs. 2) as the between-participant factor. This revealed no main effect of set, $F(1, 14) = 0.027$, $MSE = 0.292$, $p = 0.87$, . = 0.002, or of version, $F(1, 14) < 0.001$, $MSE = 0.004$, $p = 0.997$, . < 0.001, and no interaction between set and version, $F(1, 14) = 0.445$, $MSE = 0.002$, $p = 0.516$, . = 0.031.

For Phase 1 (i.e. the visual-verbal serial recall) the allocation of sets and versions to participants was counterbalanced such that equal numbers (15) of participants in the random and blocked condition received Set 1A, Set 1B, Set 2A and Set 2B as task-irrelevant sound.

The presentation order of the category-exemplars within each set and version was presented in a fixed order according to decreasing output dominance. This fixed order was used to create the lists for the random condition wherein one item from each of the eight levels of output dominance appeared in each list. For example, in Set 1A the sequence of Animals was "giraffe, rabbit, mouse, goat, bear, hippopotamus, cheetah, wolf" for the blocked condition. For the random presentation condition, an example sequence is "giraffe, buttercup, blueberry, woodlouse, stone, typhoon, starfish, cellar". Note that across sequences for the blocked and random presentation conditions, a given exemplar always occurred in the same position (e.g. giraffe was presented first, regardless of whether it occurred in a blocked or random sequence). This was undertaken to control for any effect of item position in a sequence on semantic priming of individual exemplars. During the category production task in Phase 2, participants were required to generate responses to the eight categories from which auditory distracters were drawn in Phase 1 and the eight categories that had not been previously exposed. See Appendix 1 for details of the category-exemplars presented according to Set and Version.

Auditory distracters were digitally recorded using Sound Forge (Sony Inc.) in an approximately evenpitched male voice in 16-bit, with a sampling rate of 44 kHz. The task-irrelevant sequences were eight seconds in duration with distracters being presented at a rate of one per second. Task-irrelevant sequences were presented binaurally to participants across wired Sennheiser HD-202 stereo headphones at approximately 65 dB (A) and were presented at the onset of the visual sequence of to-be-remembered digits.

Meaningless versions of each sound sequence were created by time-reversing each category-exemplar within a sequence. The order of the category-exemplars for each irrelevant sequence was the same regardless of whether they were presented in a forward (meaningful) or reverse (meaningless) direction. Participants who were allocated a particular set and version (e.g. Set 1A) were subjected to both the meaningful and meaningless sequences, to closely match the acoustic properties of the sequence types. For example, when the meaningful irrelevant sequences presented to a participant were drawn from Set 1A, the meaningless sequences comprised the same category-exemplars in the same order but presented in reverse.

Category-exemplar production test

Phase 2 of the study consisted of the presentation of category labels (e.g. "Vegetables") and a text box with eight bullet points for participants to produce the required number of words for each category. The category labels appeared in black 72-point Arial font on a white background. The exemplars produced by participants appeared in 36-point Arial font. The dependent measure was degree of priming, measured by recalled responses to, for example, Version A exemplars, relative to Version B exemplars for the set the participant received. For example, if a participant received Set 1A, priming was computed by comparing the frequency with which category-exemplars from Set 1A were produced relative to Set 1B. However, priming was also computed by comparing the frequency with which Set 1A responses were produced relative to Set 2A responses and Set 2B responses that were not primed at all, and hence were dummy coded.

Serial recall task

For each trial, eight digits from the set of 1–9 were sampled pseudo-randomly without replacement, by ensuring that each integer was omitted from the list approximately the same number of times throughout the block. The constraints were that no sequence could begin with a 1, that there could be no repeats of a digit, and that no ascending or descending runs of digits could occur within a sequence. The digits were presented individually in the centre of a white screen, in a black 72-point Arial font. Digits were presented at a rate of one per second (250 ms on, 750 ms off).

Procedure

Participants were given verbal and written instructions. They were also told that they could withdraw from the study at any time without penalty.

Phase 1—Serial recall task

In Phase 1, participants were told that they would be presented with random permutations of eight digits sampled, without replacement, from the set 1–9 and that they were required to remember and reproduce the sequence of numbers in their order of presentation. They were also told that they would sometimes be presented with sounds over their headphones that they should ignore. To begin this phase, participants completed two practice trials in quiet, which were not analysed. Next, the participants undertook 24 experimental trials comprising eight meaningful speech trials, eight meaningless speech trials and eight quiet trials presented in a randomised order.

After each trial, participants were presented with a screen showing the set of digits (1–9) in canonical order. Participants were instructed to select the digits in the order in which they were presented using a mouse-driven pointer. No accuracy feedback was given. Digits could not be deselected once they had been selected, thus no revision of the to-be-remembered sequence was allowed. The next trial started automatically once all eight digits had been selected.

Participants were asked not to rehearse aloud during presentation of the to-be-remembered stimuli.

Phase 2—Category-exemplar production task

Participants were informed that Phase 2 of the study was unrelated to the first part and was a category-norming study. Participants were presented with 16 category-names, eight of which corresponded to the category from which category-exemplars had been drawn in Phase 1 of the study. The other eight categories functioned as "fillers" and served to disguise the purpose of Phase 2, as well as later providing an independent index of priming that was free from prior exposure to a category. Participants were presented with one category name at a time and were requested to produce the first eight words that came to mind from each category by typing the words into a response box on the computer screen. Once participants had produced all eight words for a category, they were asked to press "0" to be presented with the next category. There was no time limit for the category-exemplar production task.

Post-experimental phase

On completion of all trials in Phase 2, participants answered an awareness questionnaire. This comprised a series of three questions that became increasingly more specific and were designed to investigate whether participants were aware of the relationship between the first and second experimental phase. The three questions were:

> "In order to produce the words, did you deliberately try to recall any words that you may have heard earlier when you were doing the digit short-term memory task? Y/N" "If you thought you were deliberately trying to recall words that you heard earlier when you were doing the digit short-term memory task, how often do you think you were doing this? Respond between 1–7 where 1 = *none of the time*, 7 = *all of the time*".

> "Were you aware that any of the words you were producing were presented earlier as speech when you did the digit short-term memory task? Respond between 1–7 where 1 = *not aware at all*, 7 = *completely aware*".

Results

In this results section, we present Cohen's *dz* for within-participant comparisons and Cohen's *d* for between-participant comparisons to indicate effect size. Additionally, Bayes factors were calculated using the default standard Cauchy prior width of 0.707 in JASP (version 0.17.3; jasp-stats.org).

Serial recall task (Phase 1)

Data for the serial recall task were scored according to a strict serial recall criterion, whereby responses were scored as correct only if the digits were reproduced in accordance with the serial position that they had occupied during presentation. Data were collapsed across serial position to provide means for analysis.

Figure 1 demonstrates evidence of an irrelevant sound effect: more errors were committed following presentation of irrelevant speech as compared to a quiet control condition. Further, there did not appear to be any additional disruption following the presentation of meaningful (forward) speech as compared to meaningless (reversed) speech.

A 3 (sound condition: quiet vs. meaningless speech vs. meaningful speech) × 2 (organisation: blocked vs. random presentation) mixed ANOVA revealed a main effect of sound condition, $F(2, 236) = 129.383$, $MSE = 0.009$, $p < 0.001$, . = 0.588, but no main effect of organisation, $F(1, 118) = 0.379$, $MSE = 0.064$, $p = 0.379$, . = 0.007, nor a sound condition × organisation interaction, $F(1, 118) = 0.588$, $MSE = 0.011$, $p = 0.445$, . = 0.005. Pairwise comparisons revealed a significant difference between quiet and meaningless speech, $p < 0.001$, 95% CI [0.148, 0.196], $dz = 1.187$, $BF_{10} = 2.936 \times 10^{+21}$, and between quiet and meaningful speech, $p < 0.001$, 95% CI [.148, 0.201], $dz = 1.295$, $BF_{10} = 1.510 \times 10^{+24}$, but not between meaningless speech and meaningful speech, $p = 0.876$, 95% CI [−0.021, 0.025], $dz = 0.014$, $BF_{01} = 9.750$. The conclusions did not change when set was included as a variable in the analysis (see Supplementary Analyses Document).

Category-exemplar production task (Phase 2)

Our analyses closely followed those of Röer et al. (2017). We first computed how often participants produced the eight highest output-dominant category-exemplars that were excluded from Set 1 and Set 2 when the materials were prepared. These were calculated as a proportion of the number of responses generated for each category in the context of the category-exemplar production task. Thus, if participants produced the high output-dominance exemplars "banana", "pear" and "apple" but none of the other five high output-dominance exemplars among their eight responses during category-exemplar production, the score would be 3/8 = 0.375. Similarly, the production frequencies of the items assigned to Set 1A, Set 1B, Set 2A, and Set 2B were computed by summing how many were produced from each category within each set and dividing them by the overall number of exemplars per category produced. A mean score was computed for each condition by averaging across the eight trials.

For the highest output-dominance exemplars, the mean scores (collapsed across the organisation and priming status variables) were 0.528 ($SE = 0.008$) for Set 1 and 0.532 ($SE = 0.007$) for Set 2. There was no difference in the production frequencies of the highest output-dominance exemplars from the two sets, $t(119) = 0.385$, $p = 0.701$, $dz = 0.035$, $BF_{01} = 9.175$. Collapsing across set, an ensuing 2 (organisation: blocked vs. random presentation) × 2 (priming status: primed vs. unprimed) mixed analysis of variance on the production frequency data showed no between-participants main effect of organisation, $F(1, 118) = 0.054$, $MSE = 0.010$, $p = 0.817$, . = 0.000, or priming status, $F(1, 118) = 1.079$, $MSE = 0.004$, $p = 0.301$, . = 0.009, and no interaction between these variables, $F(1, 118) = 1.968$, $MSE = 0.004$, $p = 0.163$, . = 0.016. Thus, the production frequencies of high output-dominant items were not influenced by

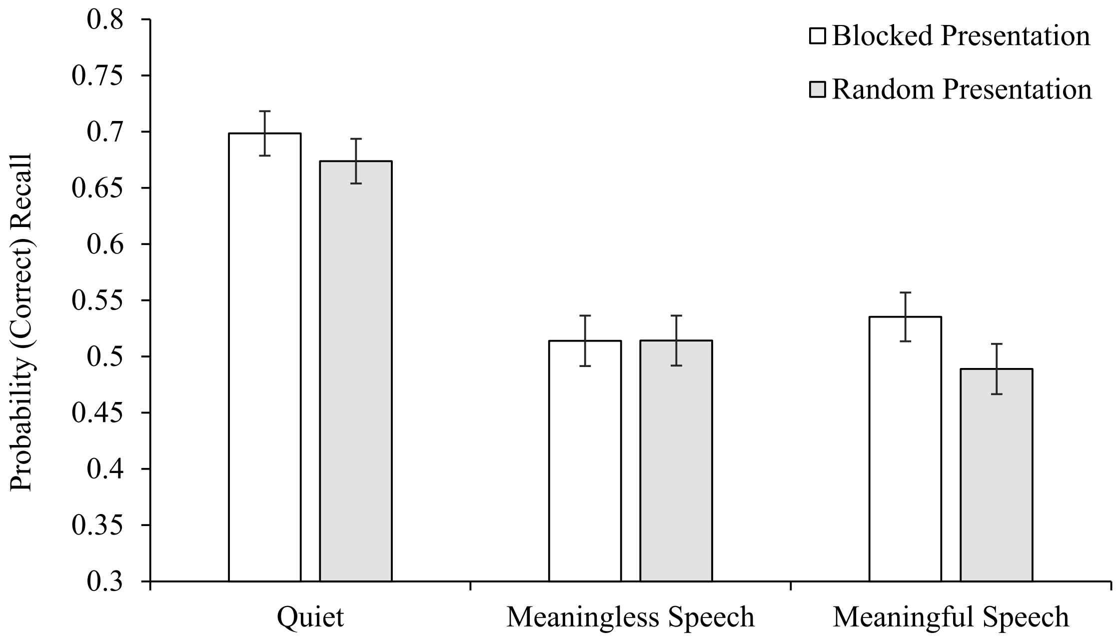

Figure 1. Mean proportion of items correctly recalled in the visual-verbal serial recall task as a function of sound condition (quiet, meaningless speech, meaningful speech) and organisation (blocked vs. random presentation). Error bars represent the standard error of the means.

whether a test category belonged to a category from which exemplars had been primed. Further analyses (see Supplementary Analyses Document) found no evidence of systematic differences between the different sets and versions of the category-exemplars deployed within the study.

Next, we moved on to investigate whether semantic priming had occurred. The most straightforward way to determine priming is to investigate whether the production frequencies of Version A responses, differed from those of Version B whereby A and B responses are both drawn from the same (primed) semantic category. For example, recall that the category-exemplars in Set 1B were drawn from the same semantic category as the Set 1A category-exemplars—that for other participants served as distractors—but had not previously been heard by the participants as distractors in the context of the serial recall task.

Figure 2 demonstrates evidence of a semantic priming effect: more category-exemplars were produced following their earlier presentation as irrelevant speech compared to the control condition. However, this priming effect appeared to be observed only for blocked presentation. To investigate whether this pattern was borne out with inferential statistics, a 2 (organisation: blocked vs. random presentation) × 2 (priming status: primed vs. unprimed) mixed analysis of variance was undertaken. This confirmed a main effect of priming status, $F(1, 118) = 23.503$ $MSE = 0.006$, $p < 0.001$, . = 0.166: participants produced category-exemplars from the previously ignored set with a higher probability ($M = 0.169$; $SE = 0.008$) than category-exemplars from the comparison set ($M = 0.121$, $SE = 0.004$). There was also a main effect of organisation, $F(1, 118) = 17.464$, $MSE = 0.003$, $p < 0.001$, . = 0.129: production frequencies were higher with blocked presentation ($M = 0.16$, $SE = 0.008$) than with random presentation ($M = 0.131$, $SE = 0.004$). Crucially, there was a significant priming status × organisation interaction, $F(1, 118) = 13.605$, $MSE = 0.006$, $p < 0.001$, . = 0.103. A simple effects analysis (LSD) revealed higher production rates for primed versus unprimed items for the blocked presentation condition, $p < 0.001$; 95% CI [.057, 0.113], Cohen's $dz = 0.618$, $BF_{10} = 1582.958$, but not the random presentation condition, $p = 0.414$; 95% CI [−0.016, 0.039], Cohen's $dz = 0.165$, $BF_{01} = 3.267$. Further, primed items had a higher production frequency in the blocked presentation condition against the random presentation condition, $p < 0.001$; 95% CI [.036, 0.097], Cohen's $d = 0.786$, $BF_{10} = 557.562$, whereas the production frequency of unprimed items did not differ between conditions, $p = 0.362$; 95% CI [−0.023, 0.008], Cohen's $d = -0.167$, $BF_{01} = 3.522$. Thus, priming only arose when the primed (i.e. previously presented task-irrelevant exemplars) were organised by semantic category. These conclusions held when set and version were included within the analysis (see Supplementary Analyses Document).

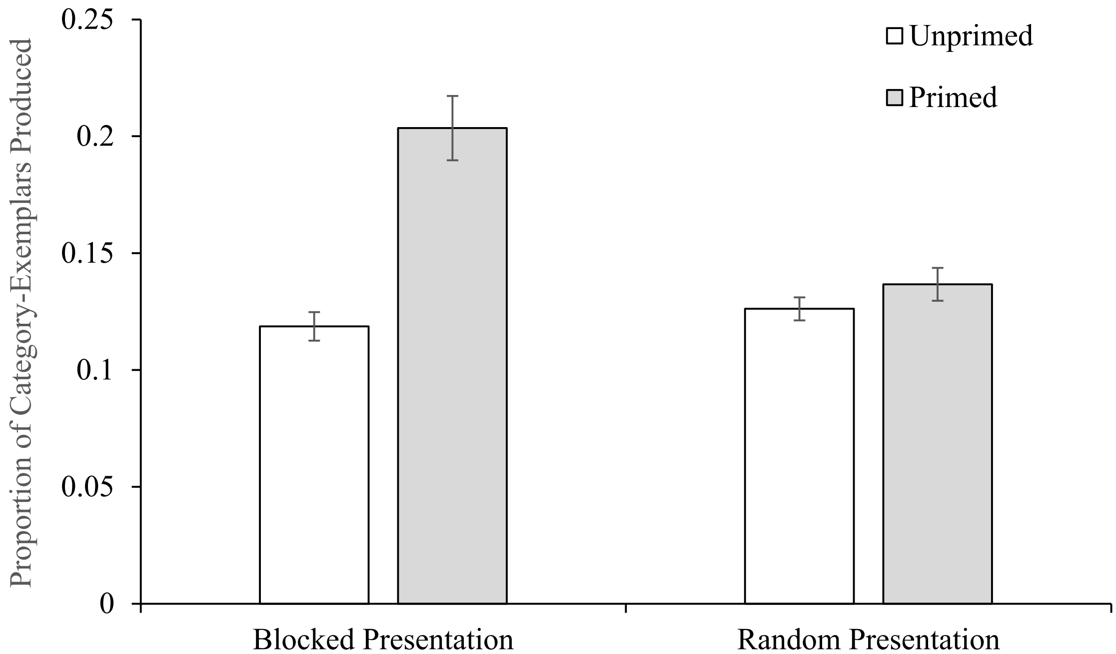

Figure 2. Mean proportion of category-exemplars produced according to priming status in Phase 2 of the experiment. Error bars represent the standard error of the means.

It should be noted that there are several alternative ways to compute priming that are *independent* of computing priming based on the proportion of unprimed and primed category-exemplars *within* a category. For example, the production frequencies of primed category-exemplars with a matched set of category-exemplars from different categories can be compared, whereby neither the category, nor exemplars, have been previously experienced as distractors materials. Our supplementary analysis showed that regardless of the method of computing priming, the results pointed to the same conclusion (see Supplementary Analysis Document).

To investigate whether there was an association between the magnitude of semantic priming and individual differences in vulnerability to disruption produced by meaningful task-irrelevant speech in the context of the serial recall task, we computed two difference scores. First, we subtracted the mean scores for the meaningful speech condition from that of the meaningless (reversed) speech condition in Phase 1, which generated an index of vulnerability to disruption attributable to the meaning of irrelevant speech. Second, we computed a semantic priming index by subtracting the mean production frequency for unprimed and non-primed category exemplars from that of the primed category exemplars. This semantic priming index was created by using the production frequency of the non-presented set of exemplars drawn from the same category as the primed exemplars as the baseline (e.g. Set 1B when Set 1A was primed). This vulnerability and semantic priming index were then correlated with one another. The resulting Pearson's correlation tests revealed no significant correlation between vulnerability scores and priming for blocked presentation distractor sequences, $r(58) = -0.018$, $p = 0.892$. There was a significant correlation between vulnerability scores and priming for random presentation distractor sequences, $r(58) = 0.268$, $p = 0.038$. Thus, there was weak evidence that susceptibility to disruption via the semantic properties of speech was associated with greater semantic priming, but only in the random presentation condition.

Awareness Questionnaire

The data from the awareness questionnaire demonstrate that participants claimed they were not deliberately trying to retrieve words heard earlier, even though a small proportion of participants responded that they sometimes tried to recall earlier heard words. Further, most participants were unaware that any of the words they produced during the category-exemplar production task had earlier been presented as speech during the serial recall task. Given these small numbers, we were unable to categorise enough participants as aware versus unaware for a meaningful analysis as to whether awareness was related to the magnitude of semantic priming (cf. Richardson et al., 2022).

Table 1. Summary of the responses from the Awareness Questionnaire given in the study. The question text has been truncated to fit the table.

		Response								
Question	Condition	Yes	No	1	2	3	4	5	6	7
Deliberate recall of previously heard words?(Yes/No)	Blocked		60							
	Random		60							
If deliberately recalled, how often? (1 never—7 always)	Blocked			59	1					
	Random			54	4	2				
Aware recalled words were heard earlier? (1 not aware—7 completely aware)	Blocked			47	3	3	2	1	3	1
	Random			44	6	3	3	2	1	1

General discussion

This study was undertaken to investigate the boundary conditions for the emergence of semantic priming from task-irrelevant sound and to characterise its nonconscious post-categorical (semantic) processing. To address this, participants were presented with meaningful and meaningless irrelevant speech while performing a visual-verbal serial recall task. In a between-participants manipulation, the meaningful speech comprised eight exemplars that were drawn from a single semantic category, or from eight different semantic categories. Semantic processing of the task-irrelevant speech was determined via a category-exemplar production task that participants were informed was unrelated to the previously undertaken serial recall task. The results were compelling. There was clear evidence that the production frequencies of items in the category-exemplar production task were *facilitated* by their presence within previously heard task-irrelevant speech. However, this semantic priming was only observed when the category-exemplars were blocked by semantic category during presentation, as compared to randomly presented. This suggests that organisation is a boundary condition for the manifestation of semantic priming from task-irrelevant speech as measured with the category-exemplar production task. Further, the failure to observe disruption via the meaning of speech on visual-verbal serial recall suggests that the semantic priming effect observed from task-irrelevant speech in the context of category-exemplar production arises in the absence of its propensity to disrupt earlier online focal task performance.

The current study was also undertaken to address the notion that the semantic priming observed by Röer et al. (2017) was attributable to the salience of the distracter sequences. In the current study meaningful (conveying intelligible primes) and meaningless speech sequences were manipulated within-participant rather than between-participants as in Röer et al. This arguably reduces the salience of the task-irrelevant category-exemplars during the serial recall task at Phase 1, diminishing their distinctiveness and accessibility to explicit retrieval processes. The fact that semantic priming was obtained in the blocked condition of the current study undermines the view that the salience of category-exemplars drove the semantic priming effect observed in Röer et al.'s study. Additionally, the current study addressed whether the occurrence of semantic priming observed by Röer et al. depended on using only the categories from which task-irrelevant exemplars were previously presented in the category-exemplar production task in Phase 2. In our study, participants generated category-exemplars from 16 categories, only eight of which matched the categorical membership of task-irrelevant exemplars presented prior. Arguably our method reduces the probability of participants consciously connecting Phases 1 and 2, and therefore the use of explicit retrieval strategies to recall category-exemplars. Coupled with data from the awareness questionnaire (cf. Mulligan, 2002)—which found no evidence that the primes were produced via explicit retrieval processes (e.g. conscious recollections)—our results lean toward the view that the semantic priming from irrelevant speech we observed in the blocked condition of our study reflects an implicit process.

The results of the current study shed light on the nature of the semantic processing of task-irrelevant items. The finding that semantic priming emerged for blocked but not random presentation of category-exemplars is at odds with the view that the post-categorical identities of each word are processed within a task-irrelevant stream (e.g. Marsh et al., 2014; Underwood & Everatt, 1996). If post-categorical processing of individual identities occurred regardless of their categorical membership, then at least some semantic priming would have been expected in the random presentation condition. We explore some possibilities for this absence of priming later in the discussion. The data are more consistent with the notion that nonconscious, cumulative semantic priming occurs for items within the task-irrelevant sequence when they share categorical membership. Processing semantic associations between same-category items within the task-irrelevant sequence explains why semantic priming, via task-irrelevant speech, occurs when the list comprises items drawn from one semantic category, but not eight different categories, even though across the entire experiment participants are exposed to the same task-irrelevant items. That semantic priming occurs due to the shared categorical membership between task-irrelevant exemplars within the auditory sequence provides evidence that nonconscious processing can occur for stimuli comprising multiple words (cf. Greenwald, 1992). Although the semantic priming effect observed in category-exemplar production was dependent on blocked against random presentation of category-exemplars, this might not be a precondition for priming effects using different tasks such as lexical decision (Meyer & Schvaneveldt, 1971), or word-stem competition (Jacoby & Dallas, 1981), and this requires further exploration.

The findings are compatible with spreading activation theories (e.g. Anderson, 2007; Anderson et al., 1996), according to which semantic knowledge is represented in a network of semantically related items, with this network being distinct from, but connected to, a lexical network. Localised items within the semantic network are linked based on previous experience, with such items interacting with one another to improve, or impede, recall. Presentation of one category-exemplar activates an item above a threshold level but also activates other semantically related exemplars within a localised semantic network. This explains why lists of semantically related words are better remembered than lists comprising unrelated words (e.g. Poirier & Saint-Aubin, 1995; Saint-Aubin & Poirier, 1999): recurrent spreading activation between the items maintains higher activation levels than for lists of unrelated items and, as activation governs recall, categorically related lists of words are better recalled than lists of unrelated items.

In classic semantic priming experiments (see Neely, 1991, for a review), responses to targets (e.g. cat) are faster when immediately preceded by a semantically related prime (e.g. dog), compared to a semantically unrelated prime (e.g. lorry). In addition, including a semantically unrelated item that intervenes between the prime and target (e.g. cat—lorry—dog), removes the facilitation (Masson, 1995). According to one account, the intervening item resets activation in (e.g. feature) nodes that are shared between two semantically related words (Masson, 1995).

The results of the current study provide support for the view that semantic processing occurs in a similar way for task-irrelevant streams of items as it does for attended streams of items (e.g. Bentin et al., 1995; Richardson et al., 2022). In this way, blocking the presentation of task-irrelevant category-exemplars by semantic category produces sequential, cumulative semantic priming that enhances activation between the list of task-irrelevant items, relative to non-presented items from the same category, within a network of interconnected nodes (Collins & Loftus, 1975; Nelson et al., 1998; Nelson & Zhang, 2000; see also Oberauer, 2002). This finding coheres with previous work that provides indirect support (Labonté et al., 2021; Littlefair et al., 2022) and direct support (Vachon et al., 2020) for the nonconscious extraction of the categorical membership between successively presented items, possibly because of cumulative semantic priming (or relational processing; Einstein & Hunt, 1980). Further, this account also explains why priming was not observed between unrelated items when the task-irrelevant stream consists of exemplars drawn from different categories—where cumulative semantic priming was not possible.

It is important to note that the findings of the current study are also compatible with global memory models (e.g. MINERVA2; Hintzman, 1984; TODAM; Murdock, 1993; SAM; Raaijmakers & Shiffrin, 1992). For example, according to MINERVA2 (Hintzman, 1984), task-irrelevant items may be automatically encoded into memory traces, albeit weaker, or with less detail, compared to attended items. Like attended stimuli, task-irrelevant items will be represented by vectors of features but may have lower activation levels. When, the category-name is presented during the category-production task it activates related traces in memory even if those traces are formed from the task-irrelevant stimuli. The category-name cue therefore resonates with all similar traces within a memory space including those from attended and task-irrelevant sources. This resonance is based on feature similarity as well as the strength of a trace. Further, activation of the traces produced by the category-cue may be weaker, but they can still contribute to the generation of an "echo" that represents a composite of all activated traces that is weighted by their similarity to the retrieval cue. The echo can be influenced by task-irrelevant information leading to the subtle priming effects observed in the current study. The weak traces derived from task-irrelevant stimuli cumulatively contribute to enhance the accessibility of related concepts. That priming occurs with blocked but not random presentation may be influenced by context—information that shares context (e.g. a temporal episode) promotes contextually relevant features in the echo—and noise and interference—task-irrelevant items that are not semantically-associated to others within the same temporal context, are weaker and more susceptible to noise, thereby diminishing the likelihood of semantic priming. The results of the current study suggest that the semantic priming between task-irrelevant items results in a post-categorical representation that transcends items. Support for this nonconscious extraction of categorical membership comes from the fact that an item that violates the categorical representation (a categorical, or semantic deviant) of the task-irrelevant sequence disrupts concurrent task performance

(Labonté et al., 2021; Littlefair et al., 2022; Vachon et al., 2020): processing of the categorical membership of task-irrelevant items is necessary to detect the post-categorical change. Moreover, the finding that meaningful speech disrupts visual-verbal task performance no more than meaningless speech challenges the idea that semantic priming arises from involuntary or voluntary shifts of attention to the meaningful aspects of task-irrelevant speech (see Holender, 1986; Lachter et al., 2004). If such attentional shifts were occurring, then one would expect to observe disruption attributable to the meaning of task-irrelevant sound on the visual-verbal serial recall (cf. Vachon et al., 2020), as occurs when a sound diverts attention (Hughes et al., 2005, 2007; Hughes & Marsh, 2020).

Further evidence for semantic priming from task-irrelevant items emanates from the finding that the presentation of associates of the non-dominant meaning of a homophone as task-irrelevant speech in the context of a serial recall task, increases its production in an ostensibly unrelated homophone spelling task even when the homophone itself is not presented in the task-irrelevant sequence (Richardson et al., 2022). This suggests that activation spreads from the task-irrelevant associates of the non-dominant homophone to facilitate its production (e.g. Anderson, 2007; Anderson et al., 1996), or that the automatically encoded task-irrelevant associates of the non-dominant homophone activate related traces by resonating with semantically associated traces within memory (Hintzman, 1984). The difference in associative structures between homophones and their associates, and between members of the same category should give rise to qualitative differences in priming. To elaborate, the priming of a non-dominant homophone via the mere presentation of its associates occurs because the associations are coordinate (i.e. they are linked at the same level), rather than subordinate (i.e. being linked at different organisational levels). Semantic priming, in the case of category-exemplars, relies on superordinate-to-item associations: priming is mediated via the parent category label, rather than directly via other category-exemplars (see also Dewhurst et al., 2007). From this standpoint, the lack of priming found with random presentations of category-exemplars is attributable to the absence of such a parent category label that characterises blocked presentations.

Previous research has questioned whether irrelevant auditory information within the context of the irrelevant sound paradigm is inhibited, thereby preventing its access to working memory (e.g. Rouleau & Belleville, 1996; cf. Hasher & Zacks, 1988). One explanation for the finding that meaningful and meaningless speech are equally disruptive of serial recall is that the semantic properties/processing of task-irrelevant speech is inhibited (Rouleau & Belleville, 1996). Our findings clearly demonstrate that this position is not tenable. Rather, the evidence of semantic priming from task-irrelevant speech we report coheres with the notion that the semantic properties of speech are processed in a task-independent manner (see Vachon et al., 2020) and, providing they have no self-relevance for participants, do not influence task performance unless the focal task itself calls upon semantic processing (Jones et al., 2012; Marsh, Hughes, et al., 2008; Marsh et al., 2009, 2021; Meng et al., 2020; but see Vachon et al., 2020). On the interference-by-process view (e.g. Jones & Tremblay, 2000; Marsh et al., 2009), visual-verbal serial recall typically involves short-term recall of digits or letters—stimuli that are not semantically rich and that are drawn from an overlearned set—so the processing of semantic identities is superfluous. Indeed, retention of items in visual-verbal serial recall is arguably underpinned by non-semantic articulatory vocal-motor processes (e.g. Jones et al., 2004) that are not susceptible to disruption via the semantic properties of sound. When efficient task performance demands or necessitates semantic processing (such as in free recall, categorisation and reading), the semantic properties of sound become disruptive because the nonconscious semantic processing of sound interferes with the deliberate semantic processing applied to the focal task (Jones et al., 2012; Marsh, Hughes, et al., 2008; Marsh et al., 2009, 2021; Meng et al., 2020; Sörqvist et al., 2012). The task-independent semantic processing view undermines the idea the semantic properties of task-irrelevant sound do not influence task performance because they are filtered out/attenuated at an early processing stage (Broadbent, 1958, 1971; Treisman, 1964, 1969), blocked at subcortical levels (Guerreiro et al., 2010), or otherwise inhibited within the cognitive system (Rouleau & Belleville, 1996).

On the face of it, the task-independent semantic processing view also contradicts research demonstrating that semantic priming can be influenced by top-down factors such as attention, intention, and task sets (e.g. Bermeitinger et al., 2011; Kiefer, 2007; Kiefer & Martens, 2010; Kunde et al., 2003; Naccache et al., 2002; Vachon & Jolicœur, 2011). One way to resolve this discrepancy is to adopt Moors and De Houwer's (2006) approach. They propose that automatic processes depend on particular preconditions, which can vary from one process to another. According to their view, "the study of automaticity should focus on identifying the set of preconditions required for an autonomous process to occur" (p. 302). We suggest that these preconditions (and thus observation of semantic processing from task-irrelevant material) might shift based on the methodological parameters used to assess a process's automaticity.

Our results provide evidence that spreading activation, untempered by cognitive control mechanisms (e.g. inhibition), occurs within the stream of task-irrelevant exemplars. However, it is possible that the nature of focal task processes and the properties of the sound jointly determine the operation of cognitive control mechanisms that act directly on representations activated by task-irrelevant sound (Marsh, Hughes, et al., 2015, Marsh, Sörqvist et al., 2015; Marsh, Sörqvist & Hughes, 2015). For example, Marsh et al. (2012) and Marsh, Sörqvist et al. (2015; but see Hanczakowski et al., 2016) found that free recall of category-items on a probe trial was poorer if they were a repeat of distracters presented during the previous prime trial. The authors argued that the semantic relatedness between the lower output-dominant to-be-remembered exemplars and higher output-dominant distracters resulted in the latter competing for the task-irrelevant items for recall (cf. Anderson, 2003). This triggered a competitor inhibition mechanism that suppressed activation of competing high output-dominant items, thereby making them more difficult to recall when they later became to-be-remembered items (see also Hughes & Jones, 2003, for a similar inhibition mechanism applied to the processing of order information). On this line of reasoning, if the focal task undertaken at Phase 1 in the current study design had involved visual memoranda and auditory distracters from the same semantic category, and permitted semantic processing (e.g. free recall), then it is possible that the activated representations of task-irrelevant speech items would be suppressed, thereby rendering them less accessible for category-exemplar production at Phase 2. We are currently addressing this possibility within our laboratories.

Conclusion

The post-categorical properties of task-irrelevant sound—specifically its semanticity—are processed regardless of their power to disrupt focal task performance. Using semantic priming as an index of the depth of processing, we provide evidence for the semantic processing of previously task-irrelevant speech. In demonstrating semantic priming for exemplars blocked by semantic category during presentation, but not randomly presented, we also shed light on the nature of nonconscious semantic processing. Further, by using more appropriate controls than have been used hitherto, our study supports the notion that semantic priming from irrelevant speech is underpinned by implicit rather than explicit retrieval processes.

Disclosure statement

No potential conflict of interest was reported by the author(s).

Funding

John E. Marsh's contribution to this article was supported by a grant received from the Bial Foundation [grant number 201/20] and the German Academic Exchange Service (Deutscher Akademischer Austauschdienst [DAAD, grant number 91875827]).

Data availability statement

The Supplementary Data Analyses document and data that support the findings of this study are available from https://uclandata.uclan.ac.uk/id/eprint/467.

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Appendix

64 category names, including the 16 used here, were presented randomly to 102 participants reporting first-language English, who were asked to list as many instances of each category as possible (a maximum of 15) within 45 s. The output dominance score for each item in each category was computed as the number of participants who listed a particular item as a category member.

	Total Different Exemplars Generated	Van Overschelde Category Potency	Dominance Set 1	Syllables Set 1	Dominance Set 2	Syllables Set 2
Fruit	48	7.5	24.375	2.375	24.625	2.25
Flowers	60	5	12.5	3	12.375	3
Animals	61	7.7	23	1.875	22.125	1.875
Building Part	98	6.5	9.5	2.125	9.75	2.125
Fish	108	5.5	12.125	1.875	12.125	1.875
Weather	58	5.8	17.125	1.375	16.875	1.5
Earth Formation	110	5.6	7.25	1.75	7.375	1.875
Insects	56	5.4	13.375	2.25	13.375	2.25
	74.875	6.125	14.90625	2.078125	14.82813	2.09375

	Total Different Exemplars Generated	Van Overschelde Category Potency	Dominance Set 1	Syllables Set 1	Dominance Set 2	Syllables Set 2
Musical Ins	64	7.6	24.75	2.5	25	2.375
Food Flavouring	92	5.7	12.5	2.375	12.25	2.375
Sport	76	7.8	17.75	2	17.75	2
Furniture	72	6.5	8.75	1.75	8.25	1.875
Fabric	62	5.3	11.125	1.625	11	1.75
Birds	78	6.1	19.375	1.875	19.25	1.75
Reading	94	5.3	7.5	2.25	7.5	2.25
Vegetables	54	5.8	20.125	2.125	20.25	2
	74	6.2625	15.23438	2.0625	15.15625	2.046875

Set 1	Version A			Version B			Dominant Items	
Category	Exemplar	Output Dominance	Syllables	Exemplar	Output Dominance	Syllables	Exemplar	Output Dominance
Fruit	melon	42	2	plum	36	1	apple	102
	peach	29	1	mango	30	2	orange	90
	blueberry	29	3	raspberry	36	3	banana	86
	lemon	24	2	pomegranate	24	4	grape	65
	cherry	19	2	grapefruit	19	2	pear	65
	blackberry	19	3	lime	19	1	strawberry	53
	satsuma	18	3	nectarine	18	3	pineapple	49
	apricot	15	3	lychee	15	2	kiwi	44
Flowers	dandelion	28	4	carnation	24	3	rose	100
	buttercup	26	3	bluebell	23	2	daisy	78
	chrysanthemum	13	4	pansy	18	2	lily	76
	foxglove	9	2	geranium	13	4	tulip	54
	hydrangea	8	3	rhododendron	6	4	daffodil	49
	lavender	7	3	petunia	6	4	sunflower	47
	marigold	5	3	violet	5	3	poppy	32
	iris	4	2	snowdrop	4	2	orchid	29
Four-footed Animals	giraffe	39	2	pig	42	1	cat	99
	rabbit	38	2	hamster	37	2	dog	98
	mouse	33	1	zebra	28	2	horse	72
	goat	28	1	rat	23	1	lion	59
	bear	14	1	donkey	17	2	cow	55
	hippopotamus	12	5	rhinoceros	11	4	elephant	49
	cheetah	10	2	deer	10	1	sheep	46
	wolf	10	1	gerbil	9	2	tiger	45
Part of a Building	foundation	19	3	chimney	18	2	door	79
	basement	13	2	entrance	14	2	window	79
	cement	13	2	attic	13	2	roof	78
	corridor	10	3	lift	10	1	wall	64
	hallway	7	2	bedroom	7	2	floor	56
	beams	5	1	kitchen	7	2	stair	48
	foyer	5	2	conservatory	5	5	ceiling	39
	cellar	4	2	porch	4	1	room	37
Fish	catfish	23	2	mackerel	29	3	salmon	72
	carp	21	1	swordfish	20	2	cod	70
	plaice	15	1	sardine	13	2	goldfish	67

(*Continued*)

Continued.

Set 1 Category	Version A Exemplar	Version A Output Dominance	Version A Syllables	Version B Exemplar	Version B Output Dominance	Version B Syllables	Dominant Items Exemplar	Dominant Items Output Dominance
	pike	11	1	puffer	10	2	tuna	46
	halibut	7	3	herring	7	2	haddock	42
	piranha	7	3	sole	7	1	trout	39
	starfish	7	2	dogfish	6	2	shark	38
	pollock	6	2	hake	5	1	clown fish	37
Weather Phenomenon	storm	33	1	wind	34	1	hurricane	73
	sun	29	1	flood	30	1	tornado	58
	fog	18	1	sleet	21	1	rain	57
	blizzard	15	2	cloud	16	1	snow	55
	heatwave	12	2	earthquake	12	2	hail	48
	typhoon	11	2	cyclone	8	2	thunder	37
	gale	10	1	monsoon	8	2	tsunami	37
	frost	9	1	rainbow	6	2	lightening	35
Natural Earth Formation	rock	16	1	beach	14	1	mountain	86
	cave	9	1	glacier	14	3	volcano	62
	island	8	2	waterfall	10	3	hill	50
	stream	8	1	geyser	5	2	river	40
	stone	5	1	canyon	6	2	valley	37
	iceberg	5	2	gorge	4	1	lake	34
	desert	4	2	crater	3	2	cliff	29
	estuary	3	4	mound	3	1	sea	17
Insects	moth	23	1	cockroach	25	2	fly	71
	centipede	23	3	caterpillar	23	4	ant	67
	grasshopper	22	3	earwig	16	2	spider	57
	woodlouse	19	2	millipede	15	3	ladybird	54
	dragonfly	10	3	mosquito	13	3	wasp	51
	locust	3	2	flea	9	1	bee	44
	aphid	4	2	gnat	4	1	butterfly	40
	termite	3	2	hornet	2	2	beetle	39

Set 2 Category	Version A Exemplar	Version A Output Dominance	Version A Syllables	Version B Exemplar	Version B Output Dominance	Version B Syllables	Dominant Items Exemplar	Dominant Items Output Dominance
Musical Instruments	recorder	39	3	trombone	36	2	guitar	87
	saxophone	34	3	harp	36	1	violin	87
	bass	34	3	oboe	34	2	piano	84
	keyboard	27	1	harmonica	26	4	drum	80
	viola	26	2	triangle	23	3	flute	77
	tambourine	23	2	banjo	23	2	trumpet	60
	piccolo	7	3	tuba	14	2	clarinet	48
	symbols	8	3	xylophone	8	3	cello	46
Substance for Flavouring Food	sugar	22	2	thyme	22	1	salt	80
	coriander	18	4	parsley	15	2	pepper	77
	mint	14	1	oregano	14	4	herbs	46
	cinnamon	12	3	ketchup	11	2	basil	33
	rosemary	11	3	vinegar	11	3	spices	32
	ginger	8	2	cumin	10	2	chilli	26
	sage	8	1	turmeric	8	3	garlic	26
	mayonnaise	7	3	mustard	7	2	paprika	25
Sports	cricket	35	2	squash	30	1	football	99
	golf	29	1	aerobics	25	3	rugby	89
	gymnastics	17	3	lacrosse	20	2	tennis	77
	volleyball	18	3	running	21	2	hockey	64
	polo	13	2	baseball	16	2	netball	62
	cycling	10	2	boxing	12	2	basketball	51
	darts	10	1	rounders	10	2	badminton	49
	rowing	10	2	snooker	8	2	swimming	48
Article of Furniture	drawers	19	2	shelves	17	1	chair	98
	lamp	16	1	armchair	13	2	table	95
	cabinet	14	3	footstool	9	2	sofa	84
	couch	5	1	bookcase	7	2	bed	80
	beanbag	5	2	sideboard	6	2	desk	71
	rug	4	1	settee	6	2	wardrobe	56
	mirror	4	2	pouffe	5	2	cupboard	35
	bookshelf	3	2	cushion	3	2	stool	31

(*Continued*)

Continued.

Set 2	Version A			Version B			Dominant Items	
Category	Exemplar	Output Dominance	Syllables	Exemplar	Output Dominance	Syllables	Exemplar	Output Dominance
Type of Fabric	velvet	24	2	leather	23	2	cotton	98
	cashmere	19	2	linen	13	2	silk	80
	lace	14	1	fur	13	1	wool	71
	felt	13	1	fleece	11	1	polyester	58
	netting	7	2	suede	9	1	denim	37
	spandex	6	2	elastic	8	3	nylon	36
	hemp	3	1	velour	6	2	satin	30
	canvas	3	2	chiffon	5	2	lycra	27
Birds	owl	31	1	parrot	37	2	robin	73
	swan	30	1	duck	27	1	pigeon	66
	hawk	25	1	dove	20	1	bluetit	59
	canary	17	3	magpie	18	2	seagull	57
	ostrich	14	2	penguin	15	2	eagle	53
	swallow	14	2	bluebird	13	2	sparrow	49
	chicken	12	2	vulture	13	2	crow	38
	woodpecker	12	3	budgie	11	2	blackbird	37
Reading Material	comic	13	2	textbook	13	2	book	89
	letter	11	2	webpage	9	2	magazine	88
	booklet	7	2	internet	8	3	newspaper	84
	advert	7	2	diary	8	2	journal	72
	pamphlet	7	2	paper	7	2	leaflet	40
	email	6	2	flyer	6	2	article	29
	biography	5	4	blog	5	1	novel	16
	essay	4	2	dictionary	4	4	poster	16
Vegetables	sweetcorn	38	2	swede	39	1	carrot	99
	peppers	31	2	sprouts	31	1	potato	70
	lettuce	24	2	leek	30	1	broccoli	67
	beans	20	1	cucumber	18	3	pea	62
	mushroom	20	2	aubergine	14	3	cauliflower	56
	courgette	12	2	spinach	12	2	cabbage	49
	asparagus	8	4	beetroot	10	2	onion	40
	turnip	8	2	celery	8	3	parsnip	40