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Re-examining the effects of verbal instructional type on early stage motor learning

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Abstract

The present study investigated the differential effects of analogy and explicit instructions on early stage motor learning and movement in a modified high jump task. Participants were randomly assigned to one of three experimental conditions: analogy, explicit light (reduced informational load), or traditional explicit (large informational load). During the two-day learning phase, participants learned a novel high jump technique based on the 'scissors' style using the instructions for their respective conditions. For the single-day testing phase, participants completed both a retention test and task-relevant pressure test, the latter of which featured a rising high-jump-bar pressure manipulation. Although analogy learners demonstrated slightly more efficient technique and reported fewer technical rules on average, the differences between the conditions were not statistically significant. There were, however, significant differences in joint variability with respect to instructional type, as variability was lowest for the analogy condition during both the learning and testing phases, and as a function of block, as joint variability decreased for all conditions during the learning phase. Findings suggest that reducing the informational volume of explicit instructions may mitigate the deleterious effects on performance previously associated with explicit learning in the literature.

Keywords: motor control, explicit learning, analogy learning, instruction, task-relevant pressure

1. Introduction

According to the traditional cognitive framework of motor skill acquisition (Anderson, 1982; Fitts & Posner, 1967), the attentional demands and knowledge that underlie motor performance differ with respect to expertise. Although more advanced performance relies on automatised procedural systems that require little conscious attention, the early stages of skill learning involve the effortful serial processing of explicit, rule-based knowledge in working memory systems in order to approximate the successive steps of motor execution. While research indicates that novices may benefit from the self-focused attention engendered by explicit information (e.g., Beilock, Carr, MacMahon, & Starkes, 2002), research also suggests that explicit knowledge is associated with skill breakdown under pressure (e.g., Lam, Maxwell, & Masters, 2009b; Masters, 2000; Masters & Maxwell, 2004).

Theorising that explicit, rule-based information might interfere with skilled performance when reinvested into typically autonomous skills, Masters (1992) demonstrated that golf-putting skills acquired implicitly—without reliance on rule-based instruction or working memory systems— were more resilient to induced stressful conditions than those same skills gained through explicit means. Subsequent studies have since shown passively-acquired motor skills to be more robust under performance pressure (J. Hardy, Mullen, & Martin, 2001; L. Hardy, Mullen, & Jones, 1996; Masters, 1992), physiological fatigue (Masters, Poolton, & Maxwell, 2008; Poolton, Masters, & Maxwell, 2007), and concurrent cognitive demands (Masters, 1992, 2000) than performance underpinned by declarative knowledge.

However, despite such favourable findings in the laboratory, several factors have limited the application of implicit instructional methods in the field. Much of the difficulty in this regard stems from the cumbersome and logistically demanding techniques employed to encourage passive skill learning, such as dual-task learning (L. Hardy et al., 1996; Masters, 1992; Maxwell, Masters, & Eves, 2000), errorless or reduced-feedback learning (Maxwell, Masters, & Eves, 2003; Maxwell, Masters, Kerr, & Weedon, 2001) and subliminal learning (Masters, Maxwell, & Eves, 2001). As Poolton, Masters, and Maxwell (2006) explained, 'implicit motor learning paradigms are ecologically challenged, generally difficult to apply in the field, and result in slower learning than normal' (p. 678).

Recognising the need for more feasible implicit instructional methods, Masters (2000) proposed the concept of 'coaching by analogy' in which a series of complex movements or behaviours are conveyed through a single analogical cue. The premise is that such an 'all encompassing biomechanical metaphor' can be readily incorporated into existing coaching and instructional paradigms as it does not require unusual modifications to the learning environment (e.g., dual-task or subliminal learning), but simply an adjustment in the type of information (i.e., analogy versus explicit rules). Studies have since shown that participants learning tasks through analogical instruction report fewer task-relevant rules (Koedijker et al., 2011; Lam, Maxwell, & Masters, 2009a; Lam et al., 2009b; Liao & Masters, 2001; Poolton et al., 2006), exhibit no deficits in performance or kinematic variables (Lam et al., 2009b), and perform without disruption under stressful (Lam et al., 2009a) or dual-task conditions (Koedijker et al., 2011; Lam et al., 2009b; Liao & Masters, 2001). A potential methodological issue, however, makes it uncertain whether these observed advantages of analogy learning arose from the *type* of instruction or the reduced *volume* of instructions compared to traditional explicit methods. In this regard, the rules for the explicit conditions in previous empirical research have outnumbered the single-cue analogy instructions by ratios ranging from 5:1 (Koedijker et al., 2011) to as high as 12:1 (Liao & Masters, 2001), even though current motor learning literature and many coaching guides advise focusing on no more than two or three key points at any one time when teaching new motor skills (e.g., Mannie, 1998; McQuade, 2003; Schmidt & Wrisberg, 2004). Given that part of the inspiration behind the concepts of implicit and, subsequently, analogy learning was to reduce the load on attentional resources engendered by the task instructions, it would seem not only equitable, but also necessary from an experimental perspective, to explore the impact of explicit instructions in their leanest possible configuration as well. The aforementioned disparity in instructional volume might also explain the propensity for explicit learners to report more task-relevant rules in follow-up questionnaires than their analogy group counterparts, as they would have repeatedly read, memorised, and performed up to eleven additional instructional steps. As it stands, it is difficult to establish whether the performance deficits attributed to explicit learning in the existing literature resulted from conscious processing engendered by the instruction itself or from competition for available attentional resources.

1.1. Content under pressure

Although a fairer comparison with explicit learning would represent a positive methodological evolution, additional refinements might further enhance the usefulness of analogy and explicit learning research to those working in applied settings. Just as the impracticalities of implicit learning methods motivated the development of the concept of analogy learning, the artificial manipulations used to simulate pressure or competitive conditions in laboratory research could too benefit from the adoption of a more practical and, perhaps, more representative approach. Part of the original rationale for employing implicit instructional methods was that it might limit susceptibility to ‘choking’ (Masters, 1992), a phenomenon of pressure-induced skill failure (Baumeister, 1984); however, choking has typically been evaluated using contrived manipulations of pressure and distraction that are often unrealistic and disproportionate to the levels experienced in sport (Gucciardi & Dimmock, 2008; Hill, Hanton, Matthews, & Fleming, 2010). This trend has continued in analogy learning research with prize money (Lam et al., 2009b), evaluation (Lam et al., 2009a), audience observation (Law, Masters, Bray, Eves, & Bardswell, 2003), and secondary task loads such as reverse counting (Lam et al., 2009b) and tone monitoring (Orrell, Eves, & Masters, 2006) accounting for just a few of the task-irrelevant methods used to evaluate the robustness of skills learned under both explicit and analogy conditions. According to Jones and Hardy (1990), however, tasks that offer more authentic anxiety manipulations represent richer opportunities for exploring the relationships between anxiety and performance. Moreover, studies that employ ego-stressor methods manage to evoke only moderate levels of anxiety that are incommensurate with those experienced during competition (Williams & Elliot, 1999). To both enhance understanding of the differential impact of various types of verbal instruction and increase the utility of this research for those in the field, research designs ought to reflect the demands and pressures experienced within authentic performance environments (see Pijpers, Oudejans, & Bakker, 2005; Pijpers, Oudejans, Holsheimer, & Bakker, 2003).

1.2. The current study

The present study sought to address concerns regarding informational imbalance and representative pressure by introducing an explicit condition with reduced instructional volume and by implementing a task-appropriate pressure manipulation in a modified high jump task. In taking these steps, the primary aim of the study was to investigate the differential effects of analogy and explicit instruction on movement learning and performance. The choice of a high jump task offered both a technique that was well suited to analogy (the scissor style) and a controllable performance-related pressure (bar height) inspired by the authentic pressure manipulation of climbing height previously used by Pijpers and colleagues (2005; 2003). In competitive contexts, the rising height of the bar is associated with increasing levels of pressure and anxiety, especially as the bar begins nearing heights perceived to be at the limits of one’s capabilities (for accounts, see Kangaroo Track

Club, 2010; Lee, 2010). Although all aspects of the jump should remain consistent from one attempt to the next (Gillespie, 2007), anecdotal evidence indicates that the anxiety that accompanies higher bar heights can affect the execution of movements (e.g., Keogh, 2015), resulting in failed attempts, even though clearances at previous heights suggest the physical and technical capabilities for success. In using this task, it was of particular interest to learn if verbal instructional type differentially affected either the accumulation of declarative knowledge or technical performance under the task-relevant pressure conditions.

Just how instructional type affects coordination *during* the jumping movement itself—and not simply the result of the jump—is also of particular interest to this study. While recent research has explored the impact of pressure or anxiety on movement (e.g., Collins, Jones, Fairweather, Doolan, & Priestley, 2001; Pijpers et al., 2005; Pijpers et al., 2003), only a single study, to date, has compared the differential impact of explicit and analogy instruction on movement mechanics. In that one study, however, Lam et al. (2009b) did not find any kinematic differences between analogy and explicit learners, so the possible effects of these two instructional types on movement coordination remain unclear. To gain greater insight into movement, a number of sport science researchers have advocated a transition from descriptive biomechanical analyses to more analytical approaches for conceptualising and evaluating movement mechanics (e.g., Elliot, 1999; Glazier, Davids, & Bartlett, 2003; Nigg, 1993). In recent years, researchers have increasingly investigated changes in movement coordination using methods inspired by concepts rooted in dynamical systems theory (Hodges, Hayes, Horn, & Williams, 2005; Pijpers et al., 2005; Pijpers et al., 2003). According to Glazier, Davids, and Bartlett (2002; 2003), dynamical systems theory—which views behaviour and movement solutions as emergent consequences of external variables and constraints (Hodges et al., 2005)—may just provide the relevant theoretical foundation necessary for conducting sport science research, because of its interdisciplinary approach to coordination and motor control.

Although the current study was not primarily concerned with dynamical systems theory per se, the theory offers a framework for exploring, quantifying, and understanding movement and coordination, by examining the control and movement of joints, largely inspired by Bernstein's (1967) proposed universal motor learning solution. According to Bernstein (1967), learners constrain movement early on by rigidly fixing joint angles in order to reduce the number of degrees of freedom requiring active control, before gradually releasing them over practice and transitioning to smoother, more economical movement. This process of freeing degrees of freedom should be characterised by increasing variability within and between joints (Vereijken, van Emmerik, Whiting, & Newell, 1992). A secondary aim of the study, therefore, was to examine differences in joint variability to investigate how instructional type affects the nature of motor learning. As Bernstein's motor learning solution is intended as a universal theory, it was of particular interest to see if variability differed in any way with respect to instructional type.

2. Method

2.1. Participants

Twenty-one healthy male volunteers (mean age = 23.7 years, *SD* = 4.3) were randomly assigned to one of three experimental conditions: the analogy condition (*n* = 7), the explicit light condition (*n* = 7), or the traditional explicit condition (*n* = 7). Participants were considered novices in high jump if they had not received any formal coaching instruction in the event (Poolton et al., 2006, 2007). Two participants from the traditional explicit condition were excluded from the study following data collection for failing to follow the task instructions; consequently, two new participants were recruited using purposive sampling techniques to ensure equal-sized groups. Following previous precedent (e.g., Lam et al., 2009a; Poolton et al., 2006), a control group was not included as research suggests that these uninstructed groups perform identically to traditional explicit conditions (Lam et al., 2009a) by learning explicitly, reporting high levels of rule-based knowledge, and exhibiting disrupted performance under anxious or dual-task conditions (e.g., Liao & Masters, 2001; Masters, 1992). All participants provided informed consent prior to commencing their involvement in the research. Ethical approval for the study was granted by the University of Edinburgh School of Education ethics committee

2.2. Apparatus and task

The setting for the study was a purpose-built sport science laboratory with rubber flooring similar to a running track surface. As shown in Fig. 1, a rectangular 'take-off' area was clearly marked on the floor to limit the length of the run-up and to ensure that participants approached the bar at an angle of 30° in line with recommended high jumping technique (Morgan, 2002)**.** Following advised practice for novice jumpers, the approach run was restricted to two steps, because it allows learners to develop a sense for the rhythm, technique, and body positioning necessary for the high jump (American Sport Education Program, 2008; Otte, 1999) without having to worry about the speed and strength required to perform the fast, curved full-length approach.

Due to constraints arising from the layout and design of the laboratory, it was possible to accommodate run-ups from only a single side. As all participants were novices and laboratory research has demonstrated similar leg kinematics and kinetics between both dominant and non-dominant legs in jumping tasks (van der Harst, Gokeler, & Hof, 2007), it was not expected that the use of either leg would affect learning or performance in the scissor technique. Because it is most common for individuals to approach from the right side to use their left foot in high jumping tasks (Peters, 1988), however, the left side was chosen to limit skill transfer from related tasks or activities.

*******Figure 1 near here*******

Three Canon MD101 video cameras recording at 50 fields per second filmed the jumping trials for the biomechanical analyses. The image space was calibrated before and after each session using a custom-built metal frame measuring 1.90 m × 1.90 m × 2.89 m (Coleman & Rankin, 2005). To obtain the kinematic data, the positions of eighteen body landmarks including joint centres and limb extremities were manually digitised, transformed into three-dimensional coordinates using the direct linear transformation method (Abdel-Aziz & Karara, 1971), and smoothed using the APAS three-dimensional motion analysis system (Ariel Performance Analysis System; Ariel Dynamics, Inc.; San Diego, CA, USA).

2.3. Design

The experiment featured a mixed design comprising a two-day learning phase and a single-day testing phase. Because high jump athletes do not make many full-effort jumps in a single session (Dapena, McDonald, & Cappaert, 1990)—typically between 10 and 20 jumps in three sessions weekly (Keogh, 2015)—learning trials were reduced compared to previous research (e.g., Lam et al., 2009a, 2009b; Liao & Masters, 2001; Poolton et al., 2007) to make the design more representative of real-world practice and to limit the possibility of fatigue impacting performance. During the learning phase, participants performed 2 identical blocks of 10 jumps for each day of learning. The testing phase, in contrast, was divided into two distinct parts: a retention test and task-relevant pressure test. During the retention test, which was used to assess learning and provide a baseline for the testing phase, participants again performed 10 jumps. For the task-relevant pressure test, however, participants continued jumping until they recorded three successive failures in accordance with the competition rules of the high jump. Between all days of the study, participants received 47 hours rest to allow for sufficient recovery (i.e., they attended the lab at the same time every other day).

2.4. Procedure

Participants individually learned and performed the scissor-style high jump technique using the instructions for their respective conditions by jumping over a foam-covered, low-height elastic band held in position by two uprights. In order to simulate competitive conditions, a 4-m high jump bar replaced the elastic band during the task-relevant pressure test and was raised 5 cm following each successful clearance. The height of the elastic band, which remained unchanged for the learning phase and retention test to prevent hypothesis testing (Maxwell, Masters, & Eves, 1999), was systematically calculated using a modified model for predicting Fosbury Flop performance (Laffaye, 2011). This calculation, which was based on the physical characteristics and vertical-jumping reach height of each participant, also served as the starting height for the bar during the task-relevant pressure test. For reasons concerning both safety and technique, participants were informed that they must always land upright (i.e., on one or both feet) and only use the clearly marked run-up area for their approach and jump. Participants—who all warmed up with dynamic stretching exercises upon arrival (Ebben & Petushek, 2010)—were afforded 40-s rest between all jumps during both the learning and testing phases.

The instructions for the experimental conditions, shown in Table 1, were compiled from a variety of sources (American Sport Education Program, 2008; Morgan, 2002; Shepherd, 2009) and tailored as appropriate to suit the nature of these conditions. Participants were asked to read through the instructions for their respective groups before commencing each block of jumps in the learning phase. For the testing phase, participants were not reminded at any point of their instructions, but were asked to maintain effort and maximise jumping performance, following the example of previous research (Lam et al., 2009b). Throughout the study, the technique was called the ‘Penn State style high jump technique’ to mitigate the possibility of any possible prior knowledge or awareness of the scissors style affecting participant performance. For the task-relevant pressure test, trials were deemed successful only if the participants both jumped over the bar without dislodging it (i.e., the bar stayed on the standards) and landed upright on the mats.

*******Table 1 near here*******

2.5. Dependent variables

2.5.1. Psychological measures

Subjective anxiety was measured at the end of the learning and testing phases using the 'anxiety thermometer'—a self-report measure used in recent anxiety-performance research (Lam et al., 2009a; Pijpers et al., 2005; Pijpers et al., 2003) with moderate to high correlation (r = .64–.77) with the State-Trait Anxiety Inventory (STAI; Spielberger, Gorsuch, & Lushene, 1970)—which asked participants to rate their current level of anxiety by placing a cross on a 10-cm continuous scale, ranging from 0 (left end; not anxious at all) to 10 (right end; extremely anxious). The physical distance in centimetres between the left edge of the scale and participants' crosses was used as the measure of self-reported anxiety.

Self-reported mental effort was assessed using the Rating Scale for Mental Effort (RSME; Zijlstra, 1993), which has been employed previously to measure effort in sport (e.g., Cooke, Kavussanu, McIntyre, & Ring, 2010; Wilson, Smith, & Holmes, 2007), and has demonstrated acceptable reliability in both laboratory and work settings (r = .88 and .78 respectively; Zijlstra, 1993). At the conclusion of both the learning and testing phases, participants were asked to rate the amount of effort invested during performance on a vertical axis scale ranging from 0 to 150. Nine category anchors illustrated points throughout the continuum, including 3 (no mental effort at all) and 114 (extreme mental effort) at the extremes.

2.5.2. Psychophysiological measures

Harrison et al. (2001) and McKay et al. (1997) argued that sports competition incites cardiovascular responses that extend beyond the typical physiological effects of the task. If the bar height manipulation evokes physiological effects representative of real-world competitive conditions, it was expected that the average heart rate readings would increase in the task-relevant pressure test relative to all other sets. With this in mind, heart rate was measured using Polar Electro Sports Testers (Polar Electro, Finland), in order to evaluate the effectiveness of the task-relevant pressure manipulation and levels of physiological arousal during the task (e.g., L. Hardy & Parfitt, 1991). Readings were collected in 5-s intervals using heart rate transmitters and data receivers that were fitted to each participant's chest and wrist.

2.5.3 Amount of verbal knowledge

Based on the verbal protocols of Lam et al. (2009b), immediately following the task-relevant pressure test, participants were asked to reflect upon their performances and describe in as much detail as possible 'any methods, rules, or techniques that they remembered using while performing the high-jumping task during both the learning and test phases'. Two independent raters examined all reports. Only statements referring directly to technical or mechanical aspects of high-jumping technique were counted; any statements unrelated to task performance were excluded from the tally. In this instance, the verbal protocol questionnaire not only served as a measure of the accumulation of explicit knowledge, but also as a control measure to ensure that participants were focused only on the instructions for their respective conditions. In this regard, the verbal protocols helped to reveal that two of the participants had intentionally disregarded the task instructions and relied upon knowledge relating to other movement skills (e.g., basketball lay-ups), leading to their exclusion from the study.

2.5.4. Technical efficiency

Unlike a typical high jump competition, the highest successful clearance is not necessarily meaningful in the present study due to the shortened approach run, which could overemphasise physical differences between participants. For this reason, based on the methods of Hay and Reid (1982) and Dapena (1992), a standardised measure of technical efficiency was calculated to assess learning for each participant by dividing the clearance height (i.e., height of the bar or elastic band) by the peak height of the centre of mass (COM; see figure 1 for illustration). Higher ratings represent more efficient clearances, while lower ratings indicate less efficient clearances in which technique inhibited maximisation of flight height. Technical efficiency was calculated for all jumps of the learning phase and for the highest clearance for each participant during the task-relevant pressure test. It was expected that traditional explicit participants would demonstrate less technical efficiency than their analogy and explicit light counterparts, because of the additional instructional load compared to the other two groups.

2.5.5. Joint variability

To explore the effects of instructional type on joint variability, the standard deviations around the mean (Glazier, 2011; Vereijken et al., 1992) were calculated for four specific joints: left knee, left hip, right knee, and right hip. The knees and hips not only represent important considerations for optimising technique (see figure 1 for depiction of the scissor style) according to the coaching literature (e.g., American Sport Education Program, 2008; Reid, 2010), but also for maximising the height of the COM according to biomechanical analyses (e.g., Dapena, 2000; Dapena et al., 1990; Greig & Yeadon, 2000). In this regard, biomechanical research has identified the angle of the jumping leg at touchdown (the moment the jumping leg first contacts the floor; Dapena, 2000; Dapena et al., 1990), the drive action of the non-jumping leg at takeoff (the moment the jumping leg leaves the floor; Greig & Yeadon, 2000), and the positioning of the hips throughout the takeoff phase (i.e., from touchdown to takeoff; Dapena, 2000; Dapena et al., 1990) as important factors in high jumping performance. Although previous research has investigated joint variability by comparing standard deviation within and across joints without any transformation (e.g., Vereijken et al., 1992), the standard deviation data in this instance were converted into coefficients of variation (CV) prior to analysis to eliminate the mean differences between individual participants (James, 2004; Lam et al., 2009b).

2.6. Analyses

As shown in table 2, kinematic data were collected and analysed for the first, fourth, and tenth jumps in each block for both phases, based on precedents from related research (e.g., Hodges et al., 2005; Vereijken et al., 1992; Zentgraf & Munzert, 2009), except in the case of the task-relevant pressure test, in which the highest clearance by each participant became the final measurement trial. Across all participants, the best clearances on average in the task-relevant pressure test typically occurred on or near the ninth trial (M = 9.38, SD = 1.20). In order to cover the touchdown, takeoff, and flight phases of the jump, the starting and ending points for the analysis were defined as seven frames (0.14 sec) before the moment of touchdown and the precise moment that participants landed on the crash mats following the jump, respectively (see figure 1 for illustration). The mean duration for the kinematic analyses across all trials was 0.79 sec (SD = 0.03).

*******Table 2 near here*******

During analysis, any violations of the assumption of sphericity were corrected using Greenhouse-Geisser procedures based upon the advice of Field (2005) and the precedent established by preceding research (e.g., Hodges et al., 2005; Lam et al., 2009b). Post hoc analyses employed Bonferroni's method to control for type I error (Field, 2005), unless otherwise noted. All results reported as significant at the .05 level.

2.7. Digitising accuracy and precision

Digitising accuracy was evaluated by digitising a moving 70 mm rigid segment using the same method as participant analyses (Salter, Sinclair, & Portus, 2007; Wormgoor, Harden, & Mckinon, 2010). The mean reconstructed length of the segment was 72 mm ± 3.8, resulting in a mean error of 2 mm (2.9%), in line with results from the aforementioned studies. To assess digitising precision (Challis, 1997; Coleman & Rankin, 2005), a single jumping trial was digitised six separate times and, from these data, typical errors (Hopkins, 2000) were then calculated**.** Repeated digitisation yielded typical errors for the COM of ±4 mm, ±2 mm, ±3 mm in the *x*, *y*, and *z* axes, respectively.

3. Results

3.1. Technical Efficiency.

3.1.1 Learning phase.

To investigate the efficiency of the scissor technique with respect to condition, a 3 × 4 (Condition × Block) mixed design ANOVA with repeated measures on the latter factor was run on the technical efficiency data for the learning phase. Although participants from the analogy group demonstrated greater efficiency on average (*M* = .60, *SD*= .033, *SE* = .012) than both their explicit light (*M* = .591, *SD* = .041, *SE* = .015) and traditional explicit counterparts (*M* = .572, *SD* = .032, *SE* = .012); these differences were not statistically significant overall, $F(2, 18) = .959$, $p = .402$, $\eta_p^2 = .10$.. There was, however, a significant within-subjects effect for block, $F(3, 54) = 6.516$, $p = .001$, $\eta_p^2 = .27$., as efficiency increased across conditions as the learning phase progressed. These data pertaining to technical efficiency during the learning phase are presented in Fig. 2.

*******Figure 2 near here*******

3.1.2 Testing phase.

A one-way ANOVA was used to evaluate technical efficiency for the highest clearance of each participant during the task-relevant pressure test. Although the results approached significance, the differences with respect to instructional type were non-significant overall, $F(2, 18) = 3.137$, $p = .07$, $\omega = .47$. As in the learning phase, participants from the analogy group again demonstrated greater efficiency (*M* = .80, *SD*= .013, *SE* = .005) than those from the explicit light (*M* = .774, *SD* = .035, *SE* = .013) and traditional explicit conditions (*M* = .755, *SD* = .0377, *SE* = .014). The mean technical efficiency as a function of condition during the testing phase is shown in Fig. 3.

*******Figure 3 near here*******

3.2. Verbal rules

The accumulation of task-relevant explicit rules for each participant was assessed by two independent raters and then averaged into a single score. Intra-class correlation coefficients, which were used to evaluate inter-marker reliability, indicated significant correlations between both markers (ICC = .91, $p < .001$). A one-way ANOVA of the data revealed that the analogy condition ($M = 5.71$, $SD = 3.68$) reported fewer rules on average than the explicit light ($M = 6.29$, $SD = 1.87$) and traditional explicit conditions ($M = 7.86$, $SD = 2.14$), but the differences between the three conditions were not significant, $F(2, 20) = 1.196$, $p = .325$, $\omega = .17$. There was, however, a statistically significant negative relationship between the number of reported explicit rules and technical efficiency, $r = -.53$, $p < .05$.

3.3. Joint variability

3.3.1 Learning phase.

A 3 × 4 × 4 (Condition × Joint Angle × Block) ANOVA with repeated measures on the latter factor was conducted for joint variability. Prior to analysis, the CV data were inverse square root transformed to normalise the distribution and then reflected to restore the direction of the relationships between variables. Analysis indicated that there was a statistically significant main effect of condition, $F(2, 18) = 16.688$, $p < .001$, $\eta_p^2 = .65$, with post hoc tests revealing that the analogy group demonstrated significantly less variability across all joints ($M = 1.29$) than either the explicit light, $M = 1.84$, $p < .001$, or traditional explicit conditions, $M = 1.64$, $p < .01$. There was also a significant finding for joint angle, $F(1.991, 35.837) = 51.194$, $p < .001$, $\eta_p^2 = .74$, indicating that variability was not consistent between joints. A closer inspection of the data showed that variability was highest for the left hip ($M = 2.02$, $SE = .02$) and lowest for the right knee ($M = 1.17$, $SE = .08$). Analysis revealed a significant effect for block as well, $F(1.952, 35.133) = 5.376$, $p < .01$, $\eta_p^2 = .23$, with variability across all joints decreasing as the learning phase progressed (see Fig. 4), contrary to expectations from a dynamical systems theory perspective.

A significant interaction was detected between condition and joint angle, $F(3.982, 35.837) = 9.897$, $p < .001$, $\eta_p^2 = .52$, meaning that the variability between joints differed with respect to condition. Simple effects analysis indicated that there were significant differences between conditions for left knee, $F(2, 18) = 6.404$, $p < .001$, right knee, $F(2, 18) = 15.693$, $p < .001$, left hip, $F(2, 18) = 2.480$, $p < .05$, and right hip, $F(2, 18) = 2.682$, $p < .05$. For all of these joint angles, the analogy condition demonstrated less variability than either of the other two conditions, while the explicit light condition exhibited the greatest variability in all instances (see Fig. 5).

*******Figure 4 near here*******

3.3.2. Testing phase.

A 3 × 4 × 2 (Condition × Joint Angle × Block) ANOVA with repeated measures on the latter factor was conducted on joint variability data for the testing phase. Data were once again inverse square root transformed and reflected prior to analysis. Despite these steps, however, equal variances still could not be assumed for the right hip angle during the task relevant pressure test ($p = .03$). Howell (2009) noted, however, that ANOVA is robust against small violations of homoscedasticity such as this, especially when sample sizes are equal. Following the advice of Field (2005), the Games–Howell procedure was used in place of the Bonferroni method as it offers the best performance when there is any doubt regarding the equality of variances.

A significant main effect was found for condition, $F(2, 18) = 11.770$, $p = .001$, $\eta_p^2 = .57$, with the analogy group again demonstrating less variability on average ($M = 1.26$) than either the explicit light, $M = 1.81$, $p < .01$, or traditional explicit conditions, $M = 1.59$, although the differences were only significant compared to the former in this instance (see Fig. 4). There was also a significant effect for joint angle, $F(1.921, 34.572) = 55.145$, $p < .001$, $\eta_p^2 = .75$. Once more, variability was highest for the left hip ($M = 2.02$, $SE = .03$) and lowest for the right knee ($M = 1.09$, $SE = .10$), echoing the findings in the learning phase.

Unlike the learning phase, there was no significant effect for block, but there was a significant condition × joint angle interaction, $F(3.841, 34.572) = 6.843$, $p < .001$, $\eta_p^2 = .43$. Simple effects analysis revealed significant differences between the conditions for left knee, $F(2, 18) = 5.700$, $p = .001$, right knee, $F(2, 18) = 13.270$, $p < .001$, and right hip, $F(2, 18) = 3.592$, $p < .05$. As shown in figure 5, for each of the joints, the explicit light condition demonstrated the greatest joint variability on average, followed by the traditional explicit and analogy conditions, respectively.

Analysis of variance revealed another significant interaction between joint angle and block, $F(1.932, 34.769) = 22.041$, $p < .05$, $\eta_p^2 = .55$, indicating that the nature of the variability between joints changed from the retention test to the task-relevant pressure test. Unlike the learning phase, which saw variability generally decrease with learning for each joint, there was no such clear pattern for the testing phase. Finally, there was also a significant three-way interaction between condition, joint angle, and block, $F(3.863, 34.769) = 5.144$, $p < .005$, $\eta_p^2 = .36$. To follow up this significant interaction, three separate two-way (Joint Angle × Block) repeated-measures ANOVAs were conducted (Mullen & Hardy, 2000). To guard against inflation of type I error due to these multiple comparisons, the critical p value was changed to .0125 using a Bonferroni adjustment. Analyses revealed that there was a significant interaction effect between joint angle and block for the explicit light, $F(2.024, 12.145) = .8.991$, $p < .005$, $\eta_p^2 = .60$, and traditional explicit conditions, $F(3, 18) = .17.341$, $p < .001$, $\eta_p^2 = .74$, but the interaction was non-significant for the analogy learners, $F(3,18) = .894$, $p < .05$, $\eta_p^2 = .13$. An inspection of the data showed that variability for every joint angle increased from the retention test to the task-relevant pressure test for those in the analogy condition, whereas the variability increased only for the left and right hip joints in the case of the explicit light and traditional explicit conditions.

*******Figure 5 near here*******

3.4. Effectiveness of Pressure Manipulation

To investigate the effectiveness of the pressure manipulation, a 3 × 2 (Group × Block) MANOVA with repeated measures on the latter factors was performed on anxiety thermometer, RSME, and average heart rate data for the last block of the learning phase and the task-relevant pressure test during the test phase. Analysis did not reveal any between-subjects effects, $F(6, 34) = 1.057$, $p = .407$; however, there was a significant within-subjects effect for block, $F(3, 16) = 44.88$, $p < .001$. Pairwise comparisons showed that anxiety thermometer scores, RSME scores, and average heart rate all increased for the task-relevant pressure test, suggesting that the pressure manipulation was successful.

*******Table 3 near here*******

4. Discussion

In the current study, we sought to refine previous work in the area by matching the volume of information distributed to both the analogy and explicit light conditions, while still including a traditional explicit condition to facilitate comparison with earlier studies. With the amount of instruction controlled, the primary aim of the study was to then explore the effects of these differential instructional sets on movement learning and performance.

It has been thought that analogy learning promotes implicit skill acquisition that is more robust to performance pressures and less demanding on attentional resources than explicitly acquired skills. To investigate this, the current study measured the efficiency of technique and the accumulation of verbal knowledge as a function of condition. With regard to technical efficiency, the three conditions performed similarly throughout the learning phase, exhibiting comparable levels of increasing efficiency (see figure 2). During the task-relevant pressure test, differences in technical efficiency between the conditions for highest clearance became more pronounced, although these differences did not reach statistical significance (see figure 3). This non-significant finding corresponds with the results of Lam et al. (2009b), who did not find any significant differences in shooting performance between analogy and explicit learners in a basketball-shooting task. It cannot be ruled out, however, that differences between the conditions in this study might have been diminished due to contextual guidance, as some of the instructions for the traditional explicit condition, for instance, did not necessarily require explicit explanation because of the well-controlled experimental set up. At the same time, it is also important to recognise that the differences between the traditional explicit and analogy conditions would have been statistically significant had this study followed the typical design of the preceding research and not included the explicit light condition.

From an applied perspective, there is practical significance in the less efficient—and more variable—technical performance of the traditional explicit condition compared to the analogy and explicit light conditions with their lightened informational loads. For coaches and practitioners in the field, it is also interesting to note that only one traditional explicit participant managed a third-attempt clearance—three fewer than each of the other two conditions—even though every participant would have had *at least* one opportunity to do so (see table 4). In the context of high jump, every additional clearance is meaningful and the practical value of pressure-laden third-attempt clearances is difficult to understate. The similarity between the analogy and explicit light conditions in this regard has implications regarding the impact of instructional volume on performance, although the analogy group still performed better on average. In fact, in applied settings, the higher, more consistent, and more efficient clearances of the analogy learners—compared to their explicitly instructed counterparts—would be difficult for coaches to ignore.

*******Table 4 near here*******

*******Table 5 near here*******

With regard to verbal knowledge, the very nature of explicit instruction is thought to promote its accumulation, (Lam et al., 2009b; Liao & Masters, 2001; Masters & Maxwell, 2004; Poolton et al., 2006), however, the explicit light condition reported fewer task-relevant rules on average than the traditional explicit group, suggesting that instructional type alone cannot account for the accumulation of task-relevant knowledge. That said, the analogy condition still demonstrated greater technical efficiency and reported fewer task-relevant rules than the explicit light condition, suggesting that the reduction of instructional volume fails to fully explain the differences observed between the groups. It may be that the accumulation of verbal knowledge is moderated not by the volume of instruction, which was matched in word count between the analogy and explicit light conditions (see table 1), but by the number of rules or movement components within those instructions, as the explicit light instructions contained one additional rule—with one of those rules referencing two movement components (i.e., lift leg over the cord and bring back down). Without further investigation, it is difficult to determine whether the accumulation of task-relevant knowledge resulted from disparate properties of the instructions themselves or a discrepancy in the number of rules within these instructions. At the very least, however, the results for both technical efficiency and reported verbal rules demonstrate that more information is neither necessary nor particularly helpful for learners.

A secondary aim of the study was to investigate differences in movement coordination with respect to instructional type. Kinematically, it was hoped that the adoption of analysis techniques inspired by research in dynamical systems theory would assist in identifying and contextualising any unique biomechanical characteristics engendered by the experimental conditions. Based on previous biomechanical analyses, the technical demands of the scissor jump, and Bernstein's (1967) hypothesised motor control strategy of freezing and freeing degrees of freedom, joint variability around the mean in the knees and hips was examined for both phases of the study. Analysis revealed significant differences between conditions for both the learning and testing phases with the analogy condition demonstrating the lowest variability of the three experimental conditions in both segments. At first glance, this would seem to correspond to and possibly explain the lower standard deviation in technical efficiency for the analogy condition, but the explicit light condition exhibited the greatest variability on average across all joints. Instead, the results suggest that the instructions differentially constrained movement, because of subtle differences in the way that the movement was described. For instance, the traditional explicit instructions indicated—through the use of the word straight—and the analogy instructions implied—through the scissor analogy—that knee angles should approach 180° at some point during the jump, whereas the explicit light condition never conveyed any specific information regarding the angle or positioning of either knee. Without this information, participants in the explicit light condition could engage in more exploratory behaviour, resulting in greater knee joint variability (see figure 5).

Across conditions, joint variability generally decreased over the course of the learning phase, contrary to the predictions of dynamical systems theory. This could indicate a search for a preferred movement pattern early on—characterised by greater variability—with a gradual transition toward more stable coordination tendencies. This pattern did not hold for the task-relevant pressure test, however, as there was a significant interaction between condition, joint angle, and block for the testing phase. It could be that the high jump bar, which was introduced during the task-relevant pressure test, constrained movement as its height increased, no longer allowing the same freedom of movement afforded during the previous blocks of the study. It is also possible that the nature of joint variability changes as learning progresses. For instance, Hodges et al. (2005) found that range of motion in the hip initially decreased for the first five practice sessions of a soccer chip shot task before reversing direction, while the opposite pattern was revealed for the degree of linear coupling between joints. Although the number of trials in this study were deliberately chosen to more accurately represent applied settings and limit fatigue, additional trials might have offered additional insight in this regard.

Possible explanations aside, these findings offer limited support for Bernstein's predictions. The results of this study do, however, correspond to constraints-led approaches regarding the nature of motor skill acquisition, which build upon concepts from dynamical systems theory and ecological psychology (Renshaw, Davids, Chow, & Shuttleworth, 2009). From this perspective, verbal information represents one of many constraints that interact with the individual characteristics of the learner, such as physical attributes and cognitive capabilities, to shape movement behaviour (Chow, Davids, Button, & Koh, 2008). For coaches and sport psychologists working in the field, the challenge, therefore, is selecting the most appropriate of these sources of information to facilitate exploratory learning processes (e.g., Chow et al., 2007; Handford, Davids, Bennett, & Button, 1997; Komar, Chow, Chollet, & Seifert, 2014). Although analogy instruction in this instance appears to have placed greater constraints on movement, further investigation is required to determine whether this finding is unique to this study or applies more generally.

Considering the results of the study as a whole, it appears that reducing the instructional volume has narrowed the gap between analogy and explicit learners, suggesting that the benefits previously ascribed to analogy could have been overstated. Lam et al. (2009b) argued that analogy's advantage lay in its implicit conveyance of instruction, citing the work of Wulf and colleagues on locus of attention (e.g., Wulf, McNevin, & Shea, 2001; Wulf &

Shea, 2004) that demonstrates that focusing on even a single aspect of internal movement can disrupt performance. When explicit instruction matches analogy in its concision, however, it becomes unclear in what ways analogy distinctly benefits learners, especially in the face of research that shows that novices benefit from the skill-focused attention that is associated with explicit instruction (e.g., Beilock, Carr et al., 2002; Beilock, Wierenga, & Carr, 2002). One of the strongest arguments for analogy learning may be that it could forestall skill failure at more elite levels of performance, although this would require a longer-term study comparing analogy and explicit methods that are matched in instructional volume or, perhaps, movement components. As it stands, analogy's greatest strength rests in its comparatively concise delivery, although there is limited evidence to suggest that it offers any inherent benefits over explicit instruction otherwise.

4.1. Future directions

The exclusion of two participants for disregarding instructions and instead relying on knowledge for separate, yet related skills presents a possible limitation that could have implications for not only this study, but much of the existing literature. In this regard, most of the research in analogy and explicit learning has hinged on the assumption that the participants involved are complete novices without any previous knowledge or experience that could influence their movements or behaviours. However, in a review of motor learning research exploring the impact of focus of attention, Peh, Chow, and Davids (2011) noted that it could be unrealistic to assume that the preferred movement tendencies for a number of skills—even those that appear ostensibly novel—have not already been shaped by vicarious experiences or through personal participation in similar tasks. In this regard, the shortened, straightened, and less specialised run-up of the scissor jump technique could have permitted a transfer of skills or movement knowledge from other jumping-related skills (e.g., long jump, basketball lay-ups) that might not have been possible with the more complex and physically demanding approach required for the Fosbury Flop. In response, Peh et al. (2011) suggested the use of wholly unique movement tasks (i.e., novel tasks without any real-world equivalents) to minimise the effect of any previous experiences, although they also acknowledged that this approach could affect the generalisability of the findings to other movement skills. Rather than adjust the design of motor learning-related studies, a simpler and possibly more insightful approach could be to recruit adolescent participants who would not only have fewer experiences upon which to draw, but would also better represent the students and athletes that might be learning such movement skills in the field. Although the recruitment of younger participants can add additional ethical and logistical challenges, their inclusion could serve to enrich or, perhaps, even transform current understanding of the impact of analogy and explicit instruction while simultaneously addressing difficulties regarding task novelty.

Going forward, it may also be time to finally abandon the traditional explicit condition in future research designs, as long lists of instructions are unrepresentative of didactic methods in the field and conflict with recommended practice (e.g., McQuade, 2003; UK Athletics, 2009). As such, their continued inclusion may limit the relevance and generalisability of empirical research to real-world situations, which helps neither researchers nor practitioners alike. At the same time, it could also be time to entirely rethink the standard research paradigm in this area, as coaches typically do not provide learners with fixed, unchanging sets of instructions to learn over the course of several days. While these heavily controlled designs may be necessary to establish an initial understanding of the effects of verbal instruction, subsequent studies should begin to give way to the real-world issues faced by performers and coaches. The incorporation of more modern measurement and analysis technologies may also help in this endeavour, as the methods of analysis in analogy and explicit learning research have remained largely unchanged over the years, despite considerable technological advancements in measurement techniques that have fuelled development in other areas of skill acquisition and coordination research (Hodges et al., 2005).

4.2. Conclusion

By controlling the volume of information, performance for the explicit light condition was brought more in line with the analogy learners relative to their traditional explicit counterparts, indicating that the advantages ascribed to analogy learning might not be as pronounced as previously believed. It could still be that analogy learning promotes learning that is more robust to performance pressure in elite performers, but additional study will be required to distinguish the properties or qualities of these instructional types that engender such learning and performance benefits. Kinematic analyses failed to support Bernstein's (1967) proposals regarding the freezing and gradual releasing of biomechanical degrees of freedom, although they did suggest that movement may vary with respect to the provided instructional information, which may hold important implications for researchers in human movement studies with an interest in dynamical systems and constraints-led approaches. The results from this study raise questions regarding analogical and explicit instruction—from both theoretical and applied perspectives—that warrant further investigation.

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Figures

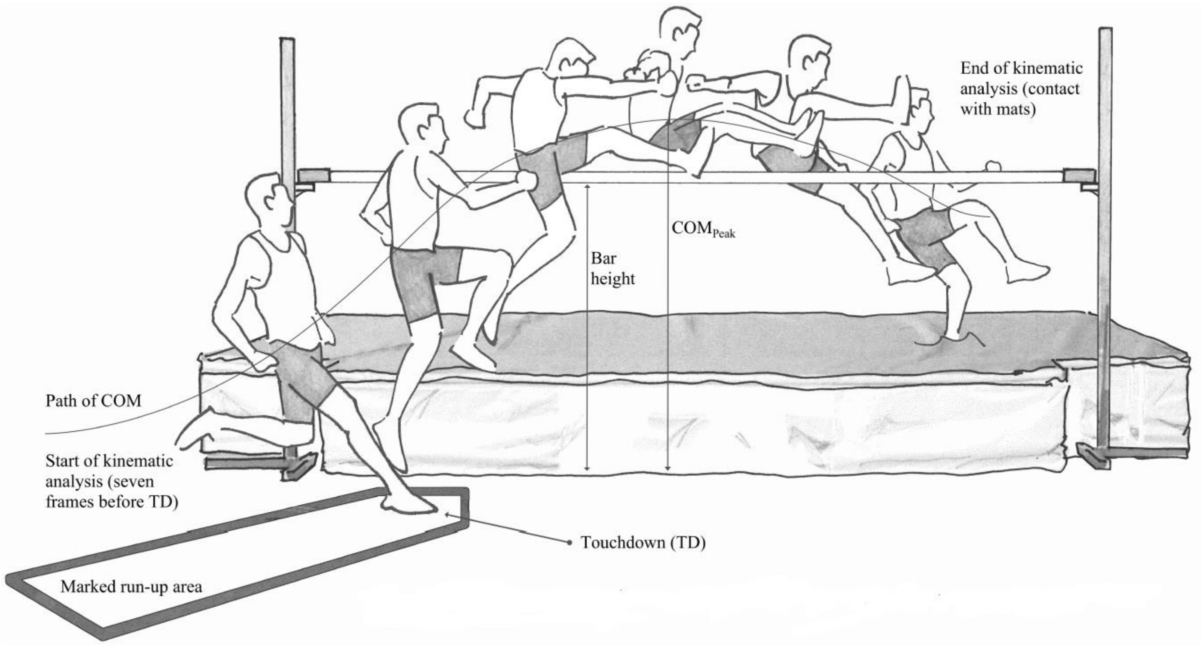

Figure 1. Illustration depicts the task set up, the scissor technique, and the key concepts related to technical efficiency and the kinematic analysis.

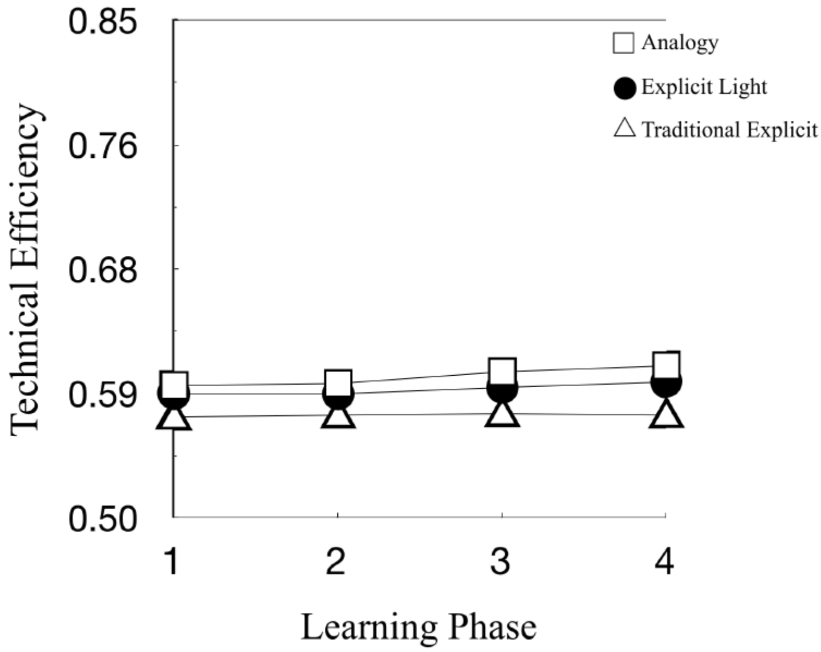

Figure 2. Mean technical efficiency as a function of condition during the learning phase.

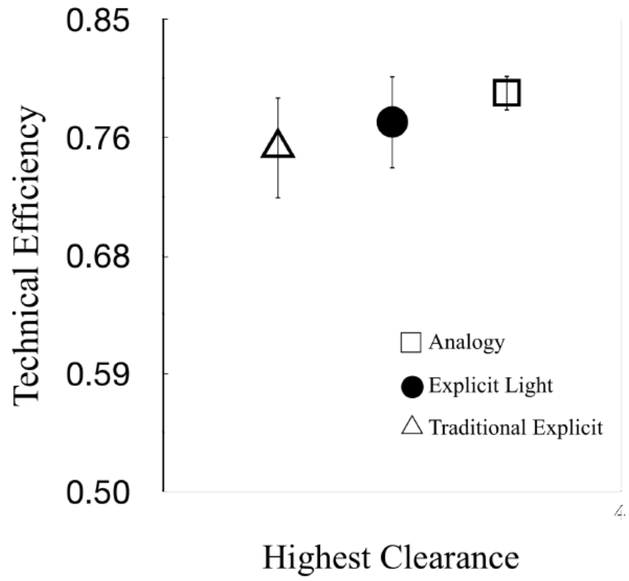

Figure 3. Mean technical efficiency for highest clearance in the task-relevant pressure test as a function of condition. Error bars show standard deviation.

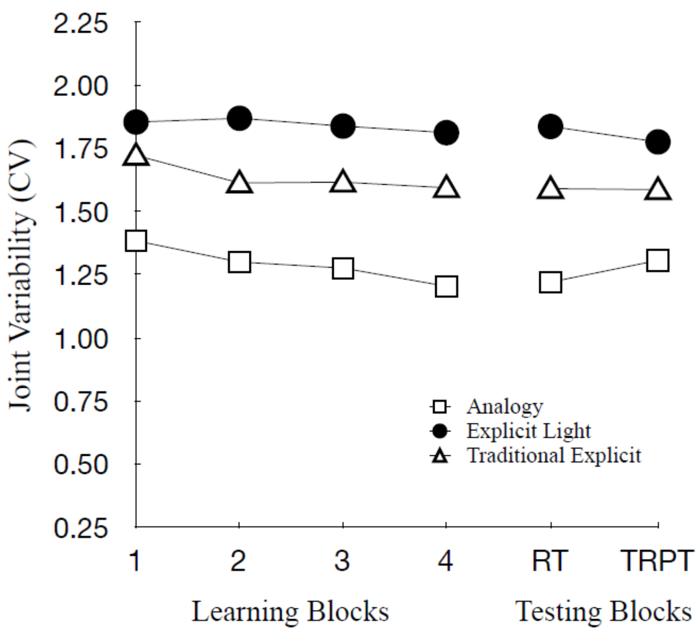

Figure 4. Transformed CV values for joint variability averaged across joint angles for each condition during the learning and testing phases (retention test and task-relevant pressure test).

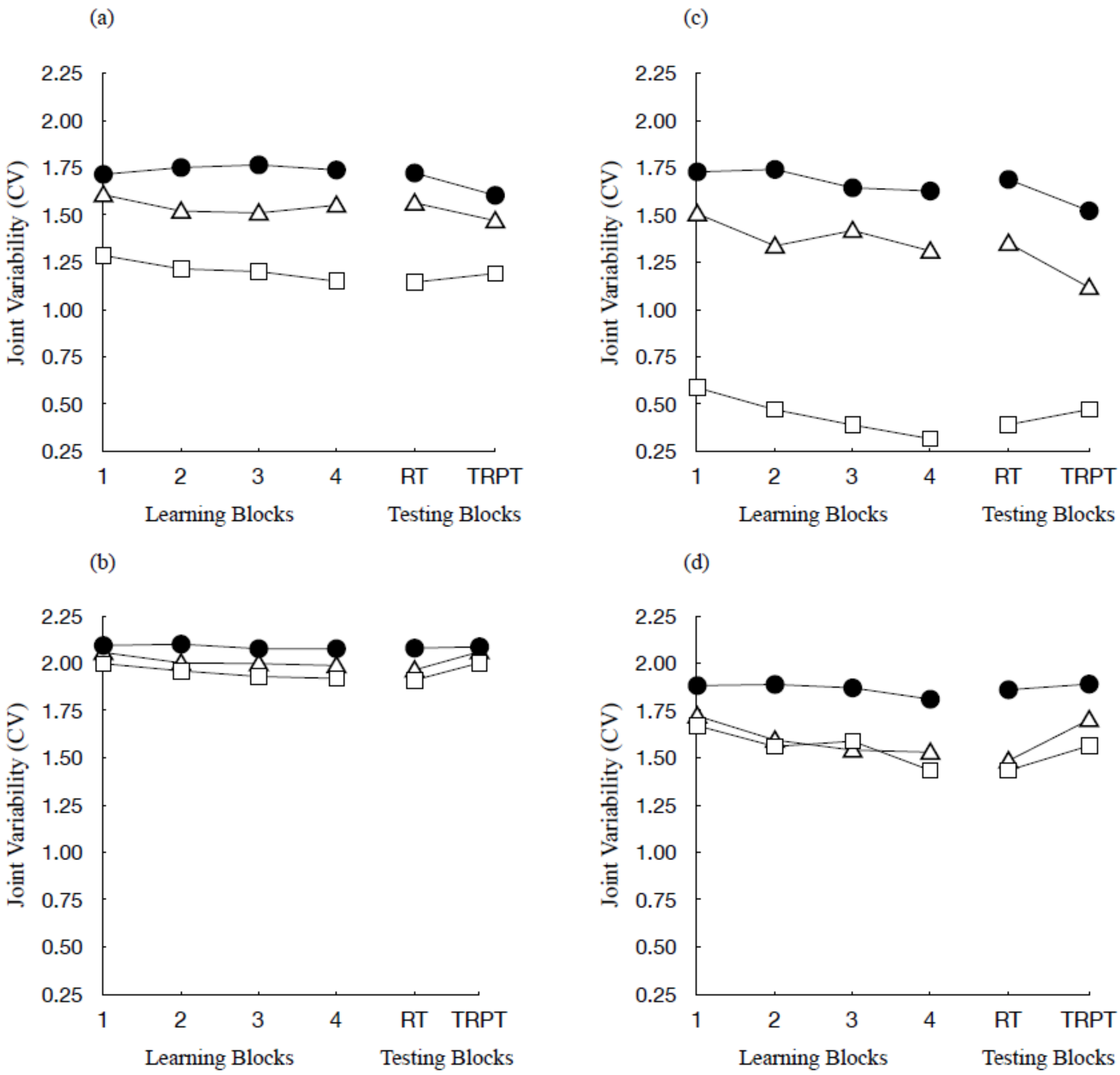

Figure 5. Transformed CV values for joint variability as a function of condition over the learning phase and testing phase (retention test and task-relevant pressure test). (a) Left Knee (b) Left Hip (c) Right Knee (d) Right Hip. □ – Analogy, ● – Explicit Light, △ – Traditional Explicit.

Tables

Table 1. *Instructions for the Experimental Conditions*

Condition	Instructions
Analogy	Keep your upper body tall like a pencil through takeoff. Alternate your legs like scissors to clear the bungee cord.
Explicit Light	Keep upper body tall through takeoff. Lift left leg up over the cord and bring down. Repeat action with right leg.
Traditional Explicit	Stand with your feet together at 30º to the crash mats. Take two steps toward the mats, leading with your left leg. As you complete the second step, firmly plant your right foot on the floor 45-60 cm from the mats. Jump up using your right leg, fully extending off of your toe (so leg is straight), while driving your left knee. Lift your left leg up and over the cord and bring down. Repeat this action with right leg. Land upright, standing on your left leg. Maintain a vertical position with upper body throughout.

Table 2. *Practice Schedule with Indication of Measurement Trials*

Block	Cumulative number of practice trials	Measurement trials	Cumulative number of measurement trials
1	10	1, 4, & 10	3
2	20	11, 14, & 20	6
3	30	21, 24, & 30	9
4	40	31, 34, & 40	12
5	50	41, 44, & 50	15
6	60	51, 54, & top clearance	18

Table 3. *Comparison of Anxiety Thermometer, RSME, and Average Heart Rate*

	Last Learning Block		Task-Relevant Pressure Test	
	M	*SE*	*M*	*SE*
Anxiety Thermometer *	1.09	0.30	3.23	0.41
Rating Scale for Mental Effort *	58.14	4.87	79.57	3.84
Average Heart Rate * (beats per min)	97.4	2.7	107.3	3.0

* Difference between blocks significant at p < .001 level

Table 4. *Mean cumulative totals as a function of condition during task-relevant pressure test*

	Successful Clearences		Successful Third Attempt Clearences		Failures*	
	M	*SD*	*M*	*SD*	*M*	*SD*
Analogy	7.86	0.90	0.57	0.53	2.00	1.00
Explicit Light	7.43	1.27	0.57	0.53	2.14	1.07
Traditional Explicit	7.86	1.07	0.14	0.38	0.86	1.21

* Does not include the final three failures for each participant that ended the task-relevant pressure test

Table 5. *Comparison of mean values for highest clearance during task-relevant pressure test as a function of condition*

	Standing Height (m)		Highest Clearance (m)		Technical Efficiency		COM_{TD} (m)		COM_{TO} (m)		COM_{Peak} (m)	
	M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Analogy	1.81	0.08	1.25	0.08	0.80	0.01	0.93	0.05	1.30	0.05	1.57	0.05
Explicit Light	1.81	0.09	1.21	0.09	0.77	0.03	0.93	0.04	1.29	0.07	1.57	0.05
Traditional Explicit	1.83	0.06	1.22	0.06	0.75	0.04	0.97	0.03	1.31	0.05	1.61	0.07

COMTD refers to the height of the COM at touchdown when the jumping leg first contacts the floor to initiate the jump. COMTO represents the height of the COM at takeoff—the moment that the jumping leg loses contact with the floor. COMPeak is the COM at the maximum height of the jump.