Effects of Balance Cues and Experience on Serial Recall of Human Movement

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One way that student dancers learn new contemporary dance, hip-hop or ballroom dancing is by observing and reproducing dance phrases or steps. For experts, learning long and complex sequences may appear effortless whereas for those new to dance, the task is challenging with both motor and cognitive demands. On the cognitive side, the first stage for increasing familiarity or perceptual fluency is registering or encoding material in the short-term memory. With rehearsal, the material may be transferred subsequently to the long-term memory. Theories propose that human memory is cue driven – the more cues that are present while taking information in, that are also present at the time of retrieving the information, the better the recall. In this study, we investigate proprioceptive cues related to relative stability, as cues to short-term memory for recalling a series of simple body movements. We ask: is the feeling of either being in a balanced or unbalanced standing position a cue to short-term memory for movement material? And, if so, are such proprioceptive cues moderated by dance experience?

An experiment was designed to test short-term memory for relatively simple body movements. Our aim was to investigate the observation of a series of movements and their immediate recall in the original order by adults with differing levels of specialist movement experience, including dance and martial arts. The experiment task was similar to a dance teacher performing a number of different movements and students recalling those movements immediately by performing them using their body and in the correct order. To minimise intrusion from long-term knowledge of biological motion – as such knowledge may distinguish novices and experts without testing their short-term memory capacity – disconnected or non-flowing simple movements were used as the material to be observed and later recalled.

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Relative stability in our experiment participants was challenged using the Tandem Romberg Position (TRP), which involves standing toe-to-heel in a line, and we reasoned that this should not impair experts' recall of movements using their body, relative to those less expert. According to the concept of encoding specificity from working memory (WM) theory, recalling items in the correct order is most likely when there is a match between cues during encoding and retrieval. If relative stability is a contextual cue during observing and learning movement, then recall should be greatest when contexts match during encoding and retrieval. In Experiment 1, low and moderate movement experience groups observed and then performed four body movements; in Experiment 2, and following the same procedure, low, moderate, and high movement experience groups recalled six movements. Recall span and movement experience were positively correlated – the more movement training, the greater the memory span. In Experiment 1, encoding specificity was observed, indicating that proprioception can be a cue to recalling movement from WM.

The results indicate that changing proprioceptive cues can reduce memory span for movement, especially among those with low or moderate experience. In teaching new movers, there is a need to maximise the cognitive resources available for learning, by reducing the number of competing demands on attention and working memory. The present results also support the common practice in dance companies to disrupt context-specific cues by changing location – and training the execution of movement phrases, in different spatial orientations. Generalisation to different environmental contexts appears to strengthen the memory trace. For dance teachers, the present results identify potential impairments to recall, the advantages of initially minimizing competing demands, and later diversifying contextual cues, including varying environments where new material is learned and rehearsed.

1 INTRODUCTION

One way that student dancers learn new contemporary dance, hip-hop or ballroom dancing is by observing and reproducing dance phrases or steps. Anecdotally, adult novice dancers, often accomplished in other fields, report their surprise and despair at not being able to 'keep up' with a dance teacher and having difficulty remembering ballroom or hip-hop steps and the order in which to do them. For experts, learning long and complex sequences may appear effortless, whereas for those new to dance, the task is challenging, with both motor and cognitive demands. On the cognitive side, the first stage for increasing familiarity or *perceptual fluency* is registering or encoding material in short-term memory. With rehearsal, the material may be transferred subsequently to long-term memory. Theories propose that human memory is cue driven – the more cues that are present while taking information in, that are also present at the time of retrieving the information, the better the recall. In this study, we investigate proprioceptive cues related to relative stability, as cues to short-term memory for recalling a series of simple body movements. We ask: is the feeling of either being in a balanced or unbalanced standing position a cue to short-term memory for movement material? And, if so, are such proprioceptive cues moderated by dance experience?

An experiment was designed to test short-term memory for relatively simple body movements consisting of a start pose, trajectory, and end pose. Our aim was to investigate the observation of a series of movements and their immediate recall in the original order by adults with differing levels of specialist movement experience, including dance and martial arts. The experiment task was similar to a dance teacher performing a number of different movements and students recalling those movements immediately, by performing them using their body and in the correct order. To minimise intrusion from long-term knowledge of biological motion, as such knowledge may distinguish novices and experts without testing their short-term memory capacity, disconnected or non-flowing simple movements were used as the material to be observed and later recalled. While the experimental method imposes constraints on the movement material and task, laboratory control enables investigation of short-term memory capacity with results that should generalise to the dance studio and teaching contexts.

1.1 Serial Recall as a Lens on Short-Term Memory

Recalling items in serial order is a task used by cognitive psychologists to discover the capacity or item span, duration, and form of knowledge, in human short-term or working memory (WM). Working memory refers to a temporary (20–30 seconds) store for information needed to accomplish a particular task (Reed, 2010); for example, watching and then reproducing a series of novel phrases of movement. WM is essential in the creation of new dance works as the choreographer/dancer images or mentally rehearses phrases, sequences, spatial positions and trajectories of a solo dancer, or juxtapositions within an ensemble of dancers, in the four dimensions of space and time. WM allows a choreographer or dancer to hold many dimensions and relations in mind at once (e.g., Halford, Wilson, & Phillips. 1998) and is intimately connected with the capacity of humans to imagine and to travel mentally forward and backward in time (Stevens, Ginsborg, & Lester, 2011). Most studies of WM have used disconnected, static items such as words, digits or spatial locations. The present experiment investigates whether WM span for these less embodied materials is comparable with the span for dynamic movement items.

The majority of models of memory propose that memory is cue driven (Surprenant & Neath, 2009) and the more environmental cues that are present while taking information in (encoding), that are also present at the time of retrieval, the better the recall. For example, a sequence of novel dance steps will be better recalled in the studio where it had been learned and rehearsed in the presence of the associated music and other dancers, than in a new location with no or new music and different dancers present. In the former context (recalling dance steps in the studio where they had been learned and in the presence of the associated music and dancers), there are many more contextual cues than when the steps are recalled in a new location without or with new music and different dancers. One assumption of the present experimental investigation is that feeling balanced *or* off-balance is a contextual cue to WM. Given classical dancers' extensive and explicit balance and symmetry training (Schmit et al. 2005; Wilmerding & Krasnow, 2009) and the diversity of postures, trajectories, stillness, and force that are hallmarks of contemporary dance (Butterworth & Wildschut, 2009; Humphrey, 1959), balance in dancers generally is likely to be highly learned and automatic, drawing on relatively few cognitive resources.

1.2 Stability, Cognition, and Movement Expertise

Stability is a learned and highly practised skill that carries a modest attentional cost (Woollacott & Shumway-Cook, 2002). Standing upright involves finding appropriate relations among body segments to maintain the desired position of the body as a whole with respect to the environment (Balasubramaniam & Wing, 2002). A handful of studies has examined effects of postural instability on cognition or, conversely, effects of cognitive tasks on postural stability (Ehrenfried et al. 2003). For example, Kerr, Condon and McDonald (1985) administered spatial and non-spatial memory tasks as participants either sat or maintained a difficult standing position. As the balance task disrupted participants' memory for spatial but not for non-spatial material, it was concluded that spatial and postural processes share neural mechanisms. The logic here follows that of an *interference paradigm* where the particular cognitive resources involved are deduced from patterns of interference from different kinds of tasks. Typically, participants perform two tasks concurrently. One task may be a task that involves keeping balanced and the other a task that involves memorising a set of spatial locations. If there is no interference (i.e., no poorer performance) on one of these tasks when a second task is introduced, it is concluded that the cognitive resources or processes that are involved in the two tasks are separate. However, if there is interference from one task on the other, then we conclude that there is some sharing of cognitive resources, such as attention or memory.

Contrasting with the conclusion of Kerr et al. (1985) of shared resources in performing a spatial task and maintaining stable posture, Dault, Frank and Allard (2001) reported no change in performance of WM when the postural stance was modified, and no change in postural sway when the difficulty of a cognitive visuo-spatial task was modified (i.e., no concurrent interference). Dault et al. concluded that the addition of a WM task forces the central nervous system to take tighter control of postural sway. The present experiment extends the previous research on memory for spatial or verbal material by investigating the effect of relative stability cues not on tasks that involve locations or words, but that involve memory for dynamic human movement.

Relative postural instability can be induced by using the Tandem Romberg Position (TRP) from the Tandem Romberg neurological test, a common static test of body stability (Diamantopoulous, Clifford, & Birchall 2003). The TRP involves standing toe-to-heel in a straight line with the eyes closed. People with impaired proprioceptive or vestibular systems may be able to compensate for their instability by having eyes open. It is common for people without neurological or balance problems to have some difficulty maintaining a steady posture when they attempt the TRP. The technique is used here as a laboratory-controlled simulation of a challenge to stability and a proprioceptive cue among dancers learning new movement material.

Dancers, athletes, and exponents of martial arts are likely to be less affected or unaffected by the demands of the TRP. Movement training may improve adaptive posture control through: i) training in the use of all sensory inputs – somesthetic, vestibular, visual – involved in maintaining equilibrium; ii) faster switching between inputs; and iii) the development of proprioception rather than vision in maintaining balance (Perrin et al. 1998). There are at least two motor control mechanisms for maintaining balance during standing (Dietz, 1993). One damps postural sway through neuromuscular coactivation. A second closed-loop control system detects movement of the centre of gravity, coupled with a fast acting error correction to reestablish vertical alignment (Simmons, 2005). Such mechanisms are probably attuned in dancers, athletes, and martial artists, as they have extensive experience with encoding and performing movements in complex and potentially unstable positions. Enhanced proprioception in dancers has been demonstrated by Ramsay and Riddoch (2001); Golomer and Dupui (2000) argued that dance training strengthens the accuracy of proprioceptive inputs and shifts sensorimotor dominance from vision to proprioception (p. 189); and Jola, Davies, & Haggard (2011) report enhanced proprioception in dancers and suggested that dancers generate proprioceptive images to visual cues.

In a visual task with eyes open and the recall of body movements using their own body to produce the movements at the time of recall, we anticipate that people with specialist movement experience will not be challenged by the TRP. People without such movement experience, by contrast, will need to divert cognitive resources to maintain their balance in the TRP. Thus, serial recall recorded by relative experts will be greater than that of non-experts.

1.3 Encoding Specificity and Serial Order Effects

In addition to memory being cue driven and according to the concept of encoding specificity (Godden & Baddeley, 1975; Tulving & Thompson, 1970), recall is greatest when cues during encoding (or study) and retrieval (or test), match. If balance and imbalance are contextual cues then recall should be greatest when cues at encoding and retrieval are congruent or match; specifically, when participants are standing in a balanced position during both encoding and retrieval (balanced-balanced) *or* a relatively unbalanced position during both encoding and retrieval (TRP-TRP); concomitantly, recall should decrease when cues at encoding and retrieval are incongruent or do no match, i.e., participants are balanced during encoding and off-balance during retrieval (balanced-TRP)

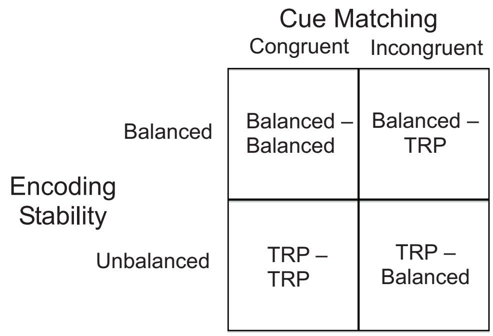

Fig. 1. There were two conditions where bodily cues during encoding and retrieval were congruent or matched and two where they were incongruent or unmatched. The congruent encoding and retrieval cues were encoding and retrieval when balanced (Balanced-Balanced) or in the Tandem Romberg (less balanced) position (TRP-TRP). Incongruent encoding and retrieval cues were: balanced during encoding and TRP during retrieval (Balanced-TRP), or TRP during encoding and balanced during retrieval (TRP-Balanced).

or off-balance during encoding and balanced during retrieval (TRP-balanced). These four experimental conditions are illustrated in Figure 1.

In studies of serial recall, much can be gleaned about the memory process from the serial position curve. The serial position curve is a graph that displays the relative recall of items when they occur in early, middle, or later positions in a list of items. Typically, in experiments on serial recall of digits or words, the serial position curve reveals good memory for items in the initial positions in the list (*primacy*) and for items at the end of the list (*recency*), but poorer recall for items in the middle of the list. This pattern of primacy and recency has been taken as evidence for a distinction between long-term memory and short-term memory, respectively. That is, the initial items are rehearsed, transferred to, and retrieved from LTM, the last items remain in and are retrieved from STM, and the middle items are lost. Interestingly, the recall of ballet steps (Starkes et al. 1987) and figure skating movements (Allard & Starkes, 1991), show only a primacy effect. Allard and Starkes (1991) speculate that once an item is forgotten, recall of the following items tends to be doomed; disconnected items used in experiments are chained without higher-order structure or chunking. Accordingly, serial recall of disconnected movement items in the present controlled experiments should reveal primacy but not recency effects.

1.4 Aim, Design, and Hypotheses

Experiment 1 investigates the effects of moderate movement experience and balance on the serial recall of sequences of four simple body movements. We manipulated cue matching (congruent versus incongruent), encoding stability (balanced versus unbalanced), serial position (1, 2, 3, and 4), and movement experience (low versus moderate). It was hypothesised that: i) serial recall is greater when encoding and retrieval cues are congruent (balanced-balanced, TRP-TRP) than when they are incongruent (balanced-TRP, TRP-balanced); ii) serial recall by the moderate experience group is greater than that by the low experience group; and iii) following the results of Starkes et al. (1987), serial recall of body movements shows a primacy effect only.

2 EXPERIMENT 1 – FOUR-MOVEMENT SEQUENCES AND MODERATE MOVEMENT EXPERIENCE

2.1 Method

2.1.1 Participants

Participants were first-year psychology students at the University of Western Sydney. Forty-eight students (9 males/39 females) received course credit for participation and ranged in age from 18 to 40 years of age (*Mean (M) or average* = 20.19 years, *Standard Deviation (SD) or dispersion* = 6.30). Participants were allocated to a group based on their experience in dance, sport or martial arts. The low-experience group consisted of 24 students with less than five years of dance sport and/or martial arts experience ($M = 1.03$, $SD = 1.95$) and ranged in age from 17 to 24 years ($M = 18.92$, $SD = 2.02$). The moderate experience group consisted of 24 students who had 5 or more years of movement experience in dance, sport and/or martial arts ($M = 12.94$, $SD = 7.93$), engaged, on average, in one training or performance session per week, and ranged in age from 17 to 49 years ($M = 21.46$, $SD = 8.58$).

2.1.2 Stimuli

Stimuli consisted of 12 different, simple body movements following those used by Smyth, Pearson, and Pendleton (1988). The movements were selected from the larger repertoire of Smyth et al. on the grounds that the movements were achievable even when standing in the TRP, including two movements using one leg. The movements are discrete rather than connected – in keeping with prior research and to be comparable with experiments on verbal WM where there are no meaningful or statistical connections between items in a list. Each movement item begins and ends in the same posture (standing and with hands relaxed at the sides of the body), enabling each trial to consist of a novel sequence of items. People with dance experience would have detailed knowledge and expectations of biological motion in dance. By using disconnected movements we deliberately control momentum and flow. Such control is essential for the examination of WM span without the intrusion of long-term knowledge of movement conventions and likely transitions.

To ensure consistency across all experiment sessions, the movements were performed by an amateur dancer and recorded on digital video. The 12 movements were: two head (head forward bend, head right turn); four arm (left arm raised straight above head, right arm raised to shoulder height to the side, both arms raised to shoulder level to front of body, both arms crossed so that fingers of each hand touch the opposite shoulder); bend of knees with torso straight; two leg (right leg raised to the side, left leg raised to the side); torso bent forward 90 degrees; left arm bent to hip; and right arm bent to shoulder. Movement duration, tempo, and spatial displacement were comparable. An example of the stimuli can be seen in Video 1.

Each trial consisted of four different movements. There were eight trials in total, two from each of the encoding-retrieval combinations shown in Figure 1. There was no repetition of any one movement in a trial and each of the 12 movements was used approximately three times during an experiment session. Two orders of experimental trials with a random order of movements within each trial, were distributed evenly across the sample. Each movement took 2 s and there was zero inter-stimulus interval (ISI) between movements making each trial 8 s long. At the end of a trial, 'recall' appeared on a black screen and participants recalled the movements in serial order. The recall period between trials was 10 s.

2.1.3 Equipment

A laptop computer was used to play DVDs of the stimuli, and a data projector projected a life-size image of the amateur dancer onto a large white screen. A digital camera recorded the projected stimuli and the participant's movement responses.

2.1.4 Procedure.

Participants read an information sheet and signed a consent form in accordance with the University of Western Sydney Human Research Ethics Committee. Participants, standing in stockings or bare feet, observed a series of movements presented on the screen in front of them and, using their body, recalled the movements in the correct sequence, and mirroring the projected image they saw (Smyth et al. 1988). For example, if the movement on the screen involved lifting the right arm above the head, the participant would need to lift their left arm. A response sheet was used to keep track of the correct or incorrect order of movements and was double-scored post-experiment using the video. A correct movement in the correct serial position earned a score of one, but correct movements in the wrong serial position were given a zero score in serial recall. To be regarded as a correct movement, it needed to include the start pose, trajectory, and end pose; movement quality did not affect the score assigned. Video recordings were also analysed for motor skill variations. Errors such as loss of balance (e.g., needing to take a step to correct balance), omission of a movement, interference from another sequence, serial position problems, and right or left side errors, were recorded. The experiment took 30 minutes.

3 RESULTS

3.1 Summary

Data consisted of serial recall with a maximum possible score of 4 which, when calculated as proportions, yield a maximum possible score of 1.0 – in general, the greater the proportion, the better the performance. The results can be summarised as follows. Serial recall was greater when encoding and retrieval cues were congruent (Balanced-Balanced; TRP-TRP), compared with when the cues were incongruent (Balanced-TRP; TRP-Balanced). Recall by the moderate experience group was not greater than that recorded by the low experience group, although recall was affected by the combined influence of experience, encoding stability, and serial position. The proportion of movement items recalled in a series was associated with the amount of dance experience – the more experience participants had, the greater the recall. A primacy effect was evident with recall greater for items at the beginning of the series than in the middle or end.

3.2 Statistical Analyses

To investigate the effect of the variables manipulated in the experiment, we used a four-way (2×2×2×4) mixed analysis of variance (ANOVA) consisting of Cue Matching (congruent, incongruent), Encoding Stability (balanced, unbalanced), Experience (low, moderate), and Serial Position (1, 2, 3, 4). Differences between experimental conditions will be regarded as statistically significant when the probability or p value is less than 0.05.

With other variables collapsed, there was a main effect of cue matching, $F(1,46) = 11.65$, $p < .05$, with significantly greater serial recall of movement items when encoding and retrieval cues were congruent ($M = .70$, $SD = .36$) than when incongruent ($M = .62$, $SD = .38$). In other words, recall was greater when participants, regardless of experience, observed and recalled movement items standing either in a balanced position or when they observed and recalled items standing in the TRP (70% correct) compared with when stability cues differed at encoding and retrieval (62% correct).

There was no significant effect of low versus moderate experience on recall. There was a main effect of serial position, $F(3, 138) = 54.81$, $p < .05$. Supporting the hypothesis, the order of the mean serial recall, revealed a primacy effect, with significantly greater recall for items in serial position one ($M = 0.81$, $SD = 0.22$) than items in serial position two ($M = 0.75$, $SD = 0.22$), $F(1,46) = 5.88$, $p < .05$, or items in serial position three ($M = 0.61$, $SD = 0.21$), $F(1,46) = 41.84$, $p < .05$. As hypothesised, there was no recency effect; recall was significantly greater for items in serial position three ($M = 0.61$, $SD = 0.21$) than items in serial position four ($M = 0.46$, $SD = 0.23$), $F(1,46) = 29.34$, $p < .05$.

There was a significant interaction between cue matching and serial position, F(2.68, 123.48 Greenhouse-Geisser correction) = 2.88, $p < .05$. Figure 2

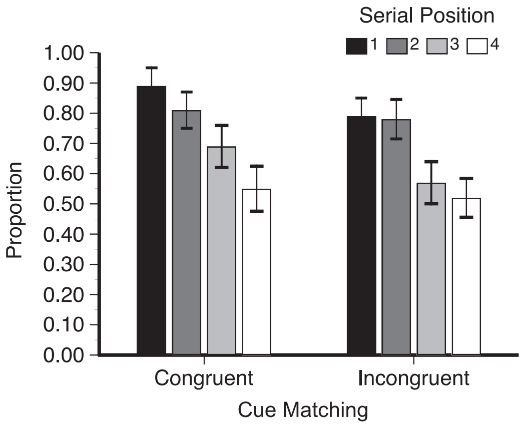

Fig. 2. Experiment 1: mean serial recall of four items shown as proportion correct and as a function of cue matching and serial position. Error bars refer to standard error of the mean.

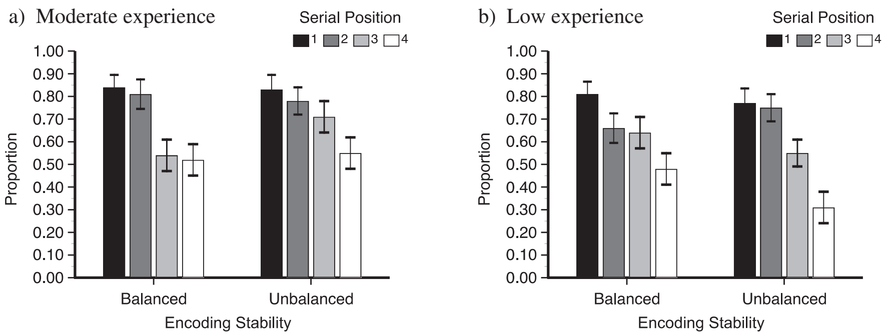

Fig. 3. Experiment 1: mean serial recall of four items shown as proportion correct and as a function of encoding stability, serial position, and a) moderate experience, b) low experience. Error bars refer to standard error of the mean.

shows the interaction. Descriptively, serial recall was poor when context cues are incongruent, compared with when they are congruent, especially for items in positions 1 and 3 in a series of four movement items.

The encoding stability x serial position x expertise interaction was significant, $F(3,138) = 4.91$, $p < .05$, see Figure 3, panels a and b. For example, those with less movement experience recalled significantly fewer movement items than those with moderate experience, when they were balanced during encoding and subsequently recalling items in position 2 in the series of items, and when relatively unbalanced during encoding and subsequently recalling items in positions 3 and 4 of the series of items. Serial recall accuracy and amount of movement experience were positively correlated ρ (Spearmans rho) $= 0.35$, $p = 0.02$. This means that a greater memory span was associated with more years of movement training.

The types of errors recorded by moderate and low experience groups are shown in Figure 4. So-called memory errors – substitution, omission, serial

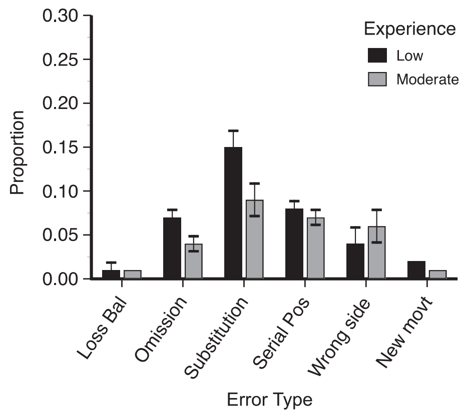

Fig. 4. Experiment 1: proportion of occurrence of different types of errors shown as a function of experience. Error bars refer to standard error of the mean.

position errors – were grouped together as they relate to substitutions from memory, lapses, or swapping the order of items, respectively. Body-related errors referred to loss of balance, using the wrong right or left limb, or constructing new movements that had not been shown. Descriptively, there were more errors that were memory- than body-based. Figure 4 illustrates relatively few errors relating to balance, that is, having to take a step to prevent falling. We take the relatively small number of these errors to mean that participants were striving to stay upright in the TRP.

4 DISCUSSION

The results of Experiment 1 indicate that when memorising disconnected, simple body movements, relative stability is a cue to short-term memory. Specifically, serial recall of simple human movements is significantly greater when proprioceptive cues are congruent during encoding and retrieval conditions compared to when they are incongruent. Standing in a balanced or unbalanced position appears to be a cue to memory like other contextual cues that have been manipulated in encoding specificity experiments (e.g., Godden & Baddeley, 1975). Put another way, recall is reduced when the stability cue from encoding is not present at retrieval.

Serial position effects were observed but, unlike word and digit span tasks, movement span does not show a recency effect (Allard & Starkes, 1991; Starkes et al. 1987). The proportion of items recalled as a function of serial position indicates that when an item is forgotten, there is less likelihood that the subsequent item will be recalled.

The amount of movement experience, correlated with recall span and interacted with encoding-retrieval cue and serial position. Specifically, the moderate experience group had significantly greater recall for items in serial position 2 when balanced during encoding, compared with those less expert.

When participants were challenged by the TRP during encoding, the low experience group was poorer at recalling movement items in serial positions 3 and 4. As expected, the amount of experience and serial recall are positively correlated – the more training, the greater the recall span. Golomer and Dupui (2000) have observed an effect of gender on postural control. However, the relatively-small number of male participants in Experiment 1 did not enable statistical analysis of the effect of gender; gender will be considered in data analysis in Experiment 2.

Expertise is generally associated with thousands of hours of deliberate practice (Ericsson, Krampe, & Tesch-Römer, 1993) and for dancers this would involve repetition to acquire skills and improve movement execution. Such repetition refines the ability to transfer weight and balance (Wilmerding & Krasnow, 2009). Thus, to scrutinise further relative balance as a cue to memory in experts, participants with extensive specialist experience in dance were recruited for Experiment 2, together with participants with low- and moderate-level experience. Given the involvement of a more expert group and the probability of their recall being extremely good (i.e., at ceiling), the span task was increased to six movements.

5 EXPERIMENT 2 – SIX-MOVEMENT SEQUENCES: LOW-, MODERATE- AND HIGH-LEVEL EXPERIENCE

5.1 Method

5.1.1 Participants.

Seventy participants, none of whom participated in Experiment 1, completed Experiment 2. Forty-eight (14 males/34 females) were students enrolled in first year psychology at the University of Western Sydney, receiving course credit for participation. The remaining twenty-two participants (4 males/18 females) were recruited from the QL2 Centre for Youth Dance in Canberra, and from the School of Dance, Deakin University. Participants were allocated to one of three groups based on their relative experience in dance, sport or martial arts: i) the low experience group comprised students who had less than five years of dance, sport and/or martial arts experience, and did not currently participate in regular specialist movement activity; the age range for this group was from 17 to 44 years of age ($M = 20.13$, $SD = 5.33$) with a mean of specialist movement experience of 1.4 years ($SD = 1.50$); ii) the moderate experience group consisted of students with five or more years of movement experience (cf. Rossi-Arnaud, Cortese, & Cestari, 2004), currently participating in occasional recreational specialist movement activity, with an age range from 17 to 24 years ($M = 19.5$, $SD = 3.53$) and mean sport or dance movement experience of 11.87 years ($SD = 6.29$); iii) the high experience group was made up of professional dancers with more than ten years of dance experience, who are currently involved in dance classes 1–2 times each week and perform often, and an age range from 20 to 47 years ($M = 33.5$, $SD = 19.09$) with a mean of specialist dance experience of 22.59

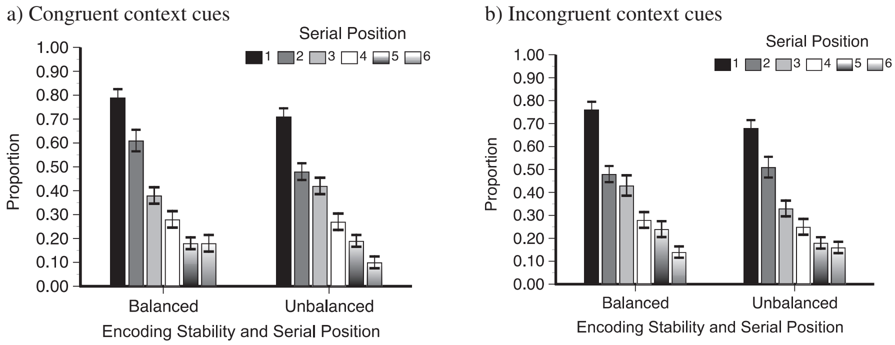

Fig. 5. Experiment 2: mean serial recall of six items shown as proportion correct and as a function of encoding stability and serial position in a) congruent and b) incongruent context conditions. Error bars refer to standard error of the mean.

years (*SD* = 15.86). The term 'high experience' here is relative, as the group has greater experience compared with the other two groups but still less than dance professionals who probably train 4–6 hours each day.

5.1.2 Stimuli, Equipment and Procedure

The movement material used in Experiment 1 was used in Experiment 2 but this time there were six different movement elements in each sequence. Across the experiment, each of the 12 movements was used four times each, with no repeats within a trial. Each of the eight trials was 12 s in length with a recall period of 15 s between trials. The equipment and procedure followed the Experiment 1 protocols.

6 RESULTS

6.1 Summary

The results can be summarised as follows. In contrast to Experiment 1, there was no encoding specificity effect with no advantage of cue matching. Recall by the high experience group was greater than that of the moderate and low experience groups. Greater memory span was associated with the amount of movement training – the more movement training, the greater the span. Finally, there was evidence of a primacy effect with better recall for items in early rather than middle or late positions in a series (Figure 5).

6.2 Statistical Analyses

Serial recall data were subjected to a four-way mixed analysis of variance (Experience (3) x Cue Matching (2) x Encoding Stability (2) x Serial Position (6)), and alpha set at 0.05. There was a significant main effect of experience, $F(2,67) = 13.63$, $p < .05$ with Scheffé comparisons revealing significantly greater serial recall in the high experience group ($M = .48$, $SD = .21$) compared with both the moderate experience ($M = .35$, $SD = .17$) and the low experience group ($M = .31$, $SD = .18$). Although the average recall here indicates that there was a trend with the moderate experience group having greater recall than the low experience group, the difference between moderate and low experience groups was not statistically significant. Experience and accuracy were positively correlated, $\rho = 0.31$, $p = .01$. There were no main effects of cue matching or encoding stability.

There was a main effect of serial position, $F(1,67) = 171.33$, $p < .05$, with higher rates of serial recall for the items in the initial positions in the series. As hypothesised, a primacy effect was evident, with greater average accurate recall of items in serial positions one ($M = 0.74$, $SD = 0.16$) and two ($M = 0.52$, $SD = 0.21$) than in serial positions three ($M = 0.39$, $SD = 0.19$) and four ($M = 0.27$, $SD = 0.17$), $F(1,66) = 201.19$, $p < .05$. Additionally, there was greater recall of items in serial positions three ($M = 0.39$, $SD = 0.19$) and four ($M = 0.27$, $SD = 0.17$) than in serial positions five ($M = 0.20$, $SD = 0.14$) and six ($M = 0.15$, $SD = 0.16$), $F(1,66) = 63.75$, $p < .05$. Unlike a recency effect, there was greater recall of items in serial position five ($M = 0.20$, $SD = 0.14$) than items in serial position six ($M = 0.15$, $SD = 0.16$), $F(1,66) = 6.91$, $p < .05$.

To examine whether there was any systematic effect of participant gender on accuracy, a 2×3 (gender x experience) ANOVA was conducted. There was no significant effect of participant gender on accuracy ($p = .78$) and no interaction between gender and experience ($p = .84$). The average proportion of items recalled accurately in serial order by males was .37 (SD = .15) and by females was .38 (SD = .11). The similarity of these averages for males and females suggests that the absence of a gender effect is unlikely to be because of the uneven numbers of male and female participants in Experiment 2.

The patterns of occurrence of different types of errors, for the three levels of experience, are shown in Figure 6. Errors were again classified as either memory-based (substitution, omission, serial position errors) or movement-based (loss of balance, wrong side, made-up movement) with more errors being memory- than movement-based. There were more serial position than omission errors, with the high experience group making more serial position errors relative to the low and moderate experience groups, and the high experience group making fewer omission errors than the other two experience level groups. Experts have remembered the item but not necessarily the exact order. Figure 6 reveals zero side errors recorded by the high experience group, possibly suggesting a more 'view-dependent' or relative rather than absolute, spatial frame of reference (see Galati, Pelle, Berthoz, & Committeri, 2010 regarding different frames of reference in memory for movement).

7 GENERAL DISCUSSION

Two experiments examined the hypothesis that people with specialist movement experience have superior recall of disconnected body movements compared with people with less specialist experience. A well-known effect in WM

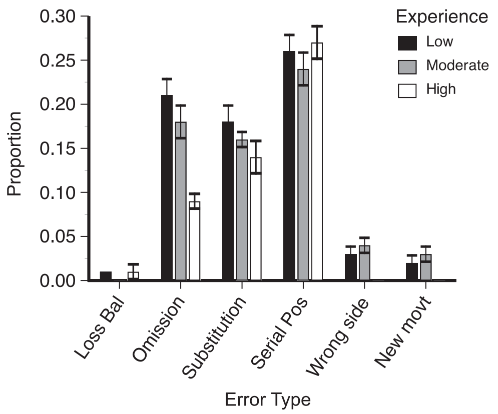

Fig. 6. Experiment 2: proportion of occurrence of different types of errors shown as a function of experience. Error bars refer to standard error of the mean.

research – encoding specificity – was investigated for the first time in the context of human movement, by comparing congruent and incongruent stability cues during encoding and retrieval. There is evidence of enhanced memory span in experts (Experiment 2). Moreover, the matching of cues at encoding and retrieval is especially important in those with little dance experience.

In both experiments, a positive correlation between the level of movement training and memory span was observed: more years of training were associated with greater memory span. Results reveal that when experience is moderate and the task moderately demanding (Experiment 1-four movements), the effects of experience are evident, interacting with encoding stability and serial position: that is: moderate, compared with low, movement experience enhances serial recall, when either stable or unstable, during the encoding and recalling of items at the beginning of a series (Figure 3). A significant effect of specialist movement experience for simple movements has been observed when movement experience is extensive and the memory demand high (Experiment 2-six movements). While the high experience group in Experiment 2 maintained the level of serial recall across cue context conditions at nearly 50% or 3 items on average, the low experience group recalled a relatively small number of items (on average 31% or less than 2 items per trial).

One explanation for the effect of expertise, is the extensive experience and automaticity of postural stability among dancers who frequently practice and perform complex poses and positions. If balance was disrupted in experts by the TRP, then the results of Experiment 2 suggest few if any of their cognitive resources were diverted from the memory task to stability. For example, if we compare Figures 4 and 6, we see that, in both experiments, few errors were balance-related in that on only a small number of occasions did participants take a step during recall to prevent falling. In Experiment 1, we interpreted this to mean low and moderate experience participant groups worked hard to maintain balance in the TRP at the expense of recall, especially for items that occurred towards the end of the series of items. See, for example, results from the low experience group standing in a relatively unbalanced encoding position, depicted in panel b of Figure 2. In Experiment 2, the relatively expert participants also made few balance errors but at less of a cost to recall accuracy. Schmit et al (2005) point to a possible explanatory mechanism. In their comparison of dancers and a control group (track athletes) they observed postural sway dynamics of dancers to be less correlated, less complex, and less mathematically stable than the control group. The authors conclude that it is not the amount of variability or postural sway but the dynamic patterns of postural sway that distinguish the participant groups; these different patterns are possibly related to focused balance training in dancers. Extensive dance training probably enhances proprioception and refines weight transfer and balance (Golomer & Dupui, 2000; Golomer et al. 2010; Ramsay & Riddoch, 2001; Wilmerding & Krasnow, 2009), becoming increasingly automatic and requiring little explicit attention.

Caution is needed when interpreting the superior performance of experts in Experiment 2, as alternative explanations cannot be ruled out. One possibility is that the TRP did not reduce the experts' stability, and all cognitive resources were available for the memory task. In fact, balance on one leg, especially for experts, may be easier from the TRP than the balanced position. Dancers, for example, start their pirouettes on one leg from a starting position that is similar to the TRP. A second possibility is that experts have a superior memory for movement, relative to novices, and that any concurrent task, not just a stability-disrupting task, would not have reduced their capacity to remember sequences of bodily configurations.

The congruency of encoding and retrieval cues led to significantly greater recall by both participant groups in recalling four items in Experiment 1; proprioception can serve as a cue for retrieval. However, in the more demanding six-item task of Experiment 2, there was no evidence of encoding specificity. It is likely that for the moderate and low experience groups, the demand of remembering six items outweighed any benefit from matched cues.

Future Directions for Research into Working Memory for Dance

Accuracy of serial recall, even for experts, was less than 100%, and may improve for all levels of experience if the movements are sequenced and connected according to momentum and biological motion. Such acquired knowledge was minimised deliberately in the present experiments to enable comparison of WM capacity, rather than acquired long-term knowledge, across different participant groups. Nonetheless, capacity will be maximised, especially for experts, where movements can be structured or chunked into meaningful sequences characteristic of plausible biological motion, particular dance genres, or choreographic traditions (Opacic, et al., 2009). Having established pure capacity for disconnected movement material, we can consider the way structured sequences of movements maximise short-term memory capacity.

Primacy effects observed in all groups and in both experiments point to the rehearsal of items occurring at the beginning of the series. The absence of a recency effect, accords with the observation of Starkes et al. (1987), that once a movement item is forgotten, the remainder of the sequence is lost. Chaining and dependency between adjacent items is implied by this result, but the use of increasingly dance-like, connected and rhythmical (i.e., hierarchically-structured) movement material, is likely to challenge the assumption of mere chaining.

Implications of the Results for Teaching New Dancers

The capacity of WM has been the focus of the present experiments. A dynamic WM is an essential cognitive apparatus for creating, perceiving, and performing contemporary dance. For example, choreographers and dancers rely on WM as they create new movement by tasking and showing movement (Kirsh et al. 2009), planning and experimenting with improvised material, and in repeating, refining and editing movement, stillness, structures, and juxtapositions. WM is active in 'mental time travel' when we reflect on previously seen material, or image new material. In addition to span, WM refers to the complexity of relations that can be processed in parallel (Halford et al. 1998) and, especially in experts, the capacity to segment and chunk material, resulting in a seemingly prodigious memory for connected movement (Stevens et al. 2011).

The pattern of errors differed across Experiments 1 and 2. Substitution errors predominate in Experiment 1 whereas serial position errors predominate for all groups in Experiment 2. It is noteworthy that in Experiment 2 side errors were never made by the high experience group, indicative of highly accurate mirroring.

The present observation, that changing proprioceptive cues can reduce memory span for movement especially among those with low or moderate specialist experience, has implications for teaching dance, sport, martial arts, and gymnastics – non-trivial cognitive resources are involved in maintaining balance, especially in learners. The results imply, for example, the cognitive load that may be imposed on novice students when recalling new choreographed sequences of movement that require body balance, spins, displacement in space, all while attending simultaneously to music and other dancers. Put simply, changing one's balance draws on cognitive resources, diverting cognitive resources from learning new material. The effect is most dramatic in the case of less expert movers who use more cognitive resources in order to keep their balance. In teaching new movers, there is a need to maximise the cognitive resources available for learning by reducing the number of competing demands on attention and working memory. The present results also support the common practice in dance companies, of disrupting context-specific cues by changing location and training the execution of movement phrases in different spatial orientations. This might introduce a different floor and different proprioceptive feedback from the feet. Generalization to such different environmental contexts probably strengthens the memory trace, and builds resistance to disruption from other varying cues.

For teachers and instructors the present results identify potential impairments to recall, the advantages of initially minimising competing demands, and later diversifying contextual cues – including varying environments where new material is learned and rehearsed. Increasingly automatic and effortless proprioception and balance will free cognitive resources for other aspects of performance precision, nuance, creativity, and expression.

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