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Recognition of Dance-like Actions: Memory for Static Posture or Dynamic Movement?

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Abstract

Dance-like actions are complex visual stimuli involving multiple changes in body posture across time and space. Visual perception research has demonstrated a difference between processing of dynamic body movement and processing of static body posture. Yet, it is unclear whether this processing dissociation continues during retention of body movement and body form in visual working memory (VWM). When observing a dance-like action, it is likely that static snapshot images of body posture will be retained alongside of dynamic images of the complete motion. Therefore, it was hypothesised here that, as in perception, posture and movement will differ in VWM. Additionally, if body posture and body movement are separable in VWM, as form- and motion-based items respectively, then there should be differential interference from intervening form and motion tasks on recognition. Two experiments examined these hypotheses. In Experiment 1, recognition of postures and movements was tested in conditions in which the format of study and test stimuli matched (movement-study to movement-test, posture-study to posture-test) or mismatched (movement-study to posture-test, posture-study to movement-test). In Experiment 2, recognition of posture and movements was compared after intervening form and motion tasks. The results indicate that (1) recognition of body movement based only on posture is possible, but significantly poorer than recognition based on the entire movement stimulus; and (2) form-based interference does not impair memory for movements, although motion-based interference does. It is concluded that while static posture information is encoded during observation of dance-like actions, body movement and body posture differ in VWM.

Recognition of Dance-Like Actions: Memory for Static Posture or Dynamic Movement?

As a dancer turns and leaps across the stage, they move in and out of multiple body configurations. An observer of this body movement will simultaneously process both form-based detail of body shape as well as motion-based detail of the temporal order in which these shapes appear. Visual perception research demonstrates that such processing of body form and of body motion differs. That is, although an action consists of a sequence of multiple body postures, action perception differs to posture-perception. In the current paper we question whether a similar dissociation between actions and postures occurs in visual memory. To date this question has not been addressed. This may be in part because visual memory research has focused primarily on static, non-biological stimuli but also as research on human action has typically been directed towards perception and production rather than memory. The following sections first review literature considering visual memory for static and dynamic stimuli and then review literature considering visual perception of human action and form. Together these research areas inform two experiments comparing memory for dynamic actions and static postures alone (Experiment 1) and in the context of other dynamic and static visual tasks (Experiment 2). It is concluded that, as in perception, action and postures differ in visual memory, relying on partially dissociable networks.

Working Memory: Static and Dynamic Processing?

Working Memory (WM) is defined as the active portion of the long-term neural network within which stimuli are temporarily maintained and manipulated for retrieval (Oberauer, 2009).

Recent models of WM build on current understanding of visual perception (Jonides, Lewis, Nee, Lustig, Berman, & Moore, 2008), visual attention (Oberauer & Bialkova, 2009), and long-term memory (Cowan, et al., 2005; Zimmer, 2008). These models diverge from the concept of WM as modality-specific stores, towards the conceptualization of WM as an extension of the perceptual process (Cowan, 2010; Jones, Hughes, & Macken, 2006; Oberauer, 2009; Zimmer, 2008). Thus, it is suggested that the way in which stimuli are initially processed will heavily influence the way in which the stimuli are remembered and retrieved (Engle, 2010; Slotnick & Thakral, 2011; Wager & Smith, 2003; Wilson, 2001). For example, Jones, Farrand, Stuart, and Morris (1995) showed that memory for both visual and verbal stimuli is impaired by a range of distractor tasks irrespective of modality (e.g., both irrelevant speech and spatial tapping) as long as both the primary and intervening tasks involved change over time; that is, the tasks were dynamic. This example and others (e.g., see Depoorter & Vandierendonck, 2009; Stevanovski & Jolicouer, 2007) is suggestive of ‘interference-by-process’ (Hughes & Jones, 2005). The form of processing needed to perceive and encode the items has as much influence on retention of items as does the modality of item content.

Notable then is the observation that while some stimuli elicit primarily static (form-based) encoding, such as remembering a configuration of shapes, other stimuli elicit dynamic (temporal-based) encoding, such as remembering the sequential order in which the shapes appeared (Logie, 2011). Typically, when investigating visual WM (VWM), visual and spatial distinctions are made (Luck, 2008). However, tasks used to target visual WM tend to require static form-based processing including, for example, Visual Pattern Tasks in which the

participant retains a static pattern of coloured squares (Della-Sala, Gray, Baddeley, Allamano, & Wilson, 1999; Luck, 2008). By contrast, tasks used to target spatial WM tend to require dynamic temporal-based processing including, for example, the corsi-block task in which the participant retains a sequence of visually identified spatial locations (Berch, Krikorian, & Huha, 1998; Vandierendonck & Szmalec, 2011). This ‘static-visual’ and ‘dynamic-spatial’ association is not often controlled (Pickering, Gathercole, Hall, & Lloyd, 2001). Therefore, it is plausible that visuo-spatial dissociations that have been reported may reflect static-dynamic processing dissociations (Luck, 2008). Confounded in this way, it is difficult to determine which characteristic — visual or static versus spatial or dynamic — is key to retention in WM.

Pickering et al. (2001) proposed that static and dynamic (rather than visual and spatial) VWM processes are separable, suggesting that the two processes may not mature at the same rate, leading to different developmental trajectories. Accuracy of VWM for static and dynamic versions of a visual task was tested with children ranging from 5 to 10 years. In the static version of the task, the entire visual stimulus was visible at the start of a trial. In the dynamic version of the task, the stimulus became visible across the duration of the trial. Although both tasks were targeting visual WM, accuracy differed based on whether the initial processing was static, form-based, or dynamic, motion-based. Specifically, while accurate performance on the static form-based task increased significantly with age, accurate performance on the dynamic motion-based task did not. Although the 10 year olds were more accurate than the 5 year olds in both the dynamic and static tasks, the slope of the increase from 5 to 10 years was much steeper for the static than for the dynamic task. This result suggests that memory for visual form is dissociable

from, and takes longer to develop than, memory for visual motion. Static-dynamic dissociations have also been reported in clinical populations. For example, a sample of patients diagnosed with schizophrenia showed impaired performance on a static form-based task, compared with non-schizophrenic controls, in the absence of impaired performance on a dynamic motion-based task (Cocchi, Schenk, Volken, Bovet, Parnas, & Vianin, 2007).

Although only a few studies have disentangled visual form and motion in VWM, those that have suggest that the retention of visual stimuli is in part determined by the processing network that was dominant when the stimuli were observed; in other words, whether the stimuli were primarily form or motion-based. When considering memory for body actions, we can expect that the type of processing undertaken during action observation will influence the means by which the actions are retained.

Memory for Body Movement: Form plus Motion Processing?

While it is relatively simple to determine whether a non-body based visual task (such as the corsi-block task) will require static or dynamic processing, it is relatively difficult to determine what form of processing will be required in retaining human actions. This is because human body movement consists of many successive changes in body form across space and time (Adshead-Lansdale, 1988). Perception and recognition of body movement might then require both static-form and dynamic-motion based processing. Indeed, while biological motion research with point light stimuli demonstrates that perception of coherent body movement can occur in the absence of form cues (Dittich, 1993), one's implicit knowledge of the unchanging structure

of the human form assists action perception when motion alone is not a useful cue (Blake & Shiffrar, 2007). Typically, while static point light (PL) stimuli appear to show a random array of dots, dynamic PL stimuli elicit perception of biological motion, despite no overt body form being present. This form-from-motion effect tends to suggest that presence of form is not necessary for action perception. Yet, Beintema & Lappe (2002) demonstrate that when pure motion of PL markers is rendered useless to participants (as the position of the markers are randomised along the body and changed unpredictably from frame to frame), participants are still reliably able to discriminate between actions. When motion is not useful, knowledge of the human form appears to help structure the perception of different human actions. Similarly, two sequentially presented static pictures of the whole body are sufficient for motion perception, despite the fact that no motion is present in the stimulus at all (e.g. Shiffrar & Freyd, 1990). Thus, both form and motion play an important role in the perception of action and are both likely to be important in memory for movement.

Neuroimaging and computational research also suggest that perception of motion and perception of body form may initially occur via separable neural pathways that later converge to facilitate a coherent dynamic action percept (Giese & Poggio, 2003). For example, while observation of body posture appears to be associated with extrastriate and fusiform body areas, observation of action is primarily associated with motion-related areas of the cortex including pSTS (Allison, Puce, & McCarthy, 2000; Grossman, & Blake, 2002; Downing, Peelen, Wiggett, & Tew, 2006; Peelen & Downing, 2007; Peuskens, Vanrie, Verfaillie, & Orban, 2005; Urgesi, Berlucchi, & Aglioti, 20047). However, some activity is invariably noted within form-processing

regions during action observation, suggesting that both motion and form processes do contribute to action perception (e.g. Grossman & Blake, 2002; Peelen et al., 2006). If processing format influences retention in VWM it can be expected that while memory for action and form will largely differ, some retention of form will also occur after action observation. This is to say that after observing a dynamic body movement, the observer will have both snapshot memory of the embodied forms and dynamic memory of the forms in motion. In Experiment 1, a change detection paradigm with manipulation of study format (movement, posture) and test format (movement, posture) investigated whether participants could correctly identify an action based only on a single static image. If so, this suggests that when observing dynamic dance-like actions, static images of posture are encoded and support recognition.

Further to this, if movement perception results in activation of both form and motion pathways, then disrupting one processing pathway might not have deleterious effects on memory for the action. That is, recognition of actions based only on form information may be possible when motion information is unavailable or the processing pathway has been blocked (i.e. by being redirected to another task). In this case, action recognition may rely on snapshots of body posture available from the form processing pathway. In Experiment 2, an interference paradigm strategically disrupted static and dynamic processing of dance-like actions in posture and movement format. Although body movement involves both form and motion cues, perception of body movement most prominently activates the visual motion processing pathway. By contrast, perception of body postures typically activates the static form-based pathway, with little input from the motion pathway. If similar processes are active in WM as are active in perception,

recognition of body movements should be selectively impaired by a motion-based interference task, while recognition of postures should be selectively impaired by a form-based interference task.

Experiment 1

Aim, Design and Hypotheses

The aim of Experiment 1 was to determine whether snapshot images of static body posture can be used for action recognition. Dance-like actions were used as an example of complex body movement, involving many changes in body postures across time and space, without being directed towards external objects. A 2 x 2 within-subjects design was used, with manipulation of study format (movement, posture) and test format (movement, posture). Therefore, recognition was compared in four conditions: 1) movement study format to movement test format (movement-movement), 2) movement study format to posture test format (movement-posture), 3) posture study format to posture test format (posture-posture), and 4) posture study format to movement test format (posture-movement). Accuracy (hit and false alarm rates) and reaction time (RT) were the dependent variables.

During the study phase, novice (non-dancer) participants were presented with sequences of three dance-like actions as either movements (complete dynamic action) or postures (snapshot image of posture; see Figure 1). During the test phase, participants decided whether a test item showed an old or new *action*, in conditions in which the item format (movement or posture) was the same as, or different to, the study format. Specifically, participants were instructed to ignore item format (i.e. whether it is a movement or a posture) and decide if the test item depicted the

same action as one of the study items. For example, if a study sequence comprised Movement A, Movement B and Movement C, and the test item was Posture A the correct response would be 'old', despite the change from movement at study to posture at test.

[Figure 1 about here]

First, it was hypothesised that recognition would be best when study and test format match. Hence, recognition of *movement* stimuli will be most accurate in the movement-movement condition in which memory for movements is probed by a complete movement at test. Likewise, recognition of action *postures* should be best in the posture-posture condition in which memory for posture is probed by a posture at test. As movement stimuli potentially contain more information overall that can be used to support recognition, accuracy is hypothesized to be greater in the movement-to-movement condition than in posture-to-posture conditions.

Second, in both the movement-movement and posture-posture conditions the format of the test stimulus exactly matches the format of the study stimulus, meaning that the processing pathways active during perception are reactivated at test. Recognition rates in these conditions should be high. Alternatively, in the movement-posture and posture-movement conditions the study stimulus must be transformed in VWM to enable an accurate response to the test stimulus. When a movement is observed, both form and motion pathways should be active. Therefore, accurate posture recognition after encoding of movements during study (movement-posture condition) should be possible as body posture will have been encoded. However, accuracy should still be poorer than in the movement-movement condition

By contrast, when a single posture is observed at study, only form pathways should be active. Therefore, as movement information is not encoded, movement recognition after encoding of postures during study (posture-movement condition) should be poor relative to posture-posture condition. Finally, to provide an accurate response in the posture-movement condition, participants need to search the movements at test for the posture stimuli they encoded. Therefore, in the posture-movement condition RT should be slow relative to the movement-movement condition.

Method

Participants. Thirty-five students enrolled in first-year psychology at the University of Western Sydney ($M=22.0$, $SD=6.59$, 3 male) volunteered in return for course credit. All of the participants were naive to the task. Five participants reported some non-professional dance experience, primarily involving classes taken during childhood or casual fitness classes ($M=9.8$ years, $SD=6.57$ years). Four of these participants had some non-professional experience specifically with Ballet ($M=8.25$ years, $SD=6.44$ years). Data screening revealed no significant effect of participant dance expertise and so these participants were retained in the sample. All participants reported normal or corrected to normal vision.

Materials and equipment. Dance-like action stimuli consisted of a set of 10 video-recorded ballet items performed by an experienced male ballet dancer, used previously by Calvo-Merino, Glaser, Grèzes, Passingham & Haggard (2005). The raw dance-like items were three seconds in length and involved one performer executing one ballet item. The same male dancer

performed all 10 movement items wearing fitted black clothing, against a dark blue backdrop. All movements began from roughly the right hand side of the screen (stage left) and travelled towards the left (stage right). An additional two movement items were available but not used in the stimuli set, as the dancer stayed centered within the frame and did not travel right to left. For the dynamic movement items, the raw action items were played in complete format (25 frames per second) for three seconds. For the static items, a single frame capturing the peak of the item was shown on screen for three seconds. The static frame was chosen as that which represented the critical moment of the action, for example at the height of the jump or full extension of the leg. This posture represented a maximal state of deviation from the start and end position of the body in the dynamic phrase. The postures occurred at a different frame and time point for each item, occurring on average at around two seconds. Each item was presented in the centre of the computer screen, surrounded by a black background.

The experiment was run on Lenovo PCs with DMDX software (Forster & Forster, 2003). Responses were made on the computer's internal keyboard.

Procedure. Participants signed informed consent forms conforming to ethical standards (HREC H9302). Detailed instructions were then given regarding the task. Participants were told that they would observe sets of three dance-like actions presented either as static 'photographs' or dynamic 'movies' and they were to try and remember what *action* was being performed regardless of the format in which it appeared.

Each trial progressed in the following way: A blank screen showing the word 'study'

appeared. Subsequently three dance-like actions appeared sequentially in the centre of the screen. On any given trial *all* items were *either* static postures *or* dynamic movements at study (that is three movement items or three posture items were shown at study, never a combination of the two formats). The word ‘test’ was then displayed in the centre the screen, followed by the test item. Participants responded ‘old’ or ‘new’ using the computer’s shift keys which were labeled accordingly. Response was time limited with a response period of 5s in total, including the 3s duration of the test item. Participants were instructed to observe the study items and to respond “as soon as they know” so that responses could be made at any point during the item. After the response was recorded and trial completed, a new trial began (see Figure 2).

[Figure 2 about here]

Eight practice trials (one for each study-test combination in old and new trials) with corrective feedback were completed before the task began. A set of capoeira movements, matched for kinematics and limb displacement to the ballet items (Calvo-Merino et al., 2005) were used for the practice trials. In total there were 40 experimental trials with 10 trials for each study-test combination. Trials were counterbalanced across participants. Within each set of 10 trials, five trials contained a ‘new’ action at test, while five trials contained an ‘old’ item at test. At the end of the experiment, participants were debriefed and asked to note any strategies they attempted to use to help them remember the dance-like actions. The experiment took approximately 35 minutes to complete.

Data processing and exclusion criteria. Data were categorized into hits (old item

correctly identified as old), correct rejections (new items correctly identified as new), misses (old items incorrectly identified as new), and false alarms (new item incorrectly identified as old) for each study-test category. Accuracy was calculated as the proportion of correct responses: (hits + correct rejections) / (hits + misses + correct rejections + false alarms), where chance is equal to 0.5

Reaction time (RT) was calculated, both from the onset of the test item (oRT) and from the offset of the test posture (pRT). For the pRT measure, the point in time at which the test posture occurs in the dynamic sequence was subtracted from the oRT. Using this measure we can determine if participants were responding before, after or at the time when the test posture occurs in the dynamic action. Negative pRTs indicate responses occurring before the test posture, while positive pRTs indicate responses occurring after the test posture.

Criteria for exclusion, based on results of pilot testing, stated that participants would be excluded if they had a) more than six *missed* responses (i.e. no response made) across the experiment in total (representing 15% of total trials), and/or b) more than two missed responses in two study-test conditions, and/or c) one or more condition in which the false alarm rate exceeded the hit rate. Based on these criteria five (out of 35) participants were excluded from the analysis (three for criteria c and two for criteria b), leaving $N=30$ ($M= 22.5$ yrs., $SD=6.97$ yrs.; 3 male).

Results and Discussion

Accuracy. Table 1 shows accuracy rates across the study-test conditions. A 2 (Study format; Movement, Posture) x 2 (Test format; Movement, Posture) repeated measures analysis of variance (ANOVA), with planned comparisons to test specific hypotheses (Tabachnick, Fidell & Osterlind, 2001). With alpha set at 0.05, the Study Format x Test Format interaction was significant, $F(1,29) = 37.67$, $p < .001$, $\eta_p^2 = .57$. As predicted, accuracy was greatest when study and test format were congruent, and weakened when they were not. Three planned comparisons clarified this interaction.

[Table 1 about here]

First, accuracy in the posture-posture condition ($M = .87$, $SD = .13$), was significantly greater than accuracy in the movement-movement condition ($M = .80$, $SD = .14$) $t(29) = 2.13$, $p = .04$, $d = .52$. This is somewhat surprising as the movement stimuli arguably contained more detail that might be used for recognition purposes than do the single key-frame posture stimuli. However, in a limited capacity VWM system, memory for movements has often found to be best at around two items (Cortese & Rossi-Arnaud, 2010; Smyth & Pendleton, 1989; Wood, 2007). The extra detail afforded in the movement, compared to posture, stimuli may exceed VWM capacity, serving as a distraction rather than a benefit for memory. Alternatively, as the posture stimuli remained unchanging on the screen for 3 seconds, participants may have had a better chance to process and store details of the represented action.

Second, as both form and action pathways are active during perception of body movement, it was predicted that a movement item may be accurately recognized based only on a static snapshot of goal posture at test, but that recognition would be best when the entire movement stimulus was available. This hypothesis was supported with accuracy in the movement-movement condition significantly greater than accuracy in the movement-posture condition ($M = .71$, $SD = .13$), $t(29) = 2.92$, $p = .002$, $d = .66$. With specific reference to the hit and false alarm rates, it is notable that accuracy in correctly rejecting ‘new’ items was comparable across the movement-movement and movement-posture conditions (FAR of .22 and .28, respectively). However, recognition of ‘old’ items from static posture was poor compared with recognition in the movement-movement condition (HR of .83 and .71, respectively). Participants were able to correctly dismiss new items equally in the two conditions, but could better recognise previously seen items when the complete movement stimulus was available.

Finally, as hypothesized, accuracy in the posture-posture condition was significantly greater than accuracy in the posture-movement condition ($M = .70$, $SD = .14$), $t(29) = 5.89$, $p < .001$, $d = 1.2$ (Figure 3). When postures were observed, no motion was encoded and therefore recognition in the posture-movement condition required a search of the test item for the correct static posture.

[Figure 3 about here]

Reaction time. Figure 4 shows average RT from the onset of the test item (oRT). A 2 x 2 repeated measures ANOVA produced a significant Study Format x Test Format interaction $F(1,29) = 17.86$, $p < .001$, $\eta_p^2 = .38$. Specifically, the oRT in the movement-posture condition

($M=1675.97\text{ms}$, $SD= 463$) was not significantly different to the oRT in the posture-posture condition ($M=1590.49\text{ms}$, $SD= 408.15$) $t(29)= 1.49$, $p=.15$, $r=.26$. This indicates that there was no difference in RT to postures at test despite the differences in the format of the study sequence. However, the oRT in the movement-movement condition ($M=2838.75\text{ms}$, $SD= 524.10$) was significantly faster than oRT in the posture-movement condition ($M=3222.17\text{ms}$, $SD= 682.75$), $t(29)=4.38$, $p<.001$, $r=.63$. As predicted, the time taken to respond to test item in movement format is significantly slower after observing postures, compared to movements, at study.

[Figure 4 about here]

RT in relation to the test posture (pRT) was also analysed. As the test posture captures the goal of the movement in this experiment, it is possible that this posture is used to make recognition judgments even when dynamic movement stimuli are observed. If so, in the movement-movement condition, responses should have been close in time to the appearance of the posture. Figure 5 shows that when the test item was a movement (movement-movement and posture-movement conditions) the response was made around 1s after the onset of the test posture within the action ($M= 909.98\text{ms}$ and 1324.73ms , respectively). In the movement-movement condition, RT was significantly different from the point in time at which the test posture occurred within the action $t(29)=9.51$, $p<.001$, $r=.87$. The frame capturing the test posture was always approximately 2s into the item. This result suggests that the participants were not responding in reaction to recognition of the posture but observed the entire dynamic item before making a response.

In summary, Experiment 1 shows that when body movements are observed, static posture information is encoded, but form information may not be the primary source of movement recognition. Recognition of a movement was most accurate when a complete movement item, compared to the test frame capturing goal posture, was seen again at test. Additionally, the pRT measure demonstrates that participants observe the entire movement item before responding. This result suggests that while it is possible to recognise an action based only on static posture, it is unlikely that this is the primary manner in which an action is temporarily retained.

[Figure 5 about here]

Experiment 2

Pickering et al. (2001) hypothesise that recognition of form (posture) may rely on a VWM mechanism dissociable from VWM for recognition of motion (action). In Experiment 1, the movement items were primarily encoded as ‘motion-based’ stimuli, although some posture based information was stored. As such, VWM for movements should be most impaired by a secondary task that disrupts dynamic, motion-based processing, in comparison to a secondary task that disrupts static, form-based processing. Alternatively, motion-based processing plays little role in VWM for postures and therefore VWM for postures should be impaired by a secondary task that disrupts form-based processing, in comparison to a secondary task that disrupts motion-based processing. Experiment 2 investigates this hypothesis using an interference paradigm to selectively disrupt form- or motion-based VWM.

Aim, Design and Hypotheses

The aim of Experiment 2 was to dissociate form and motion processing in VWM for postures and movements. As in Experiment 1, participants observed sequences of three movements or postures and judged whether a single test item was old or new. To determine if different WM systems are recruited, static and dynamic visual interference tasks occurred between study and test. A digital version of the corsi-block task was used for the interference conditions. The corsi-blocks are a set of blue squares which may be selected as targets by the appearance of a black circle. The participant's task is to remember the pattern of target blocks. This task was classed as static if all the targets were presented simultaneously and dynamic if the targets appeared sequentially across the trial. To consider the effects of interference on memory for movements and postures, only congruent movement-movement and posture-posture trials were included. Therefore a 3 (Interference; Control, Static, Dynamic) x 2 (Item Format; Movement, Posture) mixed design was implemented, with between subjects manipulation of the interference factor. Accuracy (proportion correct) was the dependent variable.

It was hypothesised that (1) if body movements are retained primarily via a dynamic, motion-based VWM, then recognition should be impaired by the dynamic, but not static, interference task; and (2) if body postures are retained primarily by a static, form-based VWM process, then recognition of body postures should be impaired by the static, but not dynamic, interference task. The effect of static and dynamic interference tasks on recognition was compared against a no-interference, control condition.

Method

Participants. Sixty students enrolled in first- year psychology at the University of Western Sydney volunteered in return for course credit ($M= 25.6$ yrs., $SD=8.3$ yrs.; 17 male; 20 in each Interference group). All participants were naive to the task. Ten participants reported some non-professional dance experience ($M=8.6$ years, $SD=4.1$ years), six of whom had some prior experience specifically with Ballet ($M=8.16$ years, $SD=7.19$ years). Data screening revealed no significant effect of participant dance expertise and these participants were retained in the sample. All participants reported normal or corrected to normal vision.

Materials and equipment. Dance-like action stimuli were the same as used in Experiment 1. Stimuli for the intervening tasks consisted of two digital versions of the corsi-block task. Both corsi-block task manipulations consisted of a white rectangle featuring 10 blue squares at irregular locations. In the static corsi-block task (static task) five black circles appeared simultaneously on five different squares and remained in place for five seconds. After five seconds the entire static task disappeared from the screen. Alternatively, for the dynamic corsi-block task (dynamic task) a single black circle appeared sequentially at five different locations. This task has been chosen to replicate the dynamic task involving ‘flashing’ matrix targets used by Pickering et al. (2001). In the dynamic task, each black circle had an 800ms duration and was separated from the appearance of the next black circle by a 30ms inter-stimulus-interval (ISI). This is within the range of ISIs typically shown to elicit a percept of apparent motion (Shaw, Flascher & Mace, 1995). A path length of ‘five’ targets was chosen to

fall within, but not exceed, VWM capacity (Cowan, 2010) and to allow the same patterns to be presented in the dynamic and static conditions (larger path sizes would require repetition across blocks which cannot be represented effectively in the static task). Ten corsi-block patterns were chosen and displayed randomly throughout the experiment. To ensure that the only difference between the static and dynamic task conditions was the simultaneous or sequential appearance of the circles, the same patterns were used for both. Both tasks lasted five seconds in total.

Procedure. The primary (actions) task progressed as in Experiment 1. On each trial in the static and dynamic interference conditions participants would observe a set of three dance-like actions (postures or movements), observe the interference task stimulus and then respond to a test item. On any given trial, the test item could be either a dance-like action or a location from the corsi-block task. Participants were not aware of which test item (dance-like action or corsi-block location) would be shown at test until the test item was displayed, ensuring that correct performance required memory of *both* tasks until the test phase (Cowan & Morey, 2007). In the control (no interference) condition, the test item was always a dance-like action. As in Experiment 1, half of the trials had a correct response of ‘old’ and half of ‘new’. For dance-like actions old and new were defined as in Experiment 1. For the corsi-block location, ‘old’ referred to a location that was occupied during the interference task, while ‘new’ referred to a location that was not occupied during the interference task (see Figure 6).

Before completing the task, participants undertook practice trials with corrective feedback to ensure the instructions were clear and the task was understood for each possible

study-test condition. In total 10 trials per stimuli condition were completed, allowing 5 ‘new’ and 5 ‘old’ trials. In the interference conditions, an extra 10 trials per study-interference condition (i.e. dynamic task with movement study items and dynamic task with posture study items) format were completed also allowing test of 5 ‘new’ and 5 ‘old’ corsi-block locations per condition. The experiment took approximately 30 minutes to complete.

[Figure 6 about here]

Results and Discussion

Descriptive statistics are shown in Table 2, and mean proportion correct is shown in Figure 7. It was hypothesised that if dissociable static and dynamic VWM systems are used to retain postures and actions, respectively, then a double dissociation should be observed for accuracy. Specifically, recognition of movement items should be impaired by dynamic, but not static interference (relative to control), while recognition of postures should be impaired by static, but not dynamic interference (relative to control).

[Table 2 about here]

Four planned comparisons with alpha maintained at 0.05 tested these pre-specified hypotheses. As expected, mean accuracy for recognition of movement stimuli in the control interference condition ($M=.80$, $SD=.13$) was significantly greater than mean accuracy for

recognition of movement stimuli in the dynamic interference condition ($M=.72$, $SD=.15$), $p=.04$, $d=.58$, but did not differ from mean accuracy for recognition of movement stimuli in the static interference condition ($M=.79$, $SD=.15$), $p=.89$, $d=.04$. That is, in support of the hypothesis, recognition of dynamic stimuli was significantly impaired by a dynamic visual interference task, but was not impaired by a static visual interference task.

However, contrary to hypotheses, mean accuracy for recognition of posture stimuli in the control interference condition ($M=.88$, $SD=.09$) was significantly greater than mean accuracy for recognition of postures in both the static interference condition ($M=.79$, $SD=.15$), $p=.01$, $r=.74$ and dynamic interference condition ($M=.80$, $SD=.12$), $p=.01$, $r=.83$. That is, only partial support was found for the hypothesis that recognition of static stimuli would be impaired by performance of a static interference task (supported), but not impaired by a dynamic visual interference task (not supported).

Scores on the intervening static and dynamic corsi-block tasks were calculated to ensure one task was not more difficult than the other. Mean accuracy on the static corsi-block task ($M=.54$, $SD=.26$) was lower, but not significantly different from mean accuracy on the dynamic corsi-block task ($M=.63$, $SD=.33$), $p=.31$. Therefore, differences in accuracy in the primary recognition task cannot be attributed to differences in difficulty of the intervening tasks.

[Figure 7 about here]

In summary, results of Experiment 2 show partial support for the hypothesised dissociation between VWM for static and dynamic visual tasks. Accuracy on the dynamic and static corsi-block tasks was similar, indicating that the two tasks were of comparable difficulty. The dynamic corsi-block task impaired accurate recognition of actions relative to control, while the static corsi-block task did not. That is, consistent with hypotheses, memory for actions is impaired by a secondary task involving change over visual space, but is not impaired by a secondary task in which only static visual form is to be encoded. The complementary situation was not entirely supported. As predicted, accurate recognition of postures was impaired by the static task, as predicted. However, recognition of postures was also impaired by the dynamic task.

The lack of a double dissociation in the results of Experiment 2 makes it difficult to definitively conclude that dissociable dynamic and static VWM networks retain actions and postures. Consideration of the hit rate values shows that, for movements, recognition accuracy was poorest in the dynamic interference condition (hit rate of .66). Conversely, for postures, recognition accuracy was poorest in the static interference condition (hit rate of .79). This is consistent with predictions. Therefore, at least for recognition of previously seen items, the data indicate some dissociation between dynamic and static processing. However, this result is mediated by the false alarm rates. Both the dynamic and static interference tasks lead to an increased false alarm rate for posture stimuli relative to control (from .14 to .24 in both cases). It is this unexpected increase in the false alarm rate that disrupts the predicted response pattern overall.

General Discussion

The current experiments investigated VWM for actions, considering (1) whether VWM for body movement incorporates memory for body postures (form) and (2) whether memory for body posture and body movement relies on dissociable form and motion processing networks. To the best of our knowledge, this is one of the first studies to explicitly compare static and dynamic versions of the *same* task on memory for action stimuli. The two behavioural experiments reported here indicate that, as in perception, dance-like body actions are likely to be primarily stored as dynamic movements in VWM although some posture based information is encoded and available to aid recognition. Two results support this conclusion. First, recognition of body movement based only on posture was possible, but poor relative to recognition based on the entire movement stimulus. Second, when rehearsal of movement items was disrupted by a form-based task, recognition accuracy was unimpaired relative to control conditions. That is, form-based interference did not impair memory for movements. These results are discussed in turn.

Dance-like actions are more than just postures in VWM

In Experiment 1, participants observed spans of three movements or postures and made ‘old’ or ‘new’ recognition responses when a single action or posture was shown at test. Neuroimaging and behavioural research has identified distinct neural regions involved in perception of human body form and human body movement (Downing et al., 2006). Although body movement involves multiple changes in body posture over time and space, observation of

body movement appears to primarily activate motion selective neurons in pSTS rather than the body form selective neurons in EBA. Interestingly, no attempt has been made to determine whether similar processing dissociations continue to operate in VWM. If perception of body form differs from perception of body movement, then it is plausible that memory for body form will also differ to *memory* for body movement. This is particularly so given recent conceptualizations of WM not as a series of modality specific stores or workspaces, but as an extension of the perceptual process and a bridge to long-term memory networks.

If a similar posture and motion dissociation is evident in VWM, then recognition of actions based on posture alone should be poor, relative to recognition of actions in complete dynamic format. This hypothesis was supported: while participants could recognize the action based on posture at above chance levels, recognition accuracy was significantly poorer than recognition in the movement-movement condition. In the current experiments, postures do not seem to be encoded preferentially when observing dance-like actions. It is likely that with dance expertise (e.g. professional training in Ballet) this effect may differ. As ballet deliberately makes use of goal postures, ballet experts may show enhanced ability to recognize actions based on images of goal posture alone.

Evidence for separation of postures and movements in VWM in Experiment 1 is consistent with fMRI research indicating less activity in posture-processing regions (e.g., EBA and FBA) when continuous movement is observed. When body movement involves many sequential changes in body posture that are biologically plausible, it is perceived as a coherent

action sequence and motion processing regions are recruited. However, if the same changes in body posture occur in a non-biologically plausible way (i.e. because they are viewed out of order) a coherent action is not perceived and posture processing regions are recruited instead (Downing et al., 2006). In research with primates, Jellema and Perrett (2003) demonstrated that pSTS will also respond to discrete static images of body posture if the postures follow one another in an appropriate temporal sequence (i.e. each displays the next posture within a single action). In the current experiments, the movements were continuous and biologically plausible. Results of Experiment 1 indicate that identifying a posture as an instance of a studied movement item was a difficult, but achievable, task. Therefore, consistent with the neuroimaging results, the current experiments suggest that even though body form is encoded during movement observation (allowing the posture to support movement recognition), static snapshots of body form are not retained in VWM in preference to complete dynamic movements.

This result is interesting for studies of motor skill learning, for example in dance, in which a teacher will often demonstrate movement phrases and expect that they be remembered by the learner. Experiment 1 indicates that, while the key forms in the movement may be retained, the learner will be much better at identifying an instance of the movement if it is shown again in complete format than if individual movement parts, including key postures, are shown. Transitions between postures, rather than postures alone, should be emphasized in visual learning of actions (cf. Opacic, Stevens, & Tillmann, 2009)

Dynamic Motion Processing and Static Form Processing Differ in VWM

Experiment 2 tested whether actions and postures are different classes of stimuli, encoded and retained by different VWM mechanisms. If so, then this provides an explanation as to why the extraction of postures from encoded movements in the movement-posture condition of Experiment 1 was a difficult and cognitively demanding task, leading to the reduced rates of accuracy observed.

Experiment 2 compared memory for postures and actions in an interference paradigm to examine whether distinct VWM networks exist for the retention of actions and postures. A double dissociation between static and dynamic interference tasks was expected on recognition of static (postures) and dynamic (movements) items at test. Specifically, it was predicted that actions would be impaired by dynamic, but not static, interference, and that, conversely, postures would be impaired by static, but not dynamic, interference. Partial support was found for the hypotheses, with dissociation between the dynamic and static interference tasks found for recognition of actions, but not for recognition of postures.

Results of Experiment 2 provide some evidence for distinct dynamic and static VWM processes and, although not predicted, the observed pattern of interference is not entirely inconsistent with the prior literature. This is because the dynamic interference task is not purely dynamic, but also involves form-based processing. Results obtained from experiments using a dynamic task similar to that used here have previously been interpreted inconsistently with

regard to the task feature that is thought to have been primarily encoded. For example, some argue that the dynamic tracking of sequential locations across time and space is a defining factor of the task (e.g. Cocchi et al., 2007; Pickering et al., 2001). Others, for example Zimmer and Liesefeld (2011), argue that it is not just the dynamic tracking of locations that is stored in memory, but also the aggregation of final landing locations into a complete static spatial map (see also Vandierendonck & Szmalec, 2011). Essentially, the dynamic task used in Experiment 2 may have required not only encoding of a dynamic pattern, but also a static representation of its final form. If so, both the dynamic and static versions of the corsi-block task should impair memory for postures as both tasks require form-based memory. Conversely, dynamic information is only extracted from the dynamic task, with the static task having no explicit motion or requirement for dynamic tracking. Therefore, if action stimuli that have been studied dynamically are stored dynamically in memory, then they should only be impaired by the dynamic task. This interpretation is speculative but provides an explanation for why memory for the posture stimuli was impaired by both dynamic and static interference tasks, while memory for movements was impaired by the dynamic task alone.

It is possible here that this effect — encoding of form and motion from the dynamic task — was heightened by the use of a multi-static ‘dynamic’ interference task instead of one that was smoothly moving. However, given that the test phase required memory for particular locations it is likely this same effect would persist, even with a task that did involve smooth movement. In either case, participants would be likely to continue to track individual locations and store these locations as a static spatial map. The key here is that the spatial map of visual

form could be created immediately in the static interference condition, as all the targets were identified at the beginning of the trial. Alternatively, the spatial map of visual form had to be updated continually in a dynamic manner during the dynamic task as the targets were sequentially revealed. Thus, it is the comparison between the static and the dynamic elements of the two interference tasks that is crucial in the present experiment. That the static corsi-block task did not impair memory for movements is a further indication that overall form is not the primary feature being extracted from the movement. Consistent with Experiment 1, when the actions are observed in the study phase of the experiment, movement is encoded rather than the individual postures that comprise the movement.

Despite the lack of a double dissociation between the static and dynamic tasks in Experiment 2, we have some evidence to suggest body actions may be different to body postures in VWM. This finding is in accord with neuroimaging findings (e.g. Downing et al., 2006) and computational modeling research (e.g. Giese & Poggio, 2003) that posit dissociable structures for perception of human bodies and human body movement. In VWM, as in perception, body form and body movement rely on dissociable processing systems.

Future research might extend results reported here by investigating potential differences between static and dynamic VWM for objects and for human body movements. An assumption made here is that a similar VWM resource is used to retain movement and form as exhibited in dance-like actions, and as exhibited in the abstract movement of visual objects. There is evidence to the contrary (e.g., Umla-Runge, Zimmer, Krick, & Reith, 2010; Wood, 2007) but much of this

research is complicated by the use of static-visual or dynamic-spatial based tasks; that is, the categories are confounded. In the present study we disentangled these categories and showed impaired recognition of body movement stimuli after encoding visual motion and impaired recognition of body postures after encoding visual form. An experiment specifically manipulating both tasks with body-based stimuli would further clarify the results.

Conclusion

The experiments reported here demonstrate that the perceptual dissociation between body form and movement is also evident in VWM. Further, they show that while images of body posture may assist recognition, body form is not the sole means by which dance-like actions are retained in VWM. The current results suggest that, for an observer, particularly one who is inexperienced with the type of movement being observed, dance-like actions are retained as dynamic items in VWM.

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Figure 1. Experiments 1 and 2: Dance-like action stimuli. Postures stimuli are shown.

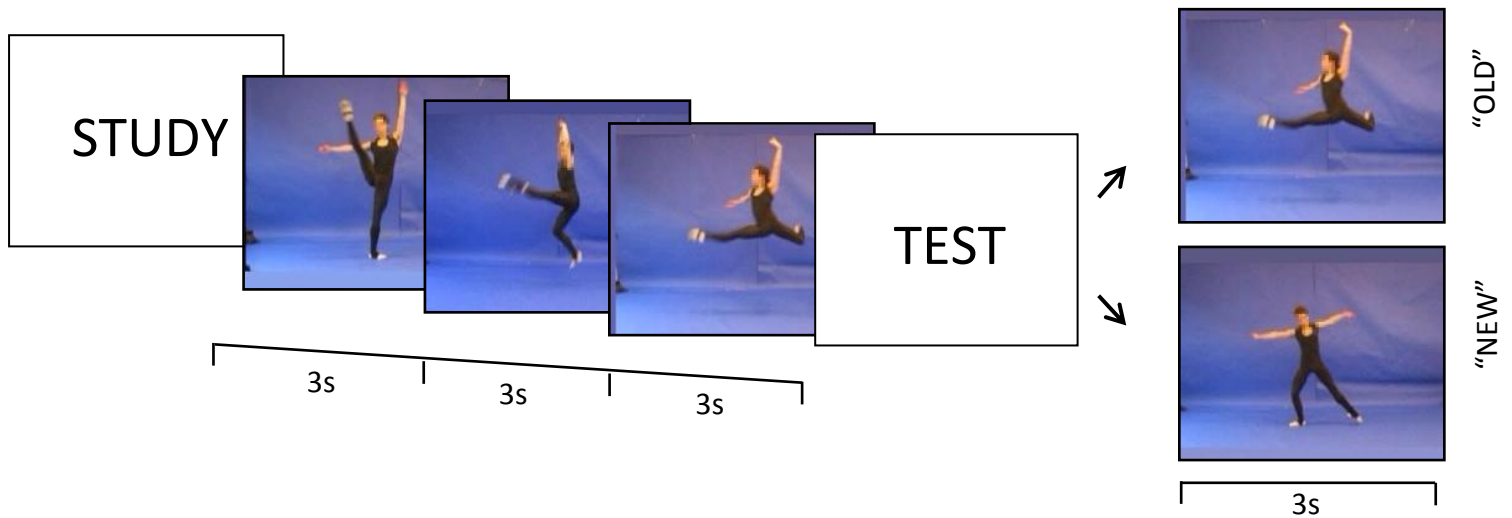


Figure 2. Experiment 1, Trial sequence. A posture-posture trial is shown. In the study phase, three postures are shown sequentially. In the test phase, participants indicate ‘old’ or ‘new’ to a posture that was or was not in the study sequence.

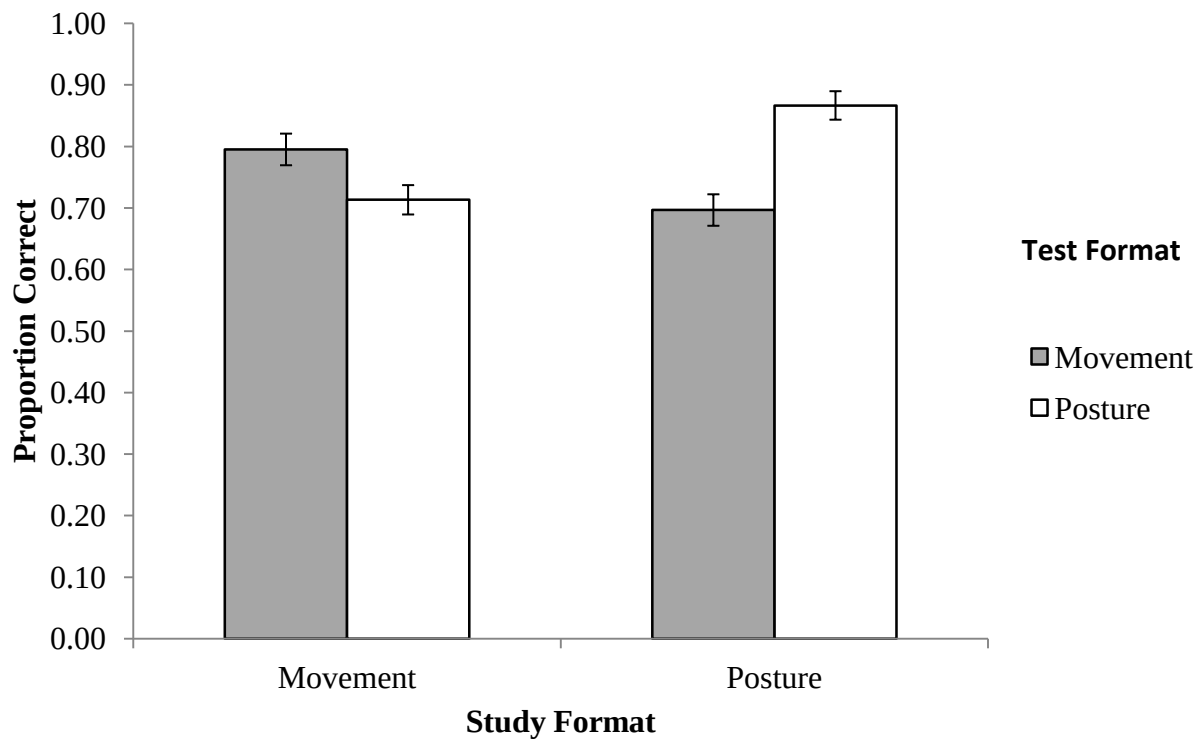


Figure 3. Experiment 1: Mean accuracy for movements and postures. Maximum = 1, Chance = 0.5. Error bars refer to standard error of the mean.

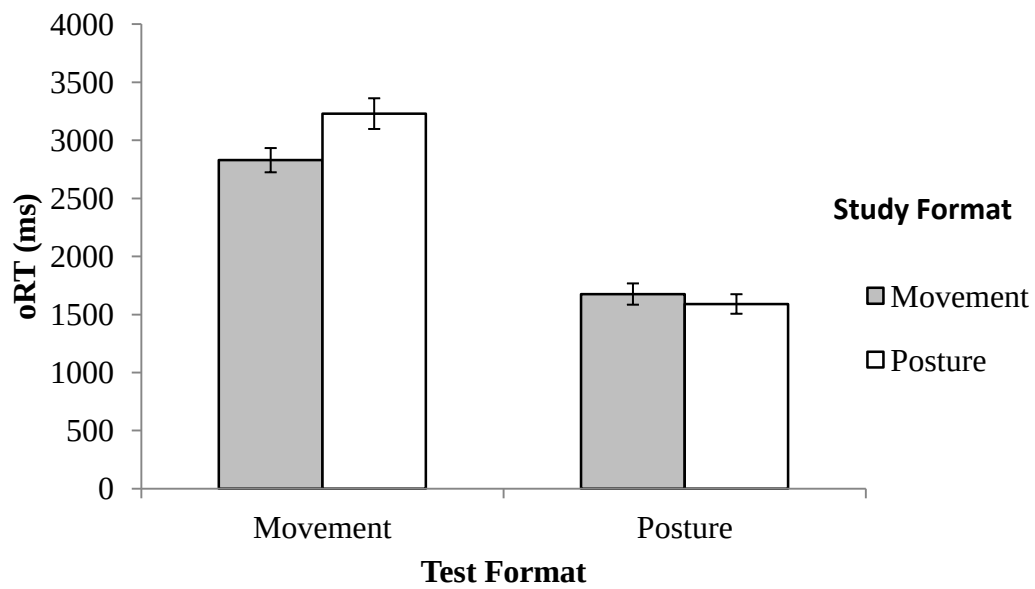


Figure 4. Experiment 1: Mean onset Reaction Time (oRT) for movements and postures. Test items had duration of 3 s. oRT was constrained to a maximum of 5 s. Error bars refer to standard error of the mean.

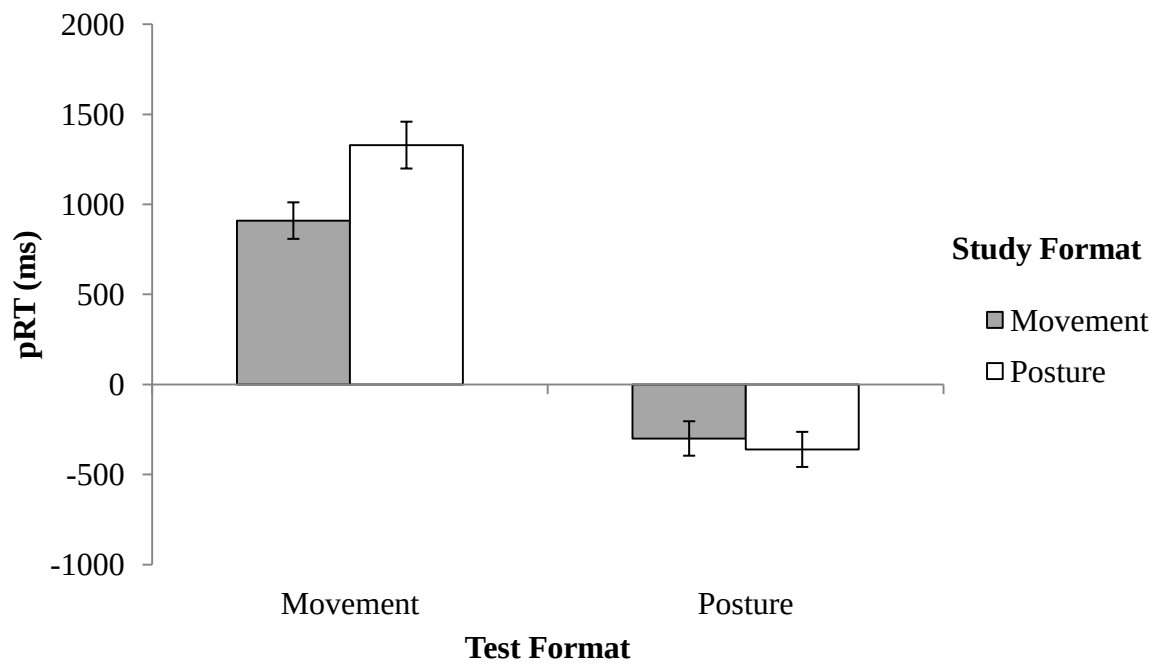


Figure 5. Experiment 1: Mean posture Reaction Time (pRT). Positive pRTs indicate responses occurring after the test posture. Negative pRTs indicate responses occurring before the test posture. Error bars refer to standard error of the mean.

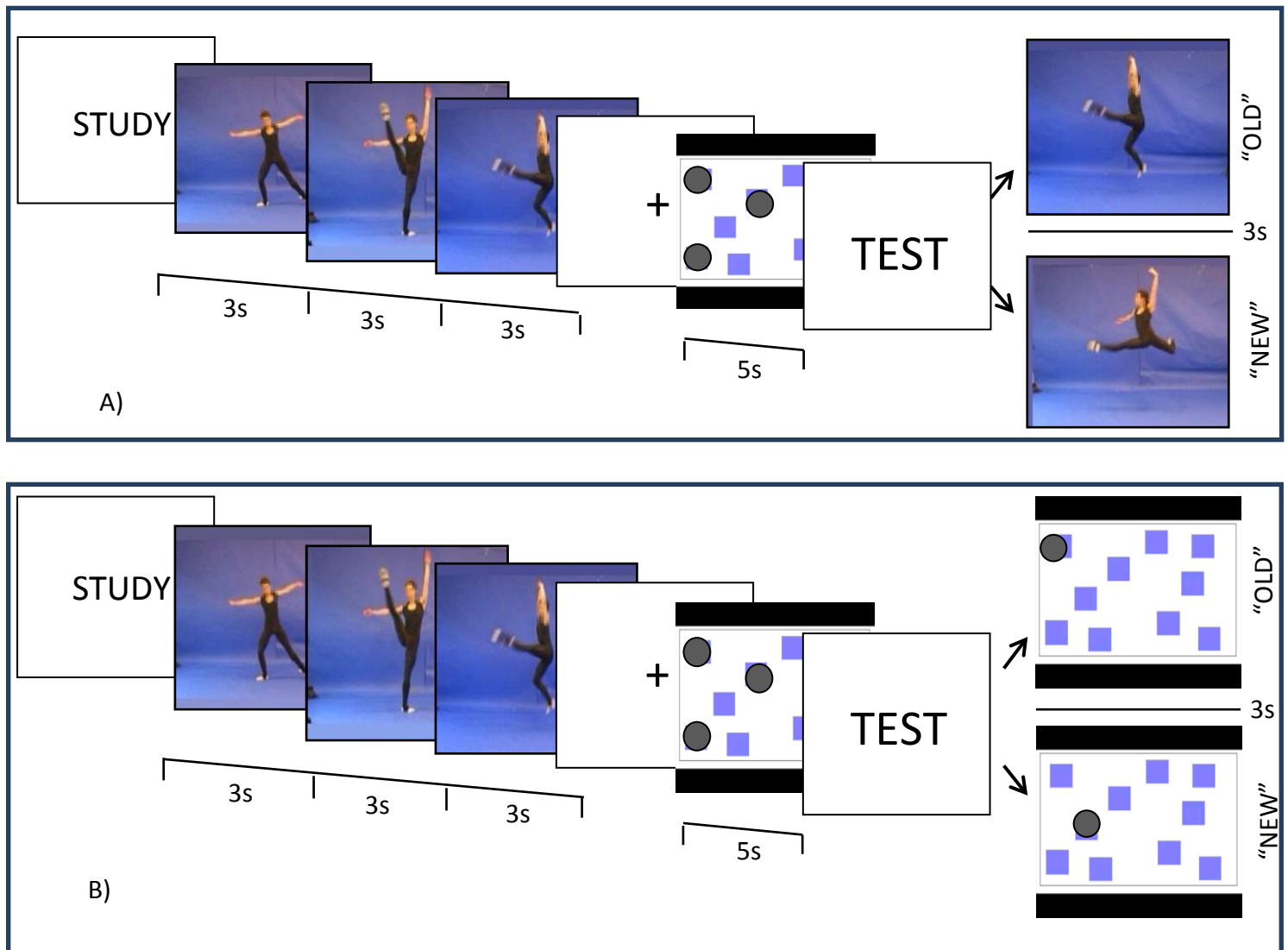


Figure 6. Experiment 2: Trial progression. Static interference trials are shown, with posture study format and posture (panel A) or location (panel B) test items. In the study phase (9s), three key-frame images are shown sequentially. In the interference phase (5s), the Corsi-block stimulus appears with 5 targets marked by black circles. In the test, participants indicate 'old' or 'new' to a posture or a Corsi-block location that was or was not in the study sequence. For an example of the dynamic interference condition with movement stimuli.

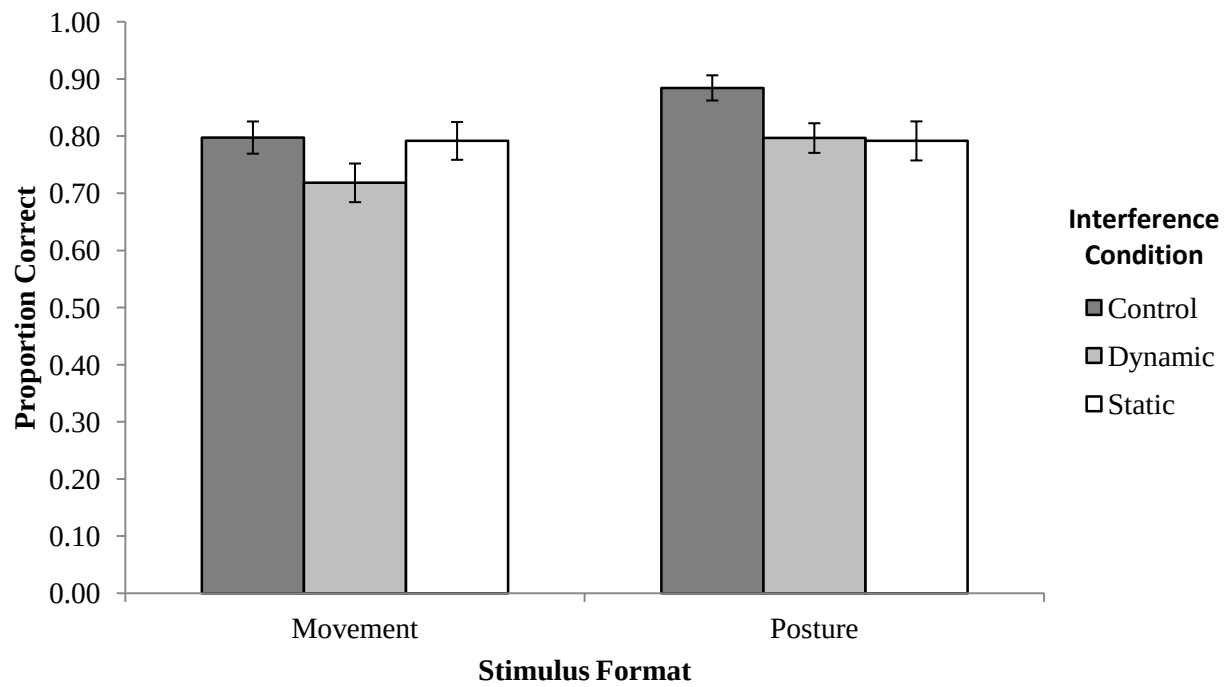


Figure 7. Experiment 2: Mean accuracy for movements and postures in control (no interference), dynamic and static interference Conditions. Maximum = 1, Chance = 0.5. Error bars refer to standard error of the mean.

Table 1. Experiment 1: Accuracy for postures and movements

Study and Test Format	M	SD
Movement-Movement	0.80	0.14
Movement-Posture	0.71	0.13
Posture-Posture	0.87	0.13
Posture-Movement	0.70	0.14

Table 2. Experiment 2: Accuracy for postures and movements across interference conditions.

Interference	Stimulus	M	SD
Control	Movement	0.80	0.13
	Posture	0.88	0.09
Dynamic	Movement	0.72	0.15
	Posture	0.80	0.12
Static	Movement	0.79	0.15
	Posture	0.79	0.15