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Long-term memory for contemporary dance is distributed and collaborative☆

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ABSTRACT

Professional dancers appear to be the embodied records of works of choreography that have been created, rehearsed and performed. Their precision in recalling extended sequences of movement developed for these works defies the conventional methods used to investigate memory. A distributed cognition view holds that memory will not only be individualistic, but also extended across a dance ensemble. Working closely with the highly skilled dancers of Australian Dance Theatre (ADT), we set out to develop an ecologically valid method that elicited memory recall and lapsing. Dancers were divided into two "teams" with each team asked to choose excerpts for memory recall from the company's extensive repertoire that would challenge individual dancers in the other team. There were 14 trials; 12 involved the dancers recalling dance excerpts on their own (solo condition) and 2 with a partner (duet condition). In the ADT studio, seven dancers recalled (reproduced) as much of the excerpt as possible in the absence of an accompanying soundscape. Recall was extensive, but contained lapses, and these recall failures form the core of the analysis in this study. Four novel types of memory recall were identified: static shapes, isolated movements, partial and full movement sequences; and two strategies for recall: looking for movement by moving and collaborative sketching. Four types of errors were observed: errors of detail, order, omission, and additions. Analysis was conducted through a new method of counting 'choreographic items'. The most detailed recall (73–96%) was for the two duet excerpts with significantly poorer recall of excerpts from complex group sections of a dance. Movement gist was generally retained. The types of recall and types of errors observed pointed to the use of not only procedural memory and chaining but also contextual cues as aids to movement recall. Collaborative elements of recall were observed that suggest the importance of distributed cognition and collective memory within a contemporary dance ensemble.

1. Introduction

Contemporary dancers train for many years and when working at the top of their professional field (such as the individuals this study worked with) they integrate mental and physical capacities in ways that are unlike other physical practices. Their ability to recall movements which they may have helped to create, then rehearse and may perform many times, has rarely been studied as it defies experimental protocol. When the question is asked of dancers working in this genre, "Is a dancer's memory for a work that has been performed a number of times a motor skill and procedural? or is the knowledge declarative and more like episodic and semantic memory?" the response will likely be both.

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These dancers have outstanding memory for movement and designing an experiment that illuminates long-term memory processes through the pattern of lapses and memory errors in this population is simply difficult to do, as their long-term memory is highly accurate. We will describe an experiment that was designed in collaboration with an ensemble of professional dancers. The experiment incorporating "the memory challenge" will be reported and the results interpreted in light of distributed, collaborative cognition and interactions between procedural and declarative processes.

In this paper, we will consider the nature of long-term memory for set works of contemporary dance, a topic for which there is very little extant literature, so we will begin with a review of research on memory for dance drawing on related work in classical ballet and other dance forms.

1.1. Long-term memory for dance

Movement sequences become automated with practice (Himberg & Thompson, 2011). Holding a series of movements in short-term memory and transferring to long-term memory, including for classical ballet steps, is based on grouping or chunking (Cowan, 2000; Miller, 1956; Oberauer, 2009) and linking (Allard & Starkes, 1991; Jean, Cadopi, & Ille, 2001; Wachowicz, Stevens, & Byron, 2011). Grouping is often hierarchical with steps chunked together as a phrase, phrases chunked into sections, and sections into a complete work (Jordan, 2011). Dancer skill level is known to affect perceptual-cognitive reference structures in long-term memory for classical dance (Bläsing et al., 2012; Bläsing, Tenenbaum, & Schack, 2009). Each reproduction of a sequence while learning enables several chunks to be re-grouped reducing the performance demands of subsequent recall (Longstaff, 1998). Sequential associative learning sets up expectations for the likelihood of particular movements following each other, enhancing recall that is associated with subject matter expertise (Jean et al., 2001; Starkes, Caicco, Boutilier, & Sevsek, 1990). Where particular music has been an accompaniment to dance and through processes of associative learning, music can become a potent contextual cue to recall of the dance (e.g., Poon & Rodgers, 2000; Starkes, Deakin, Lindley, & Crisp, 1987); exceptions also exist with music not providing an advantage to a group learning ballet from a video or still-frame depictions (Gray, Neisser, Shapiro, & Kouns, 1991). Activation of cingulate, retrosplenial and parahippocampal brain areas in dancers mediates episodic memory for dance stimuli (Calvo-Merino, Glaser, Grèzes, Passingham, & Haggard, 2005).

Most of the studies have addressed classical ballet. Do accounts of memory for classical ballet generalize to contemporary dance? Classical ballet comprises a codified vocabulary where each step has a distinguishing and descriptive label. Knowledge of classical ballet vocabulary and nomenclature can be declarative and specific movements can be declared or expressed verbally. Classical ballet can also be notated and if the performer has studied and learned a particular formal notation system,[1] then the notation itself, just as orthography and phonology become connected in processing spoken language (e.g., Stuart, 1990; Tyler & Burnham, 2006), may become interconnected with visual and motor memory for the steps. Sequencing of steps in classical ballet is also influenced by convention, aesthetics, biomechanics, and laws of physics; memory for classical ballet is likely coded not only in steps and sequences, but also within a specific vocabulary and grammar.

Contemporary dance differs from classical ballet in that generally choreographers strive to develop novel movement vocabularies and systems for organizing or structuring meaningful compositions from these (Stevens & McKechnie, 2005). Declarative vocabularies or labels are therefore likely to be more specific to individual artists' practices. Three well known examples can be seen in the differing approaches of the American choreographers Merce Cunningham and Trisha Brown, and German dance theatre artist Pina Bausch. The nature and structure of dance movements, how these movements are connected in sequences, and the organisation of movement sequences in time are completely different in the work of these artists. Learning and remembering contemporary dance may therefore be akin to learning an artificial grammar, and at least three studies have shown that an artificial grammar for the sequencing of phrases of contemporary dance can be learned through mere exposure with the learning implicit (Norman & Price, 2012; Opacic, Stevens, & Tillman, 2009) or incidental (Orgs, Hagura, & Haggard, 2013).

Moreover, innovation in contemporary choreography goes beyond creating new steps, often seeking to develop new ways of configuring and conceptualising the body itself. This may, for example, involve disrupting habitual and/or socially recognisable movement paradigms such as walking upright, presenting the face forwards (facilitating communication through speech and facial expression), or gesturing with arms and hands (Louppe, 2010). Trisha Brown, for example, described her work by saying, "lying down was done in the air." (Brown, 1978). This desire to disrupt conventional 'grammars' of movement has implications for how movement recall might be defined in contemporary dance. In contemporary dance, movement is defined in relation to specific aesthetic and artistic contexts and hence choreographically rather than biomechanically. It is, for example, difficult to quantitatively define a 'whole-body action' since motion capture data of elite dancers reveals significant differences between the movement profiles of different dancers performing the same movements, including different temporal profiles for similar movements (Vincs & Barbour, 2014).

Due to the context-specificity inherent in contemporary dance movement, combined with the lack of training in notation systems and assumptions about their applicability, contemporary dance is rarely notated using formal systems, although notebooks are frequently used as cognitive aids (deLahunta, Mcgregor, & Blackwell, 2004) and dancers learn works in re-staging ventures through processes of "showing" and "doing" (Grove, 2005). Video of past performances can be used, but video captures the movement and kinematics in two dimensions and does not always convey all spatial, temporal and inter-personal relations in the design of an ensemble work, or the force and weight, dynamic or quality of the movement, although trained dancers are extremely skilled learning these aspects from video (Noë, 2004). Contemporary dance is also often improvised and composed in silence or with a soundscape or music that is not part of the final performance and may be changing all the time. Therefore, while present in the work of creation, music may not become a reliable cue or trigger in associative memory. Choreographer and dancers frequently develop aspects of the work in a collaborative and distributed manner (Kirsh, Muntanyola, Jao, Lew, & Sugihara, 2009; Stevens & Leach, 2015). How then is such movement material retained and retrieved from human long-term memory and does the collaborative manner of creating material influence memory for the material? Some work on memorization and performance of music and drama and the phenomenon of collective memory may provide some theoretical insights.

In studies of long-term memory for music, jazz and classical musicians use their knowledge of formal structure to aid retrieval; while practicing, they use performance cues to retrieve passages from memory (Chaffin & Imreh, 2002; Geeves, McIlwain, Sutton, & Christensen, 2014; Ginsborg, Chaffin, & Demos, 2012; Noice, Jeffrey, Noice, & Chaffin, 2008). Features of the music become mental landmarks during performance. Applying Chaffin and colleagues' ideas to dance, we can identify landmarks that are structural (the form of the work including sections, phrases and switches where the same material can lead in more than one direction), basic (technical issues such as

[1] The dance notation system most likely to be learned and used for Classical Ballet is Benesh Movement Notation (Gregory, 2015). However, the job of notating the dance is normally performed by someone trained and specially hired by the company to perform this task.

spatial layout and orientation, where to breathe, postures), interpretive (interpreting the choreographer's intentions), and expressive (conveying intentions to the audience). A subset of these features become performance cues, namely those cues to which the performer attends when on stage in front of an audience (Chaffin & Imreh, 2002; Ginsborg et al., 2012; Stevens, Ginsborg, & Lester, 2011). We anticipate the pattern of recalling dance will follow the structural design of the dance excerpt. For example, movement cues that mark the beginning of phrases or sections within the dance, or significant moments of change in the form of the work might be expected to aid movement recall.

1.2. Distributed and collaborative cognition

After Hutchins (1995) and in the context of Elizabethan and Jacobean theatre, Tribble (2005, 2011) emphasizes that cognition is social and possessed not only by individuals but distributed across the entire system. Cognitive-rich environments such as repertory with actors, for example, performing six different plays each week and learning a new one each fortnight, may well demand individual *and* distributed cognition. Full scripts of plays were rarely provided to actors in Elizabethan times, Tribble notes. Rather, they received their own lines and just the immediately preceding lines of another actor to be learned as a cue (Tribble, 2005). Tools, artefacts, practices of early modern theatre (e.g., stripped down part; plot; physical space; structures and protocols of company), form elements of a cognitive structure (Tribble, 2005, p. 142) that serve to constrain, limit and achieve recollection from memory. Distributed cognition emphasizes effects of cognitively rich environments on agents operating within that system. Such a “cognitive ecology” assumes that “mental activities spread or smear across the boundaries of skull and skin to include parts of the social and material world” (Tribble & Sutton, 2011, p. 194).

In a different ecology again, that of 20th C theatre where actors, for example, have access to a complete text of a modern play, the results of an experiment indicate that spatial and visual contextual cues influence actors' recall of a play although only to limited extent (Schmidt, Boshuizen, & van Breukelen, 2002). Lines are learned through meaning, and retrieval based on a mental model of the situation, rather than rote chaining of text (Schmidt et al.). When four contemporary dance artists recalled dance exercises that had not been performed for 3 to 30 years ago (Stevens et al., 2011), an array of contextual, environmental, personal and social cues came to light – another “cognitive ecology”. The four dancers recalled the inflection of the choreographer's voice, music associated with each exercise, their own sense of self at the time of learning, the cultural, social and political milieu of the times when the material was learnt, certain somatic sensations such as tension in particular muscles, and emotions, for example, the joy associated with performing particular cherished exercises. Meaning making happens through movement; knowledge is “declared” through and with the body (Stevens & McKechnie, 2005).

Extrapolating from these studies and the concept of encoding specificity (Godden & Baddeley, 1975), it is hypothesized that lapses in dance recall occur when contextual cues such as set, costumes, other dancers, and accompanying music or soundscape are minimised.

Harris, Barnier and colleagues have demonstrated the distributed and collaborative nature of “shared remembering”, for example, when older married couples appear to retain complementary rather than redundant or overlapping mental records of appointments (prospective memory) and personally meaningful events such as family holidays and occasions (Harris, Barnier, & Sutton, 2013; Harris, Barnier, Sutton, & Keil, 2014; Harris, Keil, Sutton, Barnier, & McIlwain, 2011; Harris, Paterson, & Kemp, 2008). The collaborative recall paradigm compares output of a group with aggregated output of the same number of individuals remembering alone (Harris et al., 2014). Collaborative groups reliably remember less than aggregated groups. Such collaborative inhibition occurs for word lists, stories, picture and facts (Harris et al., 2008). Groups of strangers and friends show collaborative inhibition. By contrast, subject matter experts, such as pilots who use efficient and effective communication, show benefits – collaborative facilitation – from group recollection (Meade, Nokes, & Morrow, 2009). Similarly, intimate couples benefit from remembering together. Couples, like experts, are a special group and show no collaborative inhibition. Harris et al. (2014) argue this is because they are skilled and practised in communicating effectively and have shared knowledge and shared experiences. Collaborative facilitation demonstrated by couples and experts is underpinned by a coordinated strategy in recalling material. ADT dancers as subject matter experts are likely, like pilots and intimate couples, to reflect collaborative facilitation. Specifically, the presence of other dancers as in a duet or group dance sequences, should facilitate recall compared with solitary recall.

Serial recall is likely to reflect primacy and recency effects although recency is not always observed for chained material (Allard & Starkes, 1991) and Schmidt et al. (2002) has suggested that for plays the beginning section tends to get more rehearsal than latter sections and such overlearning explains why primacy more than recency effects are observed. Material charged with the emotion and physiological arousal of having been performed is likely to be relatively well recalled. These factors, e.g. music, environment and context, learning experience, etc. were all confirmed as relevant for long-term memory in our planning conversation with the dancers as part of the co-design of the experiment we ran with them.

1.3. The present study

In a collaborative research project with Australian Dance Theatre (ADT), we had the opportunity to develop a method to probe dancers' long-term memory, which was co-designed with the participants. ADT under its current artistic director is known for the creation of original evening length choreographic works. These works are created, set, rehearsed and widely performed during more than one season. ADT often tours these dance works internationally and those that are popular can be brought back on request from a festival or producer. Dancer recall of this material tends to be highly precise and intact. In order to elicit memory lapses/errors for this corpus of generally highly rehearsed movement material, we decided to work closely with the dancers to co-design the memory experiment they would be participating in. This became known as the ‘memory challenge’ paradigm. The first part of this process was to engage the dancers in a conversation that included describing some basic theory of memory from a psychologist's perspective, for example, explaining the relationship between declarative and procedural, episodic and semantic memory. General examples of other memory experiments in dance and music (e.g., Chaffin & Imreh, 2002; Ginsborg et al., 2012; Stevens et al., 2011) were also shared with the dancers with details about the ways in which the manipulation of variables played a key role in the experimental design. The next part of the conversation shifted to asking them which variables or factors they thought most influenced their long-term memory for dance. This resulted in a list of approximately 30 separate factors (see Table 1), many of these the kinds of constraints characteristic of a cognitively rich performance environment discussed by Tribble (2005), as a possible basis for further studies at another time.

Toward the end of the one and half hour conversation, both the scientists and the artists arrived at roughly the same idea at the same time. While the list of factors influencing long-term memory offered opportunities to the scientists to go away and return with a more classical experimental design, our goal from the start was to co-design and collaboratively develop the long-term memory experiment with the dancers. The idea arrived at together was for the dancers to split into two groups and engage separately with the question: “what would really challenge the other group in terms of memory”. Each group was tasked with coming up with a list of excerpts from ADT works that would maximally challenge memory of dancers in the other team. The experiment would then follow a conventional recall task. Individual, or

Table 1
Dancer's suggestions for factors that influence long-term memory for dance.

Music
Space
Costumes
Ease of acquisition
Strange memories
Many variables!
Emotional variables – liked it/loved it
Body is a variable
Autopilot – blank
Flow
Technical versus audience focus
Pressure: stage versus studio performance
Audience
Imagery
Space
Pathway
Learning is a different process
Improvisation – and no recollection of it
Rhythm of movement, eg as a song
Be Your Self – needed music, but not musical
Teaching each other
Learning movement from different bodies – change it for particular body
Re-teaching and re-learning Proximity
Character/state – easier to remember
Way it was taught
Movement and then background to it – not background first
Make the material yours and great for you
Emotion – expression
Exercise easier to learn than choreography

in some cases a pair of, dancers would be asked to reproduce the particular excerpt in the absence of any soundscape or other cues. They would be presented with the excerpt (usually the name of the phrase and title of the dance work) without prior knowledge and asked to recall and perform it 'on the spot'. The dancers were all familiar with the dance works in question, and were able to understand which excerpt to perform. These trials were video recorded and at the conclusion of each trial the dancer completed a one-page questionnaire, which asked them to describe the process of recall.

2. Method

2.1. Participants

The sample comprised seven dancers from ADT (2 females) with mean age of 24 years, $SD = 3.83$ years and mean training of 15 years, $SD = 4.36$ years.

2.2. Stimuli and equipment

The stimuli consisted of 14 excerpts from 6 different works, *Nought*, *G*, *Be Your Self*, *Multiverse*, *Proximity*, and *Rough Draft*. Excerpt duration ranged from 1 min to 7 min, and had been learned and/or performed by the dancers between 6 and 24 months previously. The excerpts were clearly bounded within the structure of the dance works. None of the dancers expressed uncertainty as to where the excerpt should begin and end, reflecting their familiarity with the company's repertoire. 12 of the 14 excerpts were recalled by the dancers on their own (solo recall). The original versions of these 12 excerpts had been originally performed as particular roles within group dances. The excerpts contained several different types of dancer interactions, and these were combined in various ways within excerpts, reflecting the choreographic style of the company's repertoire. The excerpts contained solos (the dancer performing independently of other dancers), duos (two dancers performing in unison, but not physically interacting), unison group work (the dancer performing as part of an ensemble in synchronisation with other dancers), and complex group work (the dancer required to move in and out of synchronisation with different groups of dancers while generating complex spatial patterns). The excerpts were categorised according to the type of dancing they contained. Three of the excerpts comprised only solos, three included solo and duo elements, one included solo and group elements, and one included duo and group elements. There were two unison group excerpts and two complex group excerpts. The remaining two excerpts were duets. The duets were originally performed by two dancers working closely together, using extensive partnering, lifts and weight-sharing, rather than dancing side by side or in group formations as in the other 12 excerpts. The duet excerpts were recalled by two dancers working together because the movement would have been impossible to recreate by a single dancer working on his or her own. The duet excerpts were therefore recalled by two dancers working together (duet recall).

Five of the solo recall excerpts had been previously performed by the dancers asked to recall them and seven had not; neither of the duets had been performed by the dancers recalling them in the experiment. Recall was recorded using a JVC digital video camera. Veridical versions of the stimuli for comparison with material recalled were sourced from the digitised video archive of ADT works.

2.3. Procedure

Dancers provided written consent to participate in the experiment (Western Sydney University Human Research Ethics Committee approval H10527). The 14 trials were ordered randomly. Each dancer or pair of dancers, depending on the trial, entered the main studio at ADT and were asked to recall the named item in silence. At the end of each trial, the dancer answered a series of questions about the recall process (Appendix 1). A discussion with the entire group of dancers followed the experiment trials. This included debriefing and discussion of the recall process and any challenges it presented.

3. Results

3.1. Coding and quantifying dance recall

The video recording of each trial was compared with the veridical version of the relevant stimulus, and a method developed to quantify the level of movement recall. Because the speed and complexity (i.e. complex movements performed by a single individual) of the movement material varied considerably between sequences, a time-based method such as 'number of seconds remembered' would not provide a valid comparison between trials. Some movement sequences contained many different movement gestures within a short space of time, whereas other sequences included fewer movements taken at a slower speed. Time-based measures (e.g. number of seconds remembered) would have distorted the findings depending on the speed and movement density of each sequence. The concept of counting 'choreographic items' was developed to address this issue. While to contemporary dance practitioners the idea of a 'choreographic item' may seem reductive, in this context, the term provides the adaptability and potentiality to encompass innovative movement vocabularies, which are integral to contemporary dance innovation. Choreographic items are comparable with "idea units" defined by Schmidt et al. (2002) as chunks of play text that coincided with sentence boundaries.

In our analysis, a 'choreographic item' was considered to have occurred with each new initiation of a new pathway, force or gestural intention, regardless of the type of initiation that occurred. New choreographic items could be initiated either peripherally (e.g. limb, hand and foot trajectories) or centrally (e.g. head, spine or pelvis trajectories), and could be defined by any distinctive choreographic idea, e.g. shape, trajectory or locomotion, to ensure that each discrete choreographic element of the movement sequences was included. Overlapping movement initiations, that is to say, multiple initiations occurring simultaneously in different parts of the body, were considered to be part of the same choreographic item to avoid deconstructing the movement

components in ways that would be contrary to the choreographic intention.

Assessment of 'choreographic items' was undertaken by the third author, who is an expert dance practitioner. The analysis was performed by close visual analysis of the video footage of each trial, and of the veridical versions of each excerpt. The number of choreographic items performed in each trial was determined, and compared with the number of choreographic items contained in the veridical version of the sequence. Choreographic items were counted as recalled where the majority of movement detail (e.g. shape, pathway and body part) was recognisably performed. This was necessary because the dancers did not always execute the movement fully, sometimes because they were 'marking' the movement – a process where dance movement is sketched rather than danced full out (Kirsh, 2011; Warburton, Wilson, Lynch, & Cuykendall, 2013) – and sometimes because they were unable to perform all the movements in sequence and therefore did not have the correct biomechanical positioning to be able to fully execute the movements. Choreographic items recalled were counted whether or not they occurred in the correct sequence. Movements that did not occur in the veridical versions of the movement sequences (addition errors) and static shapes (see below) were **not** included in the number of movements recalled.

The number of choreographic items recalled was determined for each trial and expressed as a percentage of the total number of choreographic items in the benchmark video of each excerpt provided by ADT. Videos of the trials were then examined to determine the strategies the dancers used to recall the movement and the types of errors that were made. The results are summarised in Table 2.

Six ways in which movements were recalled were identified:

i) Static shapes. No movement was recalled, but the performer adopted a distinctive, identifiable shape from the movement excerpt. The performer stopped moving and appeared to be waiting.
ii) Looking for movement by moving. The performer appeared to be moving almost randomly, seeking to recall by moving.
iii) Isolated movements. The performer performed isolated movements, stopping between each.
iv) Collaborative sketching. Two performers engaged in dialogue while trying out different approaches to specific movements, revising 'sketches' of the movement before performing the full excerpt.
v) Partial movement sequences. The performer performed several movements linked into a sequence, but some movements are omitted (dropped out), or incorrectly sequenced compared to the benchmark video.
vi) Full movement sequences. A series of movements was correctly performed, linked together with accurate sequencing.

Four kinds of errors were observed:

i) Errors of detail: the movement is performed, but includes incorrect details, e.g. the wrong leg shape with the correct head and arm movement, the wrong arm used or the wrong direction faced.
ii) Errors of order: the movement is performed out of order, either between isolated movements and partial or full sequences, or within partial sequences.
iii) Omissions: movements or movement sequences were dropped out. This occurred between full and partial sequences, and within partial sequences.
iv) Additions: movements were added that were not in the benchmark videos.

(1) *Amount of recall*

The range of recall was 0% to 96%. This range indicates that the experiment protocol was successful in avoiding a ceiling effect in which the dancers were simply able to remember everything (a prime challenge within this study given the elite artists involved). Where dancers had relatively low levels of recall (0–18%) recall was primarily in the form of isolated movements. At higher levels of recall (23–57%), both partial and full sequences were recalled. The highest levels of recall (73–96%) were achieved in the two duet excerpts, and the lowest levels of recall in the complex group excerpts (0% and 0.5%).

(2) *Type of excerpt (solo, duet or group)*

If the presence of other dancers acts as a contextual cue that aids recall, as in encoding specificity, removing other dancers from the recall condition should result in poorer recall. The more important the contextual cues provided by other dancers in the original version, the more impact removing them should have on recall. The most critical cues from other dancers occur in duets in which the two dancers move closely together in detailed and closely synchronised ways (duet excerpts), and in the complex group dances in which dancers must move in and out of synchronisation with different dancers many times and complex spatial patterns between dancers must be maintained (complex group excerpts). Excerpts involving duo and unison group movement also involve cues from other dancers, but these are less critical to the performance because they do not involve complex and rapid shifts in the relationships between dancers the way duet and complex group excerpts do, and because the physicality of the movement performance is not dependent on the other dancers as it is in partnering work (duet excerpts) or in maintain complex spatial patterning and counterpoint (complex group excerpts). Solo excerpts involve the fewest contextual cues from other dancers since the performer dances alone.

If contextual cues provided by other dancers influence recall, complex group excerpts (in which the original contextual cues were more detailed but are now removed) should be less well recalled than solo, duo or unison group excerpts. The results for excerpts from complex group sequences recalled in the solo condition were consistent with this hypothesis; Z test of proportions showed that recall of duet excerpts was significantly greater than recall of complex group excerpts, $Z = 1.64$, $p = 0.049$. Complex group excerpts were the least well recalled (0%, 0.05%), and even when help from another dancer who had also performed the work was offered and given, which occurred in trial #1 after the dancer had failed to recall any movements, it did not enable the dancer to recall any further material. Excerpts containing solo, duo (unison) and group (unison) movement recalled in the solo condition had relatively greater recall rates ranging (7–57%) although the difference between other solo conditions and complex group trial proportions did not reach significance, $Z = -0.95$, $p = 0.17$. There did not seem to be a clear relationship between excerpt type and amount of recall within this range. This may reflect variability in the excerpts themselves since several of these excerpts contained a mixture of all three types of movement (solo, duo unison and group unison).

In summary, the two sequences that were performed exclusively as duets and recalled with a partner were the most completely recalled (73% and 96%). This is consistent with the concept of encoding specificity: the presence and actions of other dancers provide contextual cues for recall, since in the duet recall condition, such social cues were present.

(3) *Collaborative versus solo recall*

It is possible that the collaborative mode of recall itself also contributed to the higher recall rates for the duets, compared with the 12 excepts recalled in solo condition. When recalling with a partner, the dancers used a particular approach to recall, collaborative movement sketching, which was not used by the dancers recalling excerpts in the solo condition. In collaborative movement sketching, the two dancers spoke in dialogue as they sketched out short sequences of movement, prompting each other with suggestions for which movement might have come next. They often stopped to repeat short sequences of movement

Table 2
Percentage of movements recalled, excerpt type, length, complexity, types of recall and types of error.

Trial	% Recall	Excerpt type (solo, duo or group)	Excerpt length (s)	Excerpt length (choreographic items)	Excerpt complexity (choreographic items/s)	Types of recall	Types of error
1	0	Group-complex	135			1 static shape recalled, with part of the preceding movement	Omission Errors.
8	0.05	Group-complex	558	282	0.50	Isolated movements. Sequences from a different work (addition errors)	Addition errors – of the 94 movements recalled, most (81) were not from this excerpt. These may have been from a different choreographic work.
5	7	Group (unison)	31	36	1.16	Isolated movements.	Error of order - the three isolated movements were recalled out of order. Errors of detail in the movements recalled.
13	16	Solo and duo	56	43	0.78	Isolated movements.	Errors of order – the isolated movements are recalled out of order
2	18	Solo	96	40	0.41	Isolated movements.	Errors of order – the isolated movements are recalled out of order
7	23	Duo and group	254	210	0.83	Full and partial sequences and moving, looking for movement.	Omission Errors – within partial sequences and between full sequences Errors of detail – often precede omissions between sequences.
14	32	Solo and group	151	82	0.54	Full and partial sequences.	Errors of detail – often precede omissions between sequences. Addition errors (3)
3	37	Solo and duo	56	46	0.82	Partial sequences	Omission Errors – within partial sequences and between sequences. Errors of detail – often precede omissions between sequences.
4	44	Solo	31	36	1.16	Partial sequences,	Omission Errors – within partial sequences and between sequences Errors of order – sequences recalled out of order Errors of detail Addition Errors (2)
10	44	Group (unison)	82	22	0.26	Partial sequences,	Omission errors – within partial sequences and between sequences
9	54	Solo and duo	318	232	0.73	Full and partial sequences	Omission Errors – within partial sequences and between sequences. Errors of detail – often precede omissions between sequences.
11	57	Solo	96	56	0.58	Partial sequences	Omission Errors – within partial sequences and between sequences. Errors of detail – often precede omissions between sequences. Additions (3)
6	73	Duet	79	65	0.82	Full and partial sequences, collaborative sketching.	Omission errors – within partial sequences and between sequences. Errors of detail
12	96	Duet	27	23	0.85	Full sequences, collaborative sketching.	Omission Errors – between sequences (very few). Errors of detail

in this way, progressing to the next sequence after two – three repeats, or when they were reasonably well agreed on the movement. The results from a *Z* test of proportions revealed that the difference between recall of duets versus all others fell short of significance, Z = 1.55, $p = 0.061$.

Because it was not possible to recall duet material in the solo condition (the complex partnering work in Stewart's duet choreography makes this infeasible), it was not possible to compare recalling duet as opposed to the other kinds of excerpts in solo mode. Hence, it is not possible to positively distinguish between type of except and type of recall in evaluating the results for duet recall. However, the use of a unique strategy for recall in the duet recall condition would indicate that there are qualitative differences in the approach to recall between collaborative and non-collaborative conditions.

(4) *Length and complexity of excerpts*

The sequences ranged in length from 27 to 558 s. The percentage of recall did not seem to be related to the length of sequence. The average rate at which choreographic items occurred within each trial sequence was calculated as choreographic items/s (Table 2) to provide a measure of the speed and hence complexity of the movement sequences within each excerpt. Choreographic items/s for the excerpts ranged from 0.26 to 1.61. Pearson correlations between percent recalled and each of the three factors were not significant. There were weak, negative but non-significant correlations between percent recalled and excerpt length in seconds ($r = -0.35$) and length in movements ($r = -0.32$) and little or no correlation between percent recalled and complexity ($r = 0.08$). This may reflect the elite skills of the dancers, who routinely learn, recall and modify large quantities of movement material every day, such that the ability to remember lengthy and complex movement material is a given at this level of elite performance.

(5) *Previous performance of excerpt*

The dancers predicted that sequences that they had performed themselves would be easier to recall than sequences that they had learned but not actually performed. The average percentage of movements recalled when the dancer had previously performed the sequence was 21% ($N = 5$), and the average percentage of movements recalled when the dancer had not previously performed the sequence was 44% ($N = 9$), $Z = -0.86$, $p = 0.19$. Some of the most accurately recalled sequences (54%, 57%, 73% and 96%) had not been performed by the recalling dancer, while some of the least well recalled sequences had been performed by the dancer (0%, 0.5%). This would suggest that other factors are more important in long term movement recall in professional dance than whether or not the dancer has previously performed the movement, and points to the need for empirical means to observe and quantify recall rather than relying exclusively on participants' opinions about ease of recall.

(6) *Serial position effects*

It was hypothesized that there would be greater recall for beginning sections than middle or end sections. To investigate this hypothesis, each sequence was divided into three equal sections based on duration (in seconds) and the number of movements recalled in each of these sections (1st third, 2nd third and 3rd third) was tabulated for each trial (Table 3). Despite some trends in the descriptive statistics, *t*-tests showed no significant primacy or recency effects: 1st versus 2nd (primacy), $p = 0.16$; 3rd versus 2nd (recency), $p = 0.44$.

(7) *Structural Landmarks*

It was hypothesized that structural landmarks in the dance excerpts analogous to those described by Chaffin and Imreh (2002) in music, are important in assisting recall of movement in both positive and negative ways. Structural landmarks in these excerpts would comprise moments where the choreographic pattern changes, e.g. two dancers begin or end performing in unison, or a dancer moves to another part of the stage to begin a new section. Recalling a specific performance cue might enable the recall of a particular section, and failing to recall, or in the case of dance, incorrectly performing a performance cue might make it more difficult to recall a particular section. To attempt to identify such key performance cues, we examined the types of recall and error in each of the trials to see whether there was any association with structural landmarks in the excerpts.

In 5 of the trials, the dancers recalled only static shapes or isolated movements. In these trials it was not possible to discern any relationship, either positive or negative, between lapses in recall and structural landmarks in the choreography, except in trial # 1, in which the single shape recalled was the ending position of one section of the excerpt, and trial #13, in which 2 of the 7 choreographic items recalled were the first movements in a phrase. Several of the choreographic items recalled were movements with easily identifiable visual shapes (e.g. a leap, outstretched in the air). However, these choreographic items did not coincide with structural landmarks in the choreography. In the other 9 trials, in which the dancers recalled partial and/or full sequences of movement, lapses occurred within sequences of movement and did not coincide with structural landmarks in the choreography.

(8) *Types of recall*

A detailed examination of the types of recall was undertaken to see whether any other factors could be identified that might be associated with recalling or lapsing. A detailed description and example of each of the types of recall identified is given in Appendix 2. Recall of static shapes and isolated movements featured in takes with relatively low overall recall, and partial and full sequences occurred in takes with higher overall recall. Collaborative sketching occurred only in the duet condition.

4. Discussion

4.1. Contextual factors in long-term memory for dance

In dance, one of the most immediate contextual factors is the other dancers with whom one rehearses, dances and performs. Perhaps the most striking feature of the present results is the relatively poor recall of excerpts involving complex group interactions compared with recall for solos, duos and unison group work. In both trials involving complex group excerpts, recall was very low (0% and 0.05%) and comprised only a few shapes and movements. Complex group excerpts provide a condition in which other dancers play a critical role. One of the dancers described the rapid shifts in relationships between dancers in complex group choreography; “it was, like, one move with that person, now you - one move with that person, two moves with this person”. Another dancer's description similarly emphasizes the complexity and dynamic nature of the spatial and temporal relationships between dancers.

> “…coming in and out of unison and … really complex and sometimes you'd be on your own and sometimes you'd be doing unison with three people or one person, and at the other end of the room so you've got be aware, so I think that's why I record, like, who I was looking at and the structure.”

The complexity of visual cueing between dancers in elite contemporary dance has been demonstrated by visualizing interactions in William Forsythe's One Flat Thing Reproduced as a ‘cue score’ (Ahlqvist, Ban, Cressie, & Shaw, 2010). Tasking performers with recalling this type of choreographic material on their own, as in this study, removes the complex cues dancers give and receive to enable them to move rapidly in and out of spatial alignment, unison and

Table 3
Movements recalled as a function of excerpt type and beginning, middle and end sections of excerpt.

Trial	% Recalled	Total movements recalled	Solo/duo/group	Previously performed	Movements recalled 1st third (beginning)	Movements recalled 2nd third (middle)	Movements recalled 3rd third (end)
1	0	0	Group (complex)	Yes	0	0	0
8	0.05	13	Group (complex)	Yes	4	0	7
5	7	3	Group (unison)	No	2	1	0
13	16	7	Solo and duo	No	2	3	2
2	18	7	Solo	No	5	1	1
7	23	48	Duo and group	Yes	24	8	16
14	32	26	Solo and group	No	19	7	0
3	37	17	Solo and duo	Yes	17	0	0
4	44	16	Solo	No	10	2	4
10	44	11	Group	Yes	2	1	12
9	54	125	Duo and solo	No	52	43	30
11	57	32	Solo	No	14	10	8
6	73	48	Duet	No	9	18	21
12	96	22	Duet	No	7	7	8
				Mean:	12	7	8
				SD:	13.63	11.51	9.16

counterpoint with other dancers, and this may provide an explanation for the relatively poor recall of complex group excerpts compared with solo, duo and group unison excerpts.

In contrast, recall for the duet excerpts, undertaken by two dancers working together, was particularly effective (73% and 96%) and suggests collaborative facilitation (Harris et al., 2013, 2014). The movement in the two duet excerpts required the dancers to be in constant physical contact with each other. The choreographic items involved mutual weight-bearing, lifts and counter-balancing actions that cannot be fully performed in the absence of the other dancer. In the duet excerpts, the dancers' attention is therefore, of necessity, directed toward each other. In the duet recall condition, the context of the other dancer was not only present during recall, but an active participant. The dancers described recalling the duets as much easier than the other excerpts. As one dancer put it, "… having another person does help recall certain things even if it's not completely right you are more than likely to have a structure of the material." The dancers also commented on the interaction with another person during the recall as being positive, with elements such as eye contact and humour contributing to putting together the structure of the excerpt. This was apparent in the recordings of the duet recall trials. While the dancers recalling excerpts on their own tended to move through the excepts linearly, either performing movements or hesitating and commenting on how they were trying to remember, the dancers recalling as a duet used a process of collaborative sketching in which they went over specific sequences several times together, each time recalling more movement. When they seemed reasonably satisfied at the level recall of a specific sequence, they moved onto the next sequence. Interactions between the dancers were integrated into the process of recalling the movements and the dancers spent longer working on specific sections, and were able to collaborate, filling in gaps for each other and pooling their collective recall. Cognition, specifically memory, for performance does appear social and collaborative (Tribble, 2005). Encoding specificity (e.g., Godden & Baddeley, 1975) is likely to be one explanation for the collaborative facilitation observed here.

The collaborative facilitation in this study is striking for both the increased levels of recall achieved for duet excerpts recalled in duet mode, compared with recall for solo, duo and group material undertaken by a single dancer, and for the different approach of the dancers to the task. The process of 'collaborative movement sketching' was only apparent in the duet trials. In the other trials (solo, duo, unison and complex group excerpts), the dancers sometimes used a technique of 'moving to find movement' when they were had come to a lapse of recall. In this technique, they moved almost randomly, as if seeking to spark a movement memory from the act of moving itself, and often vocalized during the process (e.g. "something like"). This technique frequently prompted movement recall, but resulted in omitting some choreographic items and jumping forward to another section of the excerpt, and never enabled the dancer to continue directly from the point of lapse. It is a method akin perhaps to strategies to resolve tip of the tongue experience or, for dance, the twitch of the body. In collaborative recall with another person, this gap could potentially be filled in by input from another dancer, but in the solo recall condition, this cannot happen. Thus, shared dance material that can be recalled in collaboration with another dancer seems to aid long term recall of dance. Re-mounting dance works within a contemporary dance company such as ADT is usually done in a collaborative rehearsal process where dancers work together to re-create movement sequences even when these may be solo excerpts, and also work with the Rehearsal Director and with benchmark video files. Hence collaborative recall processes seem to be built into company work processes.

Across all the trials, the dancers referred in their written reflections to other contextual factors from months or years ago, such as remembering watching other dancers perform the excerpts from side stage and in rehearsals, and watching videos of other dancers performing the roles. These reflections point to the multimodal nature of the dancers' approach to recalling dance sequences, the role of social cognition in ensemble work, and various constraints on memory comparable with those that Tribble (2005) identified in the context of Elizabethan and Jacobean theatre. Episodic memory was evident where the dancers remembered specific rehearsals in which they learnt the material from other dancers and times when they showed the material to the choreographer. They also reported remembering the specific preparation process they needed to go through in performances. For example, one dancer wrote:

> "I pictured K performing it in the studio and watching K perform it on video – and then I pictured M performing it as it became his role. I then remembered some particular moves because we gave them names. However, the end of this solo was a cue for me to stumble on stage and that was the part I remembered."

While dance is normally considered a primarily kinesthetic form, this study brings to light the very significant influence of visual impressions of movement in the dancers' reports. As the above quote implies, there is significant fluidity and change in dancers' roles in most contemporary dance companies, which is necessary to accommodate touring schedules, allow for multiple casts and understudies in case of injury, and to provide the dancers with variety and new challenges. The

dancers reported in their descriptions many instances of visual memories of others dancing the roles they were recalling in rehearsal, in performance and on video.

Dancers also reported remembering how they felt about particular roles and performances as part of the recall process, for example being anxious during a particular rehearsal process or about a particular role, or particularly enjoying a particular role. The dancers felt strongly that having actually performed the role, as opposed to simply learning and understudying it, would make it easier to recall. Surprisingly, this was not the case with no significant difference between conditions. It is possible that the condition of recall and excerpt type (e.g. alone or with a co-performer, complex group excerpt or duet) were more powerful influences on recall. Further research holding excerpt type and condition of recall constant and manipulating systematically whether or not the dancer has previously performed the work is one variable needed to shed light on the process. This finding also calls attention to the value of independent verification of artists' perceptions, which, while invaluable as the corner-stone of industry practice and of practice-based artistic research, may not always be generalizable to broader questions such as the nature of long term movement recall in dance.

The question of whether having performed the excerpt facilitates recall in this context may reflect the cohesive group approach to dance creation that this particular company has developed over a period of years. It may be that emotional and physiological arousal, which might be expected to be associated with facilitated recall, is not so specifically centred around performances in this company context, in which performances are an ongoing and normalized part of company life, but more distributed throughout the fabric of the company's daily life and process. In this scenario, rehearsals and dance-making processes, which typically last 3–4 months in this particular company, may inscribe and reinforce movement memory in ways that are as powerful or even more powerful than performances themselves. Memory for contemporary dance can be considered a by-product of the meaning making (Schmidt et al., 2002) in which dancers engage as they improvise and create, refine, and rehearse movement material.

It was also anticipated that music may play an important role in facilitating recall of dance movement. The complicating factor in the context of contemporary dance choreography is that movement is not always tightly coupled to specific musical landmarks or gestures, and music or a soundscape is often a variable factor in the overall composition, often not finalised until close to performance, and therefore not always a strong contextual factor throughout the rehearsal process. When music is introduced to a work, and at what stage leading up to performance its structure is finalised varies from work to work. In this study, since our primary method was to seek excerpts from across the company's repertoire that would challenge the dancers' recall, it was not possible to choose excerpts that had a consistent relationship between choreography and music. Hence, recall was undertaken without music, and our results do not shed light specifically on this issue. However, the dancers' written comments on the subject are interesting to consider. In answer to the question, “What role, if any, did music, other people, social or emotional factors play or become apparent to you as you recalled the material?” virtually all the dancers replied that they did not think that music would have significantly helped their recall. The very few exceptions to this related to very specific musical cues that related to one specific work and specific movements within works. However, given the observation that the dancers' perceptions on the facilitating effect of having performed the works on recall were not validated, further work on the specific issue of the role of music in recall for contemporary dance is warranted.

4.2. Movement sequencing and long-term memory for dance

Being able to link movements together in sequence is fundamental to recalling dance. Previous studies (Jordan, 2011; Jean et al., 2001) have pointed to the role of chunking series of dance movements together in the learning process, and hierarchical groupings of movements as base movement concepts (Bläsing et al., 2009). Does this chunking also play a role in recalling movement from long term memory, and are there specific landmarks within the structural design of the dance that function as cues in recall? In our study, where recall was relatively poor, the dancers remembered specific choreographic items in isolation. There is little evidence for the place of structural landmarks in the recall of dance excerpts observed here. The dancers recalled the movement concept (e.g. shape, flow, trajectory) but not its place within a linked sequence. They did not recall these isolated movements via their place in a specific phrase or chunk of movements, but by virtue of the nature of the movement itself – its distinctiveness as a choreographic item rather than its position in a sequence. It was assumed that dance recall would have both declarative and procedural components. This type of lapse would point to a declarative and conscious element to this form of recall, since a purely procedural and motor process would require sequencing to be intact.

Where the dancers did recall movements linked into sequences, we would expect lapses in memory to occur at key switching points and transitions between phrases. However, this was not borne out in these results. This may be because the structure of the choreographic material was not always inherent in the role of a single dancer, but often built up by the complex and subtle shifting relationships between dancers. Hence, key structural moments did not always exist within the movement sequencing of an individual dancers' role but in the overall arrangement of the group, even where the dancers' roles themselves may be designated solo or duo. In the case of solos, these typically functioned as single structural markers within the time course of the entire choreographic work (which were typically over an hour long), and there were few, if any, structural junctions within the solos themselves.

In the present study, where the dancers recalled movements in sequence, the two main types of lapse that occurred that may shed further light on the long term memory process for dance. The first was where an error of detail (e.g. wrong leg, wrong arm, wrong direction) in an otherwise correctly recalled movement placed the dancer in a position from which the next movement was biomechanically compromised. To move to the next movement in the sequence creates a movement that is not in the benchmark version. In essence, a wrong movement in a sequence creates a biomechanical situation that breaks the link between one choreographic item and the next. When this occurred, it brought the sequence of movement to a halt (Allard & Starkes, 1991) and may be associated with the absence of recency effects. The dancer would hesitate, stop, and then usually jump forward in the excerpt, picking up a new sequence unrelated to the one they had abandoned. However, in several cases, the dancer made 1–2 addition errors (added new movements) after the lapse and before discontinuing the sequence. An explanation might be that the dancer keeps moving in an attempt to make sense or retain the gist of the sequence despite the incorrect movement, but then realises the sequence is not correct and hesitates and/or stops. This would point to a motor program. The dancer becomes aware that the sequence is incorrect, but is not able to self-correct and pick up the sequence while still performing it, but needs to stop and start again from a new starting point.

The one exception to this in our study was Trial # 8 in which the dancer performed a large amount of movement that was similar in style to the excerpt, but actually different movement. It may be that the dancer inadvertently recalled a different work, or that he was able to synthesise, in the moment, a new facsimile of the dance, responding the way that he might if a lapse in recall occurred during a performance and he needed to continue even though not able to recall the movement. In this instance, however, the performer was unaware that he had substituted different movement, indicating that this was not a conscious decision on his part in the context of the experiment. These results are similar to the errors that Hyman and Rubin (1990) observed in the recall of song lyrics such as the tendency in erroneous recall to conserve meaning, rhythm, and poetics.

The second type of lapse that occurred where choreographic items were linked in order occurred where partial sequences were recalled. Movements were recalled and sequenced together, but some choreographic items were omitted and some contained errors of detail. These partial sequences demonstrated recall of some of the distinctive movements within the sequence, and the general order in which they occurred. However, in these instances the dancers were able to continue to link movements together in approximately the right order despite having to synthesise a different set of linking movements in the moment of performance.

This would also point to a role for declarative memory in recalling sequences, since a purely procedural approach would be expected to lead to errors and discontinuation as in the instances of biomechanical misplacement described above. It may be that combined factors are in play here. First, the degree of biomechanical displacement from the benchmark sequence may influence whether or not the dancer can continue to link the movements. Relatively small adjustments to the movement preparations and trajectories may be able to be accommodated while larger mis-matches may completely disrupt the recall of the sequence. Second, it may be that where the recall is detailed, perhaps due to contextual factors described above, small inconsistencies with the benchmark sequence can be accommodated but if the recall is less accurate, a relatively minor error of detail is enough to interrupt the recall process. Further work is needed to clarify this issue. However, in either case, the ability of the dancers to synthesise new versions of sequences, containing errors of omission and detail but approximating the overall choreographic effect, demonstrates a declarative aspect to long term memory for dance where elite dancers integrate labels and cues with the process of dance movement during learning and repetition in rehearsal.

5. Conclusion

An ecologically valid “Memory Challenge” was given to seven contemporary dance artists as a method to minimise ceiling effects in elite-level dancers recalling long sequences of dance movement. Four types of errors were observed – errors of detail, order, omissions, and additions. Erroneous recall often conserved the meaning, logic or rhythm of a forgotten movement phrase. As hypothesized, various contextual cues aided recall of dance excerpts including the presence and movement or verbal prompting by another dancer or dancers. Duet excerpts recalled by two dancers working together were recalled best with a “collaborative movement sketching” approach adopted by pairs of dancers as they collaboratively recalled movement material. Poorest recall was observed for complex group excerpts that were recalled by a dancer working alone. Although dancers expected that excerpts from works they had performed with the company would be more accurately recalled than works they had only learned (but not performed), this expectation was not upheld in the data. Movement gist was generally retained. The contemporary dance ensemble, working collaboratively and without associated music or soundscape, epitomises distributed cognition and collective memory that combines chaining, rehearsed declarative cues and extended motor sequences.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.actpsy.2019.01.002.

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