What moves us?: The intrinsic memorability of dance

Joan Danielle K. Ongchoco [1], Marvin M. Chun [1], & Wilma A. Bainbridge [2]

[1] Yale University; [2] University of Chicago

Running Head : Memorability of movement

Addresses for correspondence : Joan Danielle K. Ongchoco
Department of Psychology
Yale University
Box 208205
New Haven, CT, 06520-8205

Email : joan.ongchoco@yale.edu

Word count : 5,164 words (Main Text)

Abstract (238 words)

Actions speak loudly, and our ability to remember and keep track of how other people move is fundamental to our interactions with them. But people move in incredibly complex, varied, and expressive ways, and we can't remember all this information. Here we explore whether and how we prioritize some movements over others. With static images, previous work has found remarkable consistency in which images are remembered or forgotten across people — and this measure of how likely an image is to be remembered consistently is called its 'memorability'. We know little, however, about how such a property of '*memorability'* might influence our more dynamic experiences. Using the test case of a rich and abstract series of actions from dance, we discover memorability as an intrinsic attribute of movement. Across genres, some movements were consistently remembered, regardless of the perceiver. Such memorability was independent of static visual information and was additive (where memorability of constituent moments ultimately contributed to the memorability of the longer sequences). Amongst a comprehensive set of movement and aesthetic attributes, consistency in which movements people remembered was most predicted by subjective memorability, and importantly by both subjective (observer ratings) and objective (optical flow analysis) measures of the scale of motion, such that the less overall motion in a dance segment, the more memorable the movements tended to be. Thus, the dynamic segments that were most memorable were those that effectively created static snapshots for the mind.

Keywords

Memory; Memorability; Movement; Action sequences

Introduction

Our experiences are inherently dynamic, and of such constant motion, the most salient may be that of people. How people move can reveal their inner mental states — their goals (e.g. Baker et al., 2009; Baker et al., 2017) and their intentions (e.g. Barrett et al., 2005). Our ability to remember and keep track of such movements is crucial to our social interactions — from recognizing people to predicting their behavior (e.g. Loula et al., 2005). Consequently, previous work has explored the capacity to store these actions in both working (e.g. Wood, 2007) and long-term memory (e.g. Urgolites & Wood, 2013). When human memory for movement has been studied, however, this work has typically been constrained to static postures or simple actions (e.g. walks, jumps, turns, bends, etc.). But people are capable of moving in far more complex and expressive ways. When movements are strung together, they can constitute some of our most aesthetic experiences — such as in dance. In dance, movements are more inexplicable and semantically-ambiguous. When embedded with such rich social, cultural, and aesthetic information, how do we remember movement?

Why *dance*?

Dance is central to human and animal culture. People may have varying levels of understanding, expertise, and appreciation for it (e.g. Luck et al., 2014; see Blasing et al., 2012 for a review), and dance itself comes in incredibly varied and culturally diverse forms (e.g. Adshead-Lansdale & Layson, 2006). But there are some characteristics that seem to be consistent and universal about dance as well. Across species, the functions of dance can range from telling a story (e.g. Jowitt, 2001), comprising a ritual (e.g. Dils & Albright, 2001), or in the animal kingdom, finding a mate (e.g. Beehler, 1989). Bodies of work have explored how we can analyze dance movement — the principles behind it, how the body interacts with space (e.g. Bartenieff & Lewis, 1980), how we think through movement and express through it (e.g. Stevens et al., 2003; Stevens & McKechnie, 2005) — and even how dancers remember and perform sequences of actions (e.g. Stevens et al., 2011).

The analysis of the "how" and "why" of dance across choreographers, dance theorists, and dancers has been extensive, but one important component of dance remains under explored and underappreciated: the *perceiver*, or the viewer of dance. When watching a dynamically unfolding dance sequence, what information does a perceiver spontaneously extract? Are some movements remembered consistently, regardless of the perceiver? If so, this would suggest that amidst all the variance in dance, at least some part of how we represent human movement in this context might actually be shared across people.

From memory to 'memorability'

This property of across-observer consistency in memory is called memorability. Memorability captures how likely an item will be remembered across observers (for a review, see Bainbridge, 2019), and how much it will be prioritized for memory encoding in the brain (Xie et al., 2020). Across faces (e.g. Bainbridge et al., 2013) and scenes (e.g. Isola et al., 2011b), certain images are consistently remembered or forgotten across people, and this high across-observer consistency is not readily explained by a range of image attributes, from low-level (e.g. brightness, Isola et al., 2011a) to higher-level features (e.g. emotion, or aesthetics, Bainbridge et al., 2013). The intrinsic memorability of a stimulus has been shown to account for half of the variance in memory behavior (Bainbridge et al., 2013) and such "memorability scores" can be flexibly quantified in one experiment and then applied in another, even with changes in task, observers, and surrounding image context (Bainbridge et al., 2020).

Recent work has suggested that memorability may also hold for dynamic stimuli, such as faces across viewpoints (e.g. Bainbridge, 2017), or naturalistic videos (e.g. Cohendet et al., 2018; Newman et al., 2019). The collection of videos in these studies is typically composed of a broad array, from home videos to television show snippets and advertisements, with a whole host of content across diverse categories: animal, food, nature, people, transportation, and so on. In spite of these highly complex stimuli, memorability was still found to be robust across these varied video stimulus sets. These videos contain few similarities (e.g. same actor, or same place), and for the most part are hardly ever overlapping — so the visual and semantic distinctiveness of videos from each other is often high and memory of these visual features or semantic categories could be driving consistent memory performance for these videos.

It remains unclear then whether a consistent memorability would still emerge for dynamic action stimuli that control for these drivers of distinctiveness — i.e. if the stimuli instead spanned similar semantic categories with controlled visual features. Dance may serve as the ideal test set for this question, because it involves abstract (semantically ambiguous) movements performed by the same dancer. If we find memory consistency even for dance movements, this would update our understanding of the scope of memorability: it may be a more general property of both static and dynamic stimuli — and not just dynamic visual scenes, but also dynamic (and expressive) *human actions* — that determines what we remember.

The current study

Can there be a memorability of movement, particularly in its most expressive form — dance? The answer can split two ways. Because of the complexity and variability of dance, its deep cultural roots, and the varying familiarity and expertise across people, it is possible that we should not be able to recover any shared consistency in people's memories for dance movements. Moreover, whereas memorability has been found for dynamic video sequences that contain hardly overlapping content, the distinctiveness of dance movements is far more subtle and semantically inexplicable. But some work in how we represent music, for instance, has suggested that people, across cultures, do infer similar emotions from particular structures of music (e.g. its rhythmic structure, etc.; e.g. Cowen et al., 2020; Sievers et al., 2013). Might there then similarly be something inherent in the structure of movement (whether it's the way body parts are arranged in space, or the way segments of movement are arranged in time) that is prioritized in memory, regardless of the perceiver? If so, a natural follow-up question would be what dynamic (and not just static) movement properties contribute to their being remembered.

Here, our goal was to explore whether at all some movements would be remembered or forgotten consistently across observers, and examine the factors that contribute to such a consistency. We utilized a continuous recognition task (e.g. Bainbridge et al., 2013; Isola et al., 2011a), adapted for dynamic stimuli, to assess consistency in memory for dance movements. In each of three experiments, 400 observers watched segments of dance sequences, and reported whenever a segment repeated at any point in the series. We found a surprising level of consistency in the movements observers remembered and forgot. This consistency occurred across dance genres, ballet and Korean pop (Experiment 1), in videos where movements were isolated from other visual features (Experiment 2), and across coarse and fine-grained segments of time (Experiment 3). We found that this consistency was most related to what people subjectively found memorable and the scale of the movement—where smaller scale movements were more memorable—and that such memorability of a dynamic sequence can be computed from its constituent segments.

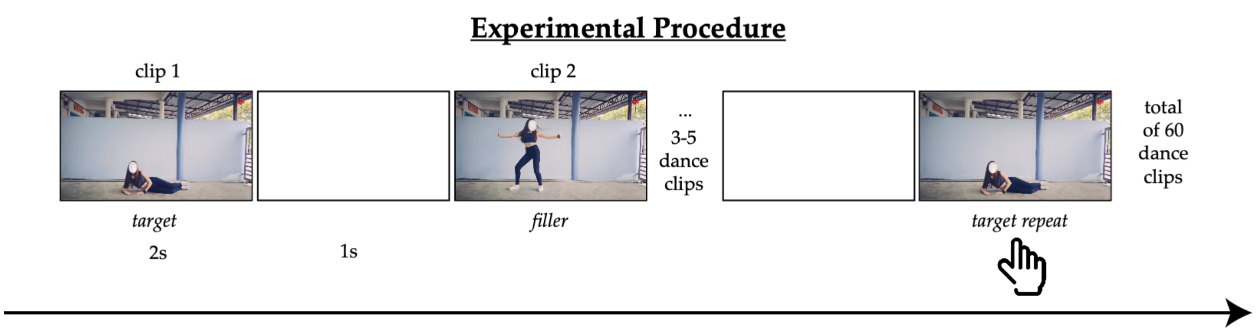

Figure 1. A caricatured depiction of the experiment, where observers watched two-second dance segments followed by a one-second delay. They viewed a total of 60 dance clips. Some segments were targets that repeated throughout the stream, and others were fillers. Observers pressed a button when they saw a segment repeat. The face of the dancer is obscured for the purposes of this Figure.

Experiment 1: Memorability across dance genres

Observers viewed a continuous stream of two-second segments from a dance video (ballet or K-pop) — and pressed a key every time they recognized a segment repeat (see Figure 1). Independent observers provided qualitative ratings (such as typicality, aesthetics, and emotionality) for each dance segment.

Method

Participants. Four hundred observers were recruited through Amazon Mechanical Turk (for discussion of this pool's reliability, see Crump et al., 2013), with the following worker qualifications: HIT approval rate above 98%, located in the United States, and had at least 1 HIT approved. This sample size was determined before data collection began, averaging across previous image and video memorability experiments (e.g. Bainbridge et al., 2013; Cohendet et al., 2018). This sample size was then fixed to be identical across all experiments reported here. After completion of the task, observers were excluded from repeat participation in this study.

Apparatus. The experiment was programmed using Javascript, CSS, and HTML. Because our experiment required the viewing of embedded videos, each observer first completed a simple browser compatibility check to ensure that their system was able to process the required animations and response measures. Each observer watched an animation, rendered in .mp4 format, where 20 single letters and digits were presented one after another for 500ms each at the center of a white background. Observers reported how many letters there were in the stream. This also served as a performance check, such that observers who did not answer the performance check question correctly were excluded from the task and replaced until the sample size was reached.

Stimuli. Dance videos were selected using two criteria: (1) it must contain a solo dancer, such that we could focus on memorability of the movement, rather than how movements are perceived in ensemble groups (which would be the case in group dances), and (2) it must contain a standard choreography, such that we can compare performance between videos of different dancers performing the same sequence of movements (to ensure that any result would not just be due to the dancer, but the movement routine instead). We considered a range of dance genres, such as hip-hop and lyrical dance styles, ballroom solo routines (such as cha-cha or the rumba), and even other cultural dances (such as Ukrainian and bhangra). Ballroom routines and other cultural dances involved multiple dancers, thus failing to meet our first criterion. Hip-hop and lyrical dances, by their natures, involve more improvisation and so did not meet our second criterion. These criteria ultimately led to the selection of videos from two visually distinctive dance genres: K-pop dance covers and ballet dance competition routines. While K-pop is faster in pace, contemporary, and takes inspiration from hip-hop dance styles, ballet is a slower and more classical dance style. We later test for other differences in attributes across these two dances. K-pop serves as an ideal testbed: With the recent international popularity of Korean pop culture, fans around the world have uploaded thousands of videos of themselves imitating the choreography from its music videos. Ballet also serves as another ideal testbed because the increasing ease of video recording and sharing has encouraged several ballet companies and competitions to make videos of routines publicly available online. Importantly, in both of these genres, multiple videos of individual dancers performing a standard choreography routine were available and easily accessible online. Dance videos were obtained from the popular video site Youtube. We selected two K-pop dance covers (i.e. same routine/choreography, but different dancers) of Blackpink's Forever Young, and two ballet covers of a Paquita wedding harp variation. Because ballet videos were shorter than K-pop videos (in general, ballet variations take only 1 to 2 minutes), we cut both ballet and K-pop videos to 2 minutes. These two-minute dance videos were automatically spliced into two-second segments, resulting in 60 dance segments. These segments were stripped of their audio, and presented in .mp4 format (1280 px by 720 px). Durations of the segments were equated to control for effects of clip length on memory.

Procedure and Design. The procedure for this experiment was closely followed from Isola et al. (2011a) and Bainbridge et al. (2013). Each observer first completed an online consent form following the guidelines of the Yale University Institutional Review Board, and then proceeded to the task. They viewed a continuous stream of two-second segments from one of the four dance videos from the two genres (which particular K-pop or ballet video was randomly assigned; see Figure 2a). Each stimulus set consisted of 60 dance segments. Each experiment lasted for approximately 5 minutes. In this period, each observer was shown a timed sequence of randomly ordered dance segments, with a blank 1-second inter-stimulus interval. Observers could press a key at any moment during the segment, whenever the dance segment was the same as any segment seen previously. Of these 60 segments per dance video, 22 of these were designated to be targets (a different randomly selected set for each observer). Because the number of segments per dance was constrained, a target segment repeated after 3 to 5 intervening segments (approximately 9-15 seconds); the rest of the videos were used as fillers between target and target repeats. Observers were not given any feedback at any point in the experiment. After the whole timed sequence, observers filled out a general debriefing procedure where they were asked about general demographic questions, along with their dance background and whether they had seen the segments of the dance video before.

In a separate survey from 278 unique observers, we obtained ratings on a set of attributes for each dance segment, in order to see how any subjective qualities might relate to the memorability of a segment. We obtained scores for a range of 11 attributes we might expect to correlate with memorability: 3 subjective-taste questions (beauty, emotionality, and interest), 5 movement-related questions (complexity of movement, speed of movement, energy of movement, scale of movement, and difficulty of movement), and 3 memory-related questions (subjective ratings of atypicality, familiarity, and memorability). Ratings were conducted on a 9-point Likert scale, ranging from 1 (not at all) to 9 (extremely). To assist observers, each attribute included a "?" that could be clicked for a pop-up window that contained a dictionary definition of the attribute in question (see Appendix A). The survey also included a 'catch' question (Which number is x?, where x was randomly selected between 1 to 9) to eliminate workers who were answering at random. Independent observers rated one dance segment on all 11 attributes.

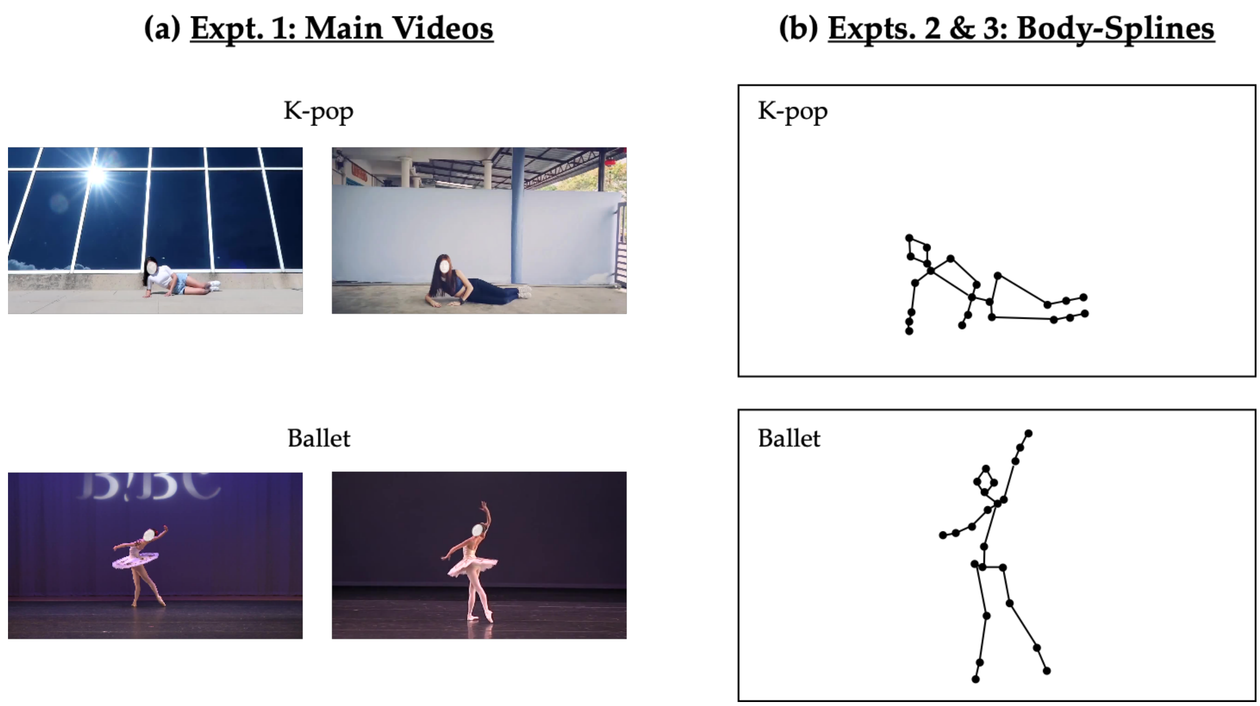

Figure 2. Sample frames from the dance videos used in the study. (a) Frames from ballet and K-pop videos used in Experiment 1. (b) Frames from spline videos used in Experiments 2 and 3. Body-splines consisted of 23 points connected together to form the silhouette of the dancer.

Memorability Analysis. To evaluate human consistency, we used corrected recognition as a measure of memorability (computed as HR - FAR; for a discussion of memorability metrics, see Bainbridge & Rissman, 2018). This will be the measure we will use for all analyses henceforth. For each video, we conducted a split-half consistency analysis, in which we split our observer pool into two independent random halves, and quantified how well memorability scores from the first half of the observers matched segment scores from the second half of the observers using Spearman's rank correlations. We repeated this process for a total of 1000 split-half iterations. As tests of significance, we conducted permutation tests, comparing the empirical distribution of correlations to a distribution of correlations where memorability scores were randomly reassigned across 1000 permutations.

Attributes Analysis. To investigate the relationship between memorability and other attributes, memorability scores were further modeled through multiple regressions, with the ratings on the 11 other attributes as predictors. Before running these regressions, we checked for partial correlations across memorability scores and the attribute ratings — looking for attributes that were highly correlated (with an $r>0.7$). In particular, energy and speed were highly correlated ($r=.78$, $p<.001$). To avoid multicollinearity in the regressions, we dropped the speed rating, because it had the most significant correlations with the other attributes.

Objective Measure of Motion. For all dance video segments, we also computed an objective measure of motion in each video. Specifically, we estimated motion using a real-time optical flow toolbox (Karlsson & Bigun, 2019), which detects the edges within a video and measures movement of these edges using the Lucas-Kanade method (Lucas & Kanade, 1981). Optical flow as a vector of direction and scale of movement was measured between every 10 frames of each 2-second clip (i.e., every 1/6 of a second), and then averaged within the clip.

All videos, memorability scores (across all three experiments), attribute scores, and optical flow measures are publicly available on a repository on the Open Science Framework (OSF, https://osf.io/e3h2z/?view_only=d5351b79c6b9464fa8fb87cf4f234701).

Results

Responses from observers who reported seeing the dance video before or who encountered problems playing some of the videos were excluded from analysis (20 out of 400 responses). The average number of dance experience of the observers was 1.08 years ($SD=3.20$). Each dance segment was seen by an average of 34.7 observers. As a measure of basic memory, mean hit and false alarm rates were computed for each of the 240 dance segments. Could people remember dance segments in the first place, given the relatively difficult nature of the task with the high visual similarity across segments and the complexity of the actions they were seeing? Average hit rate (*HR*) was 45.77% (*SD*=13.25%; and this is consistent with what has been found in previous work exploring video memorability for scenes from movies [*HR*=46.71%, Cohendet et al., 2018]), and average false alarm rate (*FAR*) was 12.29% (*SD*=6.49%). Average d' sensitivity further confirmed basic memory (*M*=1.11, *SD*=0.36). Average corrected hit rate (*HR-FAR*) was 33.53% (*SD*=11.36%), and there was no difference between corrected hit rates for ballet and K-Pop dance segments, 33.11% vs. 34.10%, $t(238)=0.67$, $p=.501$.

Results of the split-half consistency analysis for memorability scores, broken down by dance genre, are depicted in Figure 3a. The average Spearman's rank correlation across 1000 iterations was ρ=.22 (permutation test, p=.001) for all the dance segments combined, ρ=.28 (permutation test, $p=.001$) for K-pop dance segments (across the two K-pop videos), and ρ=.18 (permutation test, $p=.027$) for ballet dance segments (across the two ballet videos). Thus, here, despite the complexity and abstract nature of the segments, we recovered consistency in how they were remembered. How memorable a dance segment is in one participant split half is consistent with its memorability in the other half, across multiple split halves (see Figure 4 for frames of sample segments).

What makes a movement memorable? We obtained an average of 14 responses for each of the 240 dance segments. Mean attribute ratings across the two dance genres are reported in Table 1. A multiple linear regression that was run on the 10 attributes with memorability scores across genres showed that our selected attribute ratings explained 6.40% of the variance. As shown in Table 2, the 2 significant contributors for memorability were subjective memorability (β=0.049) and scale of movement (β=-0.027). The rest of the 8 predictors were not significant in the model (in order of high to low beta): emotionality (β=-0.023), familiarity (β=0.022), difficulty (β=-0.016), beauty (β=-0.010), atypicality (β=-0.007), complexity (β=-0.004), interest (β=0.004), and energy (β=-0.002). A multiple linear regression on only the movement-related factors explained 2.50% of the variance in the memorability, contributing more than the memory-related (less than 1% of the variance) or subjective-taste factors (1% of the variance). The salient role of movement-related ratings was further confirmed by the significant correlation of memorability scores with an objective measure of motion (i.e. optical flow), r=-.21, p=.001. The lower the amount of optical flow in a segment, the more memorable it was.

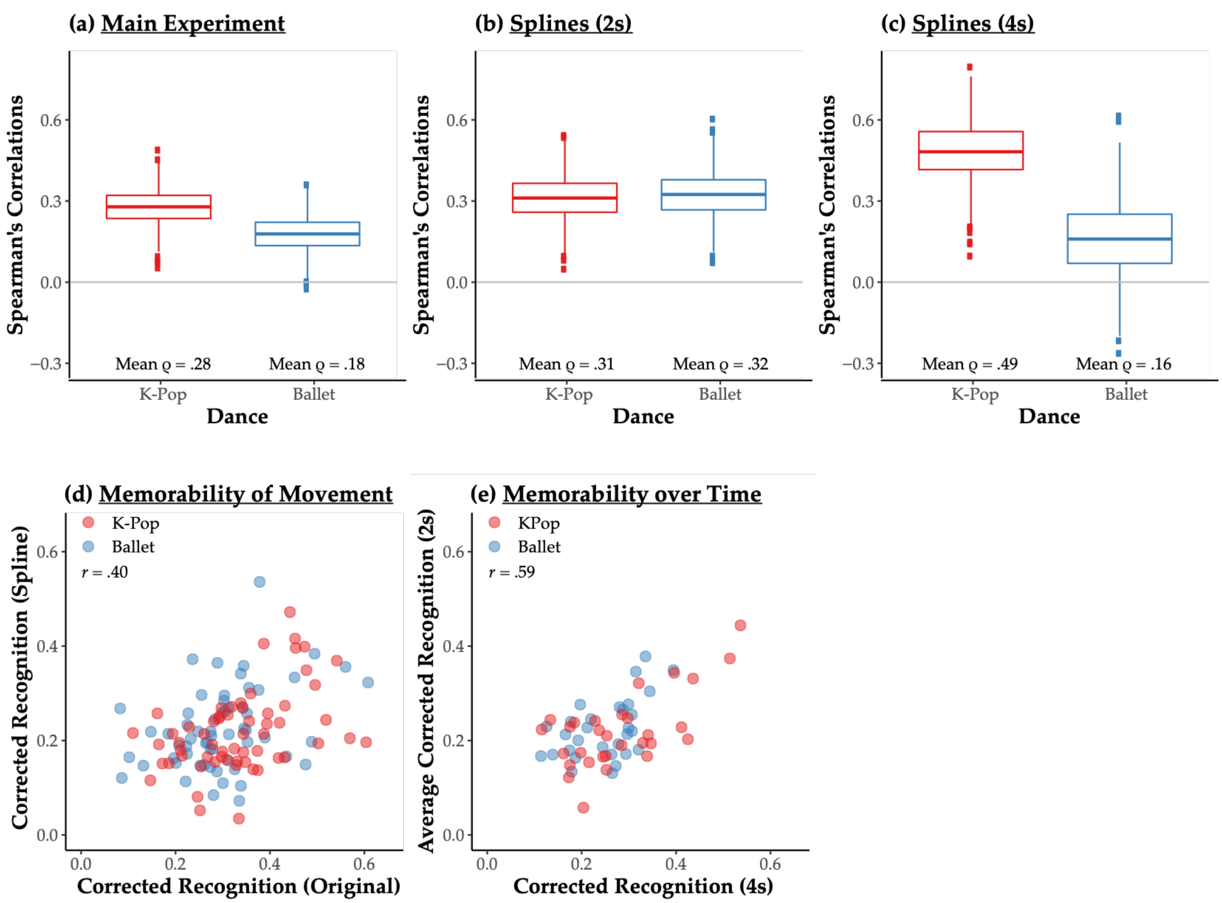

Figure 3. Results across experiments. (a-c) A box-plot of 1000 Spearman's correlations for memorability scores (corrected recognition, HR - FAR) in K-pop and ballet. (d) A scatterplot of memorability scores for the original videos vs. spline videos. Points colored red represent K-pop segments, and points colored blue represent ballet segments. (e) A scatterplot of memorability scores (or the average of memorability scores, for two-second segments) for two-second vs. four-second video segments. Points colored red represent K-pop segments, and points colored blue represent ballet segments.

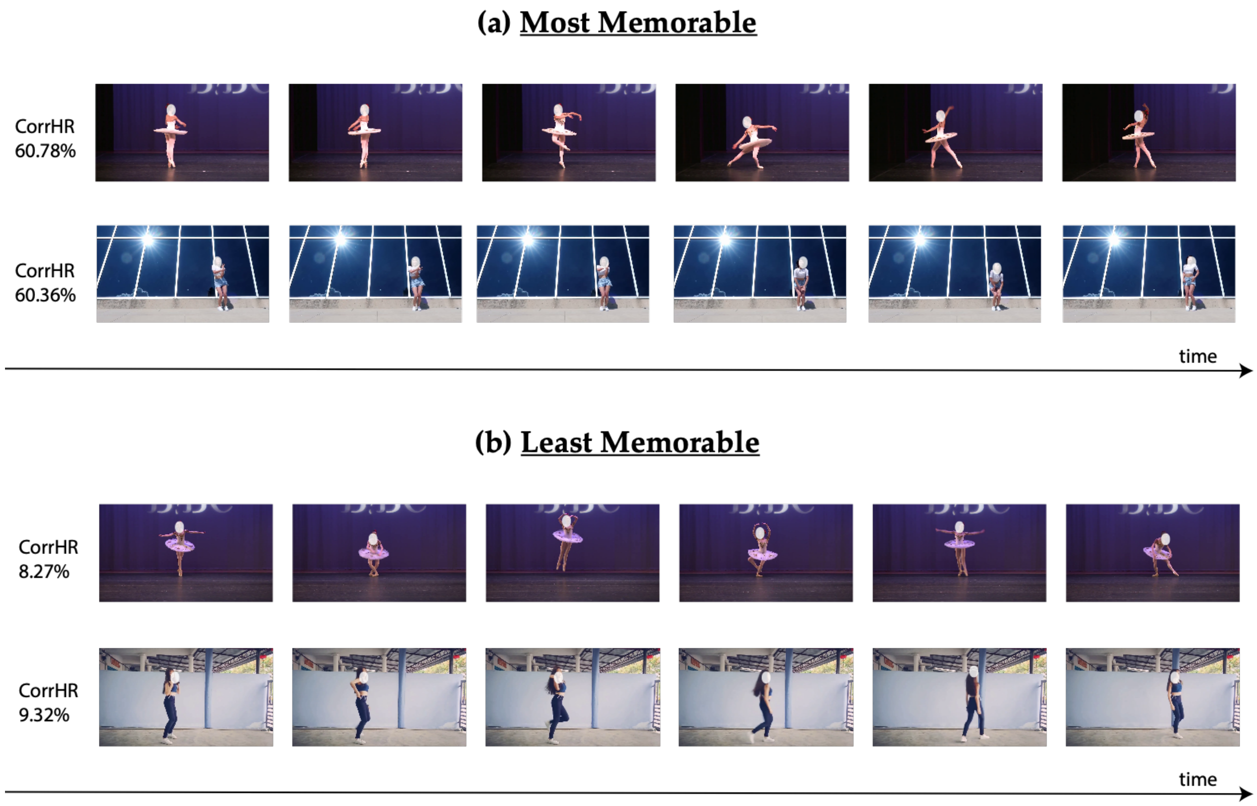

Figure 4. Sample frames from most memorable and least memorable videos.

Experiment 2: Memorability of movement separate from static visual content

Experiment 1 results revealed a memorability trace in dance movement — but to what degree are we picking up on the memorability of the static frames with all their visual content (the individual dancer, scene, stage lighting, costume, etc.), as opposed to the memorability of the movement? Here we further isolate the memorability of movement using a machine learning algorithm, DeepLabCut, to extract the body-splines of the dancers (see Figure 2b). These body-spline videos were shown to a new set of observers in a memory test.

Method

This experiment was identical to Experiment 1 except where noted. Four hundred new observers participated (with this sample size chosen to exactly match that of Experiment 1). We used one K-pop video and one ballet video from Experiment 1. To extract the body-splines of the dancers from two of the original dance videos, we utilized DeepLabCut (Mathis et al., 2018), a method originally designed specifically to estimate the poses of user-defined body parts of laboratory animals. DeepLabCut is a deep convolutional neural network (DNN) where the deconvolutional layers up-sample visual information to produce spatial probability densities for each body part. We first extracted 5 frames from each of the two-second dance segments, and labeled 23 body parts on the frames (see Figure 2b). These labeled data constituted the training set that was inputted to the DNN, which extracted the body parts for the rest of the video frames. The outputs were examined individually to ensure accurate extraction, and videos with outlier frames (frames with body parts that were labeled with DNN prediction accuracies below the threshold of 99%) were further refined. Each dance segment went through an average of 5 iterations. Labeled body parts were redrawn on a white background, and connected using line segments (see Figure 2b). As in Experiment 1, each observer viewed randomly ordered two-second body-spline segments in a memory test.

Results

Responses from observers who reported seeing the dance video before or encountered problems playing some of the videos were excluded from analysis (10 out of 400 responses). The average amount of dance experience of the observers was 1.03 years (*SD*=3.18). Each dance segment was seen by an average of 70.8 observers. The average hit rate (*HR*) was 35.02% (*SD*=11.52 %), and the average false alarm rate (*FAR*) was 12.79% (SD=6.69%). Average d' sensitivity confirmed basic memory (*M*=0.80, *SD*=0.28). Average corrected hit rate (*HR*-*FAR*) was 22.23% (*SD*=8.67%), which was unsurprisingly significantly lower than average corrected hit rate from Experiment 1 (where there was perhaps more information per segment, since visual features of segments had not yet been stripped out), 33.53% vs. 22.23%, $t(357)=9.58$, $p<.001$, $d=1.07$.

Results of the split-half consistency analysis for memorability scores, broken down by dance genre, are depicted in Figure 3b. We calculated a Spearman's rank correlation $\rho=.31$ (permutation test, $p<.001$) for all the dance segments combined, a Spearman's rank correlation $\rho=.31$ (permutation test, $p=.007$) for K-pop dance segments, and a Spearman's rank correlation $\rho=.32$ (permutation test, $p=.006$) for ballet dance segments. This demonstrates that even for these visually sparse spline videos, dance movements were consistently remembered or forgotten across observers. The memorability scores of these sparse body-spline stimuli were significantly correlated with the memorability scores of their richer original counterparts, Spearman's $\rho=.38$, $p<.001$ (see Figure 3d) — suggesting that the same movements were memorable whether performed by a human or an isolated spline, and thus reinforcing a memorability for the movements themselves, independent of other visual features.

Experiment 3: Memorability over time

As these dance video segments are intrinsically dynamic, we can also ask how memorability unfolds over time. Memorability of a dynamic sequence may be determined by the most (or the least) memorable moment, or by the average. Conversely, there may not be a relationship between an individual movement and the larger sequence, or there may not be memorability at longer timescales at all. With longer sequences, observers might attend to movements more idiosyncratically than if they were viewing a shorter segment, and might make more subjective inferences. Longer segments are also likely to capture more of the unfolding dance movements. Here we concatenated adjacent two-second dance segments (of the extracted spline videos from Experiment 2) into longer four-second dance segments. These longer segments were shown to a new set of observers in a memory test.

Method

This experiment was identical to Experiment 2 except where noted. 400 new observers participated (with this sample size chosen to exactly match that of Experiments 1 and 2). We combined adjacent two-second dance segments of the extracted spline videos into four-second dance segments, for a total of 30 segments for each of the ballet and K-pop videos. Of these 30 segments per dance video, 10 of these were designated to be targets (a different set randomly selected for each observer), while the remainder were used as fillers in between target repeats. Each observer viewed four-second body-spline segments of the same videos used in Experiment 2, and pressed a key to indicate when they remembered seeing a given dance segment previously.

Results

Responses from observers who reported seeing the dance video before or encountered problems playing some of the videos were excluded from analysis (6 out of 400 responses). The average amount of dance experience of the observers was 1.27 years (*SD*=4.38). Each dance segment was seen by an average of 64.6 observers. The average hit rate (*HR*) was 41.86 % (*SD*=9.62%), and the average false alarm rate (*FAR*) was 15.29% (*SD*=6.63%). Average d' sensitivity confirmed basic memory (*M*=0.85, *SD*=0.30). Average corrected hit rate (*HR*-*FAR*) was 26.58% (SD=9.25%), which was significantly greater than average corrected hit rate from Experiment 2 (where segments were shorter, and thus, had perhaps less information per segment), 22.23% vs. 26.58%, $t(178)=3.10$, $p=.002$, $d=.49$.

Results of the split-half consistency analysis for memorability scores, broken down by dance genre, are depicted in Figure 3c. Memorability was consistent across observers for these 4-second clips; we calculated a Spearman's rank correlation ρ=.32 (permutation test, $p=.008$) for all the dance segments combined, a Spearman's rank correlation ρ=.49 (permutation test, $p<.001$) for K-pop dance segments, and a Spearman's rank correlation ρ=.16 (permutation test, $p=.202$) for ballet dance segments. To explore how the shorter segments related to the longer ones, we computed the average, minimum, and maximum memorability scores of the two-second dance components of each four-second segment. For example, the first four-second segment consists of the first two two-second segments. We then obtained the average, minimum and maximum memorability scores across this pair of two-second segments and correlated these with the memorability scores of the four-second segments. Partial correlations of all three scores were computed against the memorability scores of the four-second segments, with average memorability explaining 33.6% of the variance (r=.585, p<.001), minimum memorability explaining 5.66% of the variance (r=.238, p=.072), and maximum memorability explaining 3.56% of the variance (r=.189, p=.156). The relationship between memorability of the longer sequences and the average memorability of the constituents suggests that the memorability of dynamic sequences may be ultimately built up from the average of the memorability of their constituent moments.

General Discussion

Across experiments, some movements, independent of dance genre, aesthetics, or static visual features, were consistently remembered across observers, and the memorability of the shorter dance segments contributed to the memorability of the larger sequence they belonged to. That we see any consistency in memory across people at all is striking given the difficulty of the task — where observers had to remember incredibly similar-looking movements within the same dance, same genre, performed by the same dancer. In terms of what features caused a dance movement to be memorable: Across both subjective ratings of movement scale and an objective measure of motion, the segments with less motion were more consistently remembered across people.

These results align with previous findings that we can effectively store dynamic actions in memory (Vicary et al., 2014; Wood, 2007; Urgolites & Wood, 2013). They also align with previous work on memorability of dynamic videos (Cohendet et al., 2018; Newman et al., 2019). But our current study departs from these two sets of findings in a key way: here we demonstrate that memory for more *semantically ambiguous* actions can still be consistent *across* people. And though consistency scores may be lower than in past image and video memorability studies (perhaps in part due to our constrained dance segment set sizes, obtained from dance routines that were only 2-3 minutes in total length), such scores were still informative, with smaller segments predicting the memorability of larger ones. These results suggest that we may be able to make more targeted predictions about memories for events based on their constituent temporal 'parts'. Future work can explore this in other dynamic domains: the memorability of a greeting might enhance the memory for a conversation, or the memorability of a frame (Khosla et al., 2015) might predict the memorability of a film.

Another key aspect of this study was the analysis of which attributes contributed to movement memorability. Despite dance being an aesthetic and expressive visual event, subjective ratings of beauty and emotionality did not significantly explain which movements were memorable. In fact, all attributes tested here altogether explained a low proportion of the overall variance in memory performance. This aligns with previous work where memorability has been largely independent of other attributes in the domains of faces (Bainbridge, 2017; Bainbridge et al., 2013) and scenes (Isola et al., 2011b). Memorability may instead reflect how information may be organized and clustered in memory based on second-order statistics (e.g., similarity, entropy) across perceptual and semantic properties (Bainbridge et al., 2017; Bainbridge & Rissman, 2018). But the current study focused on only two dance genres and a United States sample, so future work can expand to other dance styles and audiences, and consider other potential correlates to memorability (such as motion energy [e.g. Nishimoto et al., 2011] or event structure [e.g. Hard et al., 2019; Zacks et al., 2001]).

Perhaps the key contribution of the current study, however, is the finding that the more memorable segments were those with *lower,* not greater, amounts of motion. Thus, the segments that contain almost snapshot-like movements may be prioritized the most in memory (refer to sample videos on the OSF repository). In these snapshot-like segments, we informally observe how the dancer is often taking a pose — as opposed to being in transition to a new move. These results are consistent with two possible mechanisms involving event perception and memory. On the one hand, it may be that such transitions can disrupt memory (e.g. Dubrow & Davachi, 2013; 2016), because this is when the most changes occur (e.g. Huff et al., 2014; Zacks, 2001). Such disruptions may in turn lead to less 'memorable' segments. And while much of prior work on event memory involves transitions across established contexts, in the current study, the transitions occurred within only two second windows. This suggests that even just the fleeting cue of a transition may suffice to impact memory. On the other hand, it may be that segments with less optical flow were more consistently remembered because they can serve as "anchors" that people can easily recognize or retrieve. In contrast, the segments with more optical flow (and more transitioning motions) may be more differentially processed across people. Indeed, recent work has shown that there can be non-trivial differences in how people place event boundaries in time (see Radvansky & Zacks, 2017 for a review). This variability might explain why segments involving transitions are differentially remembered. Conversely, in more semantically ambiguous sequences such as in dance especially, it may be the more "snapshot-like" moments that give people something to go back to in memory.

The influences of static and dynamic stimuli on memory are often studied separately. But our results reveal a more nuanced interaction between the two. In particular, we find that the memorability of constituent moments can predict that of their longer segments, and that the more memorable dynamic segments tend to be (rather unintuitively) more static-like. Much remains to be explored about how static snapshots interact with the broader event sequences they belong to. The results here suggest though how such interaction between the static and dynamic may play a central role in how we remember the most aesthetic sequences of human action.

References

Adshead-Lansdale, J., & Layson, J. (2006). Dance history: An introduction. Routledge.

Bainbridge, W. A. (2017). The memorability of people: Intrinsic memorability across transformations of a person's face. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, *43*, 706–717.

Bainbridge, W. A. (2019). Memorability: How what we see influences what we remember. *Psychol Learn Motiv*, *70*, 1–27.

Bainbridge, W. A. (2020). The resiliency of image memorability: A predictor of memory separate from attention and priming. *Neuropsychologia*, *141*, 107408.

Bainbridge, W. A., Isola, P., & Oliva, A. (2013). The intrinsic memorability of face photographs. *Journal of Experimental Psychology: General*, *142*, 1323–1334.

Bainbridge, W. A., & Rissman, J. (2018). Dissociating neural markers of stimulus memorability and subjective recognition during episodic retrieval. *Scientific Reports*, *8*, 1–11.

Baker, C. L., Jara-Ettinger, J., Saxe, R., & Tenenbaum, J. B. (2017). Rational quantitative attribution of beliefs, desires and percepts in human mentalizing. *Nature Human Behaviour*, *1*, 1–10.

Baker, C. L., Saxe, R., & Tenenbaum, J. B. (2009). Action understanding as inverse planning. *Cognition*, *113*, 329–349.

Barrett, H. C., Todd, P. M., Miller, G. F., & Blythe, P. W. (2005). Accurate judgments of intention from motion cues alone: A cross-cultural study. *Evolution and Human Behavior*, *26*, 313–331.

Bartenieff, I., & Lewis, D. (1980). Body movement: Coping with the environment. Psychology Press.

Beehler, B. M. (1989). The birds of paradise. *Scientific American*, *261*, 116–123.

Bläsing, B., Calvo-Merino, B., Cross, E. S., Jola, C., Honisch, J., & Stevens, C. J. (2012). Neurocognitive control in dance perception and performance. *Acta Psychologica*, *139*, 300-308.

Cohendet, R., Yadati, K., Duong, N. Q., & Demarty, C.-H. (2018). Annotating, understanding, and predicting long-term video memorability. *Proceedings of the 2018 ACM on International Conference on Multimedia Retrieval*, 178–186.

Cowen, A. S., Fang, X., Sauter, D., & Keltner, D. (2020). What music makes us feel: At least 13 dimensions organize subjective experiences associated with music across different cultures. *Proceedings of the National Academy of Sciences*, *117*, 1924–1934.

Crump, M. J., McDonnell, J. V., & Gureckis, T. M. (2013). Evaluating Amazon's Mechanical Turk as a tool for experimental behavioral research. *PloS One*, *8*, e57410.

Dils, A., & Albright, A. C. (2001). Moving history/dancing cultures: A dance history reader. Wesleyan University Press.

DuBrow, S., & Davachi, L. (2013). The influence of context boundaries on memory for the sequential order of events. *Journal of Experimental Psychology: General, 142*, 1277–1286.

DuBrow, S., & Davachi, L. (2016). Temporal binding within and across events. *Neurobiology of Learning & Memory, 134*, 107–114.

Hard, B. M., Meyer, M., & Baldwin, D. (2019). Attention reorganizes as structure is detected in dynamic action. *Memory & Cognition, 47*, 17–32.

Huff, M., Meitz, T. G., & Papenmeier, F. (2014). Changes in situation models modulate processes of event perception in audiovisual narratives. *Journal of Experimental Psychology: Learning, Memory & Cognition*, *40*, 1377–1388.

Isola, P., Parikh, D., Torralba, A., & Oliva, A. (2011a). Understanding the intrinsic memorability of images. *Advances in Neural Information Processing Systems*, 2429–2437.

Isola, P., Xiao, J., Torralba, A., & Oliva, A. (2011b). What makes an image memorable? *CVPR 2011*, 145–152.

Jowitt, D. (2001). Beyond Description: Writing beneath the surface. In A. Dils & A. C. Albright (Eds.), Moving History/Dancing Cultures. Wesleyan University Press.

Karlsson, S., & Bigun, J. (2019). Tutorial and toolbox on real-time optical flow. *MATLAB Central File Exchange,* https://www.mathworks.com/matlabcentral/fileexchange/44400/. Retrieved August 9, 2021.

Khosla, A., Raju, A. S., Torralba, A., & Oliva, A. (2015). Understanding and predicting image memorability at a large scale. In *Proceedings of the IEEE International Conference on Computer Vision*, 2390-2398.

Loula, F., Prasad, S., Harber, K., & Shiffrar, M. (2005). Recognizing people from their movement. *Journal of Experimental Psychology: Human Perception and Performance*, *31*, 210–220.

Lucas, B.D. & Kanade, T. (1981). An iterative image registration technique with an application to stereo vision. *Proceedings of Imaging Understanding Workshop*, 121-130.

Luck, G., Saarikallio, S., Burger, B., Thompson, M., & Toiviainen, P. (2014). Emotion-driven encoding of music preference and personality in dance. *Musicae Scientiae*, *18*, 307-323.

Mathis, A., Mamidanna, P., Cury, K. M., Abe, T., Murthy, V. N., Mathis, M. W., & Bethge, M. (2018). DeepLabCut: Markerless pose estimation of user-defined body parts with deep learning. *Nature Neuroscience*, *21*, 1281–1289.

Newman, A., Fosco, C., Casser, V., McNamara, B., & Oliva, A. (2019). To Decay or not to Decay: Modeling Video Memorability Over Time. Presented at the annual meeting for Neural Information Processing Systems.

Nishimoto, S., Vu, A. T., Naselaris, T., Benjamini, Y., Yu, B., & Gallant, J. L. (2011). Reconstructing visual experiences from brain activity evoked by natural movies. *Current Biology*, 21, 1641-1646.

Radvansky, G. A., & Zacks, J. M. (2017). Event boundaries in memory and cognition. *Current Opinion in Behavioral Sciences*, *17*, 133–140.

Sievers, B., Polansky, L., Casey, M., & Wheatley, T. (2013). Music and movement share a dynamic structure that supports universal expressions of emotion. *Proceedings of the National Academy of Sciences*, *110*, 70–75.

Stevens, C. J., Ginsborg, J., & Lester, G. (2011). Backwards and forwards in space and time: Recalling dance movement from long-term memory. *Memory Studies*, *4*, 234–250.

Stevens, C., Malloch, S., McKechnie, S., & Steven, N. (2003). Choreographic cognition: The time-course and phenomenology of creating a dance. *Pragmatics & Cognition*, *11*, 297–326.

Stevens, C., & McKechnie, S. (2005). Thinking in action: Thought made visible in contemporary dance. *Cognitive Processing*, *6*, 243–252.

Swallow, K. M., Zacks, J. M., & Abrams, R. A. (2009). Event boundaries in perception affect memory encoding and updating. *Journal of Experimental Psychology: General*, *138*, 236–257.

Urgolites, Z. J., & Wood, J. N. (2013). Visual long-term memory stores high-fidelity representations of observed actions. *Psychological Science*, *24*, 403–411.

Vicary, S. A., Robbins, R. A., Calvo-Merino, B., & Stevens, C. J. (2014). Recognition of dance-like actions: Memory for static posture or dynamic movement? *Memory and Cognition*, *42*, 755–767.

Wood, J. N. (2007). Visual working memory for observed actions. *Journal of Experimental Psychology: General*, *136*, 639–652.

Xie, W., Bainbridge, W.A., Inati, S.K., Baker, C.I., & Zaghloul, K.A. (2020). Memorability of words in arbitrary verbal associations modulates memory retrieval in the anterior temporal lobe. *Nature Human Behaviour*.

Zacks, J. M. (2004). Using movement and intentions to understand simple events. *Cognitive Science, 28*, 979–1008.

Zacks, J. M., Tversky, B., & Iyer, G. (2001). Perceiving, remembering, and communicating structure in events. *Journal of Experimental Psychology: General, 130*, 29–58.

Author Contributions

J. D. K. Ongchoco, M. M. Chun, and W.A. Bainbridge designed the research and wrote the manuscript. J. D. K. Ongchoco conducted the experiments and analyzed the data with input from M. M. Chun and W. A. Bainbridge.

Open Practices

None of the experiments reported in this article were formally pre-registered. Materials have been made available on the Open Science Framework (OSF), https://osf.io/e3h2z/?view_only=d5351b79c6b9464fa8fb87cf4f234701, and data will be made publicly available on OSF upon publication of the manuscript.

Author Note

MMC is supported by NIH MH 108591. For helpful comments, we thank the members of the Yale Visual Cognition Lab and Yale Cognitive Neuroscience group.

Tables

Mean Ratings	Ballet	K-Pop
Memory-related factors		
familiarity	5.86 (*SD*=.01)	5.23 (*SD*=.01)
memorability	5.50 (*SD*=.01)	4.45 (*SD*=.05)
atypicality	4.35 (*SD*=.04)	4.23 (*SD*=.08)
Subjective-taste factors		
beauty	6.74 (*SD*=.03)	4.48 (*SD*=.05)
emotionality	5.44 (*SD*=.01)	3.90 (*SD*=.12)
interest	5.90 (*SD*=.05)	4.87 (*SD*=.03)
Movement-related factors		
scale	5.16 (*SD*=.03)	4.84 (*SD*=.03)
difficulty	5.87 (*SD*=.03)	4.06 (*SD*=.09)
energy	5.20 (*SD*=.06)	6.16 (*SD*=.02)
complexity	4.23 (*SD*=.02)	5.43 (*SD*=.08)

Table 1. Mean attribute ratings across the two dance genres (where movements were rated for the particular attribute, with 1 represented 'Not at all' and 9 represented 'Extremely'). Standard deviation values are reported in parenthesis.

(a) Full model	β	t	p	(b) Movement-related factors only β	t	p
Memory-related factors						
familiarity	0.022	1.668	0.097			
memorability	0.049	2.246	0.026			
atypicality	-0.007	-0.453	0.651			
Subjective-taste factors						
beauty	-0.010	-0.620	0.536			
emotionality	-0.023	-1.542	0.125			
interest	0.004	0.153	0.878			
Movement-related factors						
scale	-0.027	-2.040	0.043	-0.025	-1.911	0.057
difficulty	-0.016	-0.931	0.353	-0.006	-0.432	0.666
energy	-0.002	-0.206	0.837	0.006	0.742	0.460
complexity	-0.004	-0.251	0.802	-0.003	-0.175	0.862

Table 2. Multiple linear regressions run on memorability scores. This figure shows the relationships of the attribute scores to the memorability scores. Attributes are grouped based on category (memory-related factors, subjective-taste factors, and movement-related factors). The beta-weight, t-statistic, and corresponding p-value are reported for each attribute. Colored cells indicate cells with significant values, with green indicating positive values, and red indicating negative values.

Appendix A

Dictionary definitions of attributes from Experiment 1

To be clear about what we meant about the different attributes we tested for, and to help observers appropriately rate the segments of dance videos, we included the following definitions for attributes we used in Experiment 1.

Memorable: worth remembering or easily remembered, because of being special or unusual

Familiar: well known from long or close association

Difficult: seeing much effort or skill to accomplish

Emotional: arousing or characterized by intense feeling

Big (Scale of movement): of considerable size, extent, or intensity

Energetic: showing or involving great activity or vitality

Fast (Speed of movement): urgent, instantaneous, staccato, quick, hurried

Interest: arousing curiosity or interest

Beautiful: pleasing the sense or mind aesthetically

Simple: plain, basic, or uncomplicated in form

Atypical: not conforming to the type