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ARTICLE

Effects of Mirror and Metronome Use on Spontaneous Dance Movements

Derrick D. Brown
Radboud University Nijmegen

Jurjen Bosga
Radboud University Nijmegen and Praktijk Bosga-Stork

Ruud G.J. Meulenbroek
Radboud University Nijmegen

This study investigated effects of mirror and metronome use on spontaneous upper body movements by 10 preprofessional dancers in a motor task in which maximally diverse upper body movement patterns were targeted. Hand and trunk accelerations were digitally recorded utilizing accelerometers and analyzed using polar frequency distributions of the realized acceleration directions and sample entropy of the acceleration time. Acceleration directions were more variably used by the arms than by the torso, particularly so when participants monitored their performance via a mirror. Metronome use hardly affected the predictability of the acceleration time series. The findings underscore the intrinsic limitations that people experience when being asked to move randomly and reveal moderate effects of visual and acoustic constraints on doing so in dance.

Keywords: entropy, improvisation, variability

Movement Improvisation

Humans have a seemingly endless capacity for movement variation. Real-world motor behavior necessitates spontaneous adaptation within an ever-changing environment (Riley & Turvey, 2002). Casually using one's mobile phone while crossing a busy street exemplifies the capacity to generate moment-to-moment seemingly unplanned movements. In certain contexts, maximally diverse movement patterns can be explicitly targeted in skilled motor performance, for example, in dance improvisation. Dance improvisation prompts unstructured movement patterns that are spontaneous and extemporaneous (Carter, 2000). Behaviorally, dance is a profession that exploits a continuum of movement patterns: from fully

Brown, Bosga, and Meulenbroek are with the Donders Institute for Brain, Cognition and Behaviour—Donders Centre for Cognition Nijmegen, Radboud University Nijmegen, Nijmegen, The Netherlands. Bosga is also with Praktijk Bosga-Stork, Doorn, The Netherlands. Brown (d.brown@donders.ru.nl) is corresponding author.

preplanned and highly structured movement as seen in classical ballet (Hopper, Weidemann, & Karin, 2018; Kawano & Kuno-Mizumura, 2019) via choreographies, which form a composite of preplanned, composed, and extemporized movement sequences (Waterhouse, Watts, & Bläsing, 2014), to unplanned, spontaneous, and amorphous movement patterns seen in many improvisation forms (Predock-Linnell & Predock-Linnell, 2001). Apart from its role in dance composition (Spier, 1998), improvisation is the act of sourcing novel movement materials and avoiding stagnation (Carter, 2000) or a choreographic tool enabling an improviser to generate novel movement patterns within a specified structure.

Movement Variability and Context

The variable, quasi-constant nature of repetitions of one and the same movement pattern was underscored by the neurophysiologist Nicolai Bernstein as "repetition without repetition" (Latash & Latash, 1994). In line with Bernstein's observations, Stergiou and Decker (2011) referred to movement variability as the normal variations that occur in motor performance across multiple repetitions of inherently unique motor patterns. In the present study, rather than studying multiple repetitions of a single movement pattern, we focus on maximally diverse movement patterns. In terms of joint coordination, the experimental task used in the present study targets maximum *coordinative variability*, or the interaction between and across joints (Hamill, Palmer, & Van Emmerik, 2012). In an artistic context, movement sequence variability has been studied recently in the production of novel melodic and rhythmic movement sequences during piano improvisation (Caramiaux, Bevilacqua, Wanderley, & Palmer, 2018). To assess the degree to which the participants in the present study succeeded in showing maximal upper body movement variation, we decided to quantify the extent to which their acceleration directions would be maximally dispersed in their 3D workspace. We constructed an Acceleration Isotropic Measure (AIM) to examine the frequency distribution of the realized acceleration directions of two sensors on the hand and trunk (Gordon, Ghilardi, Cooper, & Ghez, 1994).

Spontaneous Movement and Entropy

The study of entropy (e.g., information entropy, approximate entropy, sample entropy [SEn]) offers ways to capture the predictability of time series (Barrett et al., 2012; Lai, Mayer-Kress, & Newell, 2006) or movement regularity (Donker, Ledebt, Roerdink, Savelsbergh, & Beek, 2008) as well as the probable similarity within a time series (Richman & Moorman, 2000) embedded in nonlinear systems. Entropy represents how relative predictable or unpredictable movements are performed. For example, SEn has been used to reveal the regularity contained within a time series when describing center of pressure measurements factorized to whole-body kinematics in healthy individuals (Haid & Federolf, 2018). In addition, SEn, when measured via triaxial accelerometry, has been implemented to capture spontaneous infant leg movement as a potential marker of the development of infant neuromotor control (Smith, Vanderbilt, Applequist, & Kyvelidou, 2017). Thus, quantifying entropy could be a way to study the extent to which the nature of dance improvisation in a dance education setting is either relatively predictable and anticipated or surprising, unexpected, and unforeseen for an audience. To that end, we captured the hand and trunk accelerations digitally and analyzed the time series using SEn. In the following section, we describe the experimental conditions that we used to constrain the participants' ability to generate maximally diverse upper body movement patterns in dance.

Factors Limiting Spontaneous Dance Performance

Mirror and metronome use are factors likely to constrain movement variation. In dance, these factors define traditional methods in which dance techniques are learned. Rhythmic entrainment, the coordination of internal rhythms to an external pulse (Phillips-Silver & Keller, 2012), could be considered a hallmark of dance performance across genres. When learning codified dance styles (e.g., ballet, samba), beat is normally set by the instructor via predefined tempi and musical rhythms (Matsumura, Yamamoto, & Fujinami, 2011). A predefined rhythm, however, is not a necessary condition for dance improvisation (Biasutti, 2013). Choreographically, entrainment can exemplify a compositional role via entrainment to acoustic cues (Vass-Rhee, 2010) or maintaining spatiotemporal periodicity (Waterhouse et al., 2014). In line with recent studies on improvisation (Himberg, Laroche, Bige, Buchkowski, & Bachrach, 2018), we adopted the use of a metronome as a way to elicit acoustic entrainment. We expected the metronome to function as a constraint, thus reducing the SEn values of the realized acceleration time series.

Dancers use mirrors as a principal visual feedback to mirror their own (Coker & Kaminski, 2020; Dearborn & Ross, 2006), a partner's, or instructor's reflection (Notarnicola et al., 2014). *Mirroring* garners a facilitative and coordinative effect on choreographed dance duet unison (Brown & Meulenbroek, 2016). This manner of mirroring may be explained via the on-line approach, which prescribes movement solutions emerging from the coupled agent–environment–task system. (Gibson, 2014; Zhao & Warren, 2015). Although mirroring might prove advantageous when attempting to replicate preexisting dance choreographies, it is questionable whether the mirror facilitates the creation of emergent unrehearsed improvisational movement. Similar to considering metronome use as a movement variation constraint, we also presumed mirror use would act as a task constraint and reduce the amount of movement variation in our task in which maximal variation was targeted.

In summary, we have provided evidence from studies that reveal *the mirror and metronome* as potential factors constraining spontaneous movement variation in dance. However, it is not known what effect these factors have when preprofessional dancers create spontaneous dance movement targeted at maximum variation. The purpose of this study is to examine the effects of metronome and mirror use on performing improvised movement in the upper body. We expected that mirror use would yield lower AIM values. Furthermore, we expected that the metronome would prompt more predictable movement variation patterns and, thus, lower SEn values.

Methods

Participants

A total of 10 ($N = 10$) (six females and four males; M 20.9 years ± SD 2.02 years) preprofessional second-year dance students from the ArtEZ University of the Arts

(Arnhem, the Netherlands) volunteered to participate in the study. Prior to consent, all participants were informed in writing and, once again, verbally of the purpose of the experiment. Participants were second-year students all with at least 7 years of dance and performance training prior to attending their current institution. This institution places more emphasis on the making and creation of dance rather than codified techniques (e.g., ballet) as a sole mode of learning. Thus, a familiarization phase was unnecessary, as participants were familiar with and actively participated in composition and improvisation as a part of their daily praxis.

All participants gave their written informed consent. The ArtEZ University Director of Dance and Theatre provided written approval for the study to be conducted onsite and granted use of the dance studios during all testing. The research protocol was in agreement with the Helsinki Declaration, and the study was approved by the ethics committee of the Social Sciences Faculty of Radboud University, Nijmegen, the Netherlands (approval code: ECSW-2018-010R1).

Procedure

Dance training traditionally occurs in a dance studio; thus, the current study exploited this ecological feature by conducting the experiments in the dancers' natural environment. Data collection took place in a 10- × 10-m dance studio, 4 m in height. The studio contained a wall of mirrors covering the length of the wall, 3.5 m in height. Adjustable curtains on both sides of the mirror were pulled to the center to expose only 2 m of mirror surface available for viewing. Participants were instructed to stand in the center of the dance studio with their feet facing forward (parallel), hip width apart. Subsequently, we asked the participant to create spontaneous, nonrepetitive whole-body improvisation sequences. All forms of body movement (in amplitude, magnitude, and velocity) were permissible, provided the feet remained at the prescribed fixed position on the ground. Furthermore, we informed the participants that if, due to risk of falling, they felt they could not complete a trial, they were allowed to stop, and the trial would be restarted. No participants reported or were observed to be at risk of falling; however, one participant was not able to maintain a sweat-free attachment of the sensors. Therefore, this data set was removed from the analysis. Data collection took place after a regularly scheduled dance class; therefore, no warm-up was required. Participants were free to relax in between trials.

Participants generated improvisation sequences in four orthogonally varying conditions: visual conditions were denoted as mirror versus no mirror, and entrainment conditions as beat versus no beat. To test the effects of the use of vision on spontaneous movement creation, participants were asked to either face the mirror or to face the back wall of the dance studio (thus, no mirror or reflective surface). To test for the effect of entrainment, participants completed trials either with a beat or without a beat. The beat was provided via a sinusoidal acoustic stimulus. The sinusoidal signal was set to one dance practice-relevant frequency, 1.9. Finally, to test whether fixing the sensors to the trunk and the arms had any effect on our participants' improvisation patterns, in half of the trials, we gave them the instruction to: "*Please generate your improvisation phrase while concentrating the movement creation on your torso*" and in the other half of the trials: "*Please generate your improvisation phrase while concentrating the movement creation on* *your hands*."[1] Participants received no further feedback or instructions during or after the trials. The 2 Mirror × 2 Beat conditions were generated in 3-min epochs. The 3-min trial duration was established during the pilot phase and after consultation with two dance improvisation instructors. It provided a more ecologically valid framework seen in many dance composition and dance making sessions for dancers to adequately generate their desired movement patterns.

Instrumentation

To measure accelerations of the participants' torso and hand displacements under the independent measures, three wireless triaxial accelerometers were used. The measuring device, a Trigno™ Wireless EMG System (Delsys Inc., Boston, MA), consists of acceleration sensors and receivers. The device can acutely sense the acceleration of the triaxial (*x*-, *y*-, and *z*-axes) sensor within a –9 to +9 g range. Signals from the accelerometers were collected in the EMG works software program (Delsys Inc.) via a receiver connected to the computer and they were monitored in real time with a sampling rate of 148.1 samples/sec/axis. One sensor was positioned longitudinally to the lower sternum above the xiphoid process, and two sensors were positioned on the dorsal planes of the left and right wrist, respectively. Sensors were attached via self-adhesive medical-grade tape provided by the manufacturer.

Data Analysis

The accelerometer data (in *X*, *Y*, and *Z*) were filtered for each of the three sensors with a third-order, dual-pass Butterworth filter. The low-pass filter frequency for these signals was 5.0 Hz, and the high-pass cutoff frequency was set to 1.0 Hz. A sample of a filtered *X*, *Y*, and *Z* trunk acceleration time series is shown in Figure 1, showing that, in this trial, the participant realized pronounced trunk acceleration changes in the *X* direction (lateral bending reflected by the solid black line) rather than in the *Y* direction (forward bending reflected by the dashed line) or *Z* direction (up–down acceleration reflected by the dotted line).

For each trial, the mean SEn for the three movement directions was determined to assess overall movement variability for the hand and torso displacements. The acceleration time signals of the hand and torso displacements were used to calculate the SEn per 60-s epochs for the duration of each trial. As no differences were found between SEn obtained for the first, second, and third minute epochs, the values were pooled and analyzed per trial.

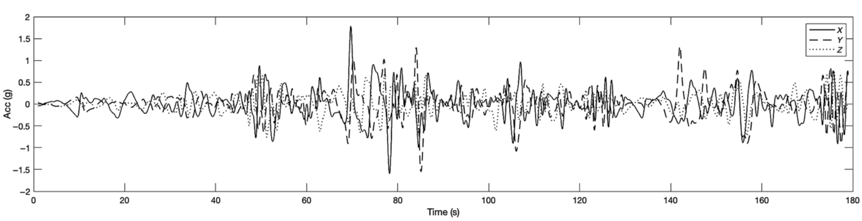

Figure 1 — Sample of acceleration time series in *X* (solid black line), *Y* (dashed line), and *Z* (dotted line) of sensor 3 attached to the sternum of participant 4 for Trial 1.

The SEn (*m, r,* and *N*) is the negative natural logarithm of the conditional probability that two sequences similar for *m* points remain similar at the next point ($m + 1$) (Richman & Moorman, 2000). This results in relative lower SEn values when data series show more similar changes between data points and, thus, predictable movement variation patterns and relative higher SEn values when data series show less similar changes between data points, that is, less predictable movement variation patterns.

For each participant and trial, the acceleration directions in the *XY* sensor plane were analyzed based on the *X* and *Y* acceleration time functions and plotted as individual, polar histograms. The resulting polar frequency plots revealed the geometric variations in realized acceleration directions that a dancer showed in each trial at the local reference planes of the trunk and wrist sensors. The polar plots (Figure 2) represent acceleration directions (in degrees) where 0° and 180° denote the rightward and leftward direction, respectively, and the 90° and 270° denote the upward and downward directions, respectively. The plots display for a single trial all acceleration directions from 0° to 360° as independent factors, and in each of these directions the number of times in which that acceleration direction occurred in the trial as a dependent measure. Finally, to capture the degree to which the participants managed to generate acceleration directions in equal distribution, an AIM was calculated for each trial as follows:

$$\text{AIM} = 100 - \frac{SSDM}{SSQ} \times 100(\%) \tag{1}$$

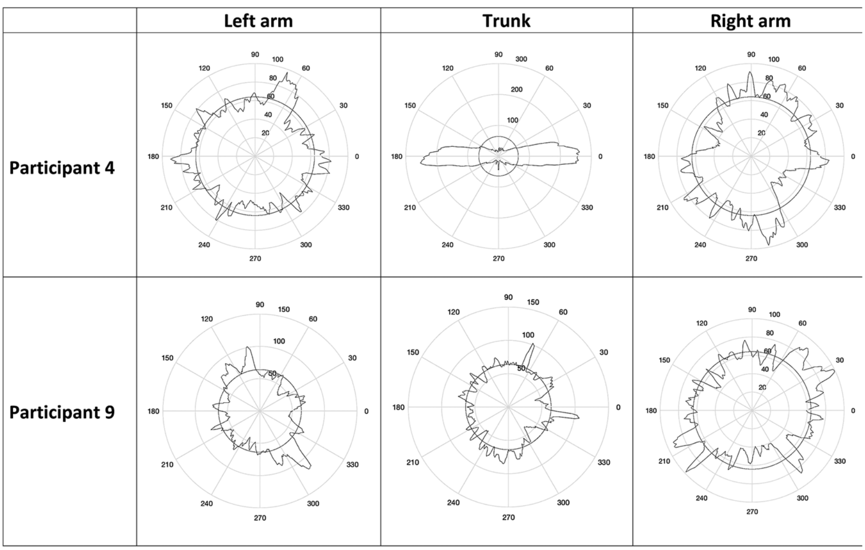

Figure 2 — Polar frequency distribution of realized acceleration directions in Trial 1 in the arms and torso of participant 4 (top row) and participant 9 (bottom row). In the trunk, for example, we can see that participant 4 preferred movement accelerations in rightward and leftward directions, whereas participate 9 explored multiple directions.

where the sum of squared deviations (SSDM) from the mean was divided by the sum of squared values (SSQ) of the polar frequency distribution of the two-dimensional representation of realized planar (SSQ) *XY* acceleration directions, the result of which was multiplied by 100 to arrive at a percentage, which, finally, was subtracted from 100% to arrive at an index of anisotropy. A circular polar frequency distribution, thus, yields an AIM of 100%, which perfectly corresponded with the task instruction to use as many acceleration directions as possible. A distribution showing preferences for specific acceleration directions but disinclination toward other directions yielded an AIM of <100%.

Statistical Analysis

Statistical analyses were conducted using SPSS statistical package (version 25; SPSS Inc., Chicago, IL) using nonparametric tests. The AIM and SEn measures were analyzed separately for sensors 1 (left hand), 2 (right hand), and 3 (trunk). The Friedman test was used to evaluate the effects of the experimental factors, and the Wilcoxon signed-rank tests were used for multiple comparisons. The level of significance was set at .05 for the all analyses.

Results

Acceleration Isotropic Measure

Table 1 depicts the AIM per participant for Trial 1, showing that, as expected, the AIM for the arm sensors was systematically higher than for the trunk sensor. With regard to the AIM of the arms, as measured by hand displacements, a paired *t* test revealed no significant difference for the right ($M = 9.98$, $SD = 2.225$) and left arm ($M = 92.95$ $SD = 1.324$; $t[9] = 1.913$, ns). Therefore, we report data for the right arm only (sensor 2).

Table 1 Acceleration Isotropic Measure for Trial 1, $N = 10$

Participant	Left arm	Right arm	Torso
1	89.60	93.32	58.53
2	94.37	94.16	58.59
3	83.48	96.74	76.17
4	97.60	95.16	46.47
5	90.68	94.13	78.64
6	87.30	96.52	67.59
7	94.08	86.79	67.20
8	94.12	94.51	81.48
9	90.61	95.84	95.44
10	95.33	93.31	92.44
Mean	91.72	94.05	72.26

We conducted four separate *t* tests, two on the AIM data of the hand sensors and two on the AIM data of the trunk. We tested the AIM differences as a function of the experimental factor Mirror and as a function of the experimental factor Beat. The two *t* tests for the trunk revealed no significant AIM difference for the trunk as a function of Mirror (Figure 3) ($t[9] = 0.676$, ns) or as a function of Beat ($t[9] = 0.400$, ns). The two *t* tests for the arms revealed a significant AIM difference for the arm as a function of Mirror (Figure 3) ($t[9] = 2.575$, *p* < *.05) and a marginal trend* but no statistical AIM difference for the arm as a function of Metronome ($t[9] = 0.641$, ns).

Sample Entropy

With regard to SEn, a Friedman test revealed significant differences in the distribution of the SEn across the three sensors, $\chi^2(2, N = 10) = 16.63$, $p < .01$. Follow-up, pairwise comparisons discriminated no differences in the SEn values observed between sensor 1 (0.31, *SD* .056) and sensor 2 (0.30, *SD* 0.56), $p = .157$. Therefore, we report data for the right arm only (sensor 2).

A Wilcoxon signed-rank test showed that SEn measures did not yield a statistically significant SEn difference as a function of mirror use for the arm (Figure 4; $Z = -2.191$, ns). SEn values in the arm sensor also did not vary as a function of metronome use ($Z = -1.886$, ns). With regard to the trunk, the Wilcoxon signed-rank test revealed that SEn measures for the visual condition did elicit a significant difference on the predictability of the movement variation patterns in the trunk (Figure 4) ($Z = -2.191$, $p < .05$), with the nonmirror condition trials yielding higher SEn values (median SEn = 0.433) than the mirror condition (median SEn = 0.396). The SEn measures comparison for beat or no beat did not elicit a significant difference as regards the predictability of the movement variation patterns for the trunk ($Z = -3.57$, ns).

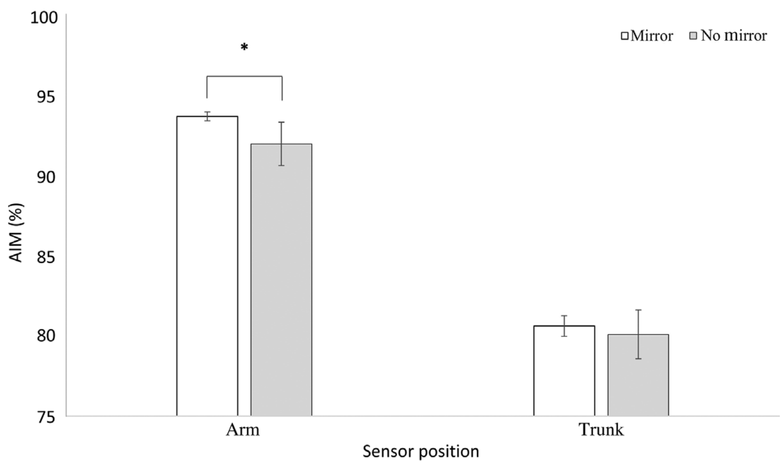

Figure 3 — Mean AIM of the arm accelerations as a function of mirror and metronome. Error bars represent *SE* of the mean. *$p < .05$. AIM = Acceleration Isotropic Measure.

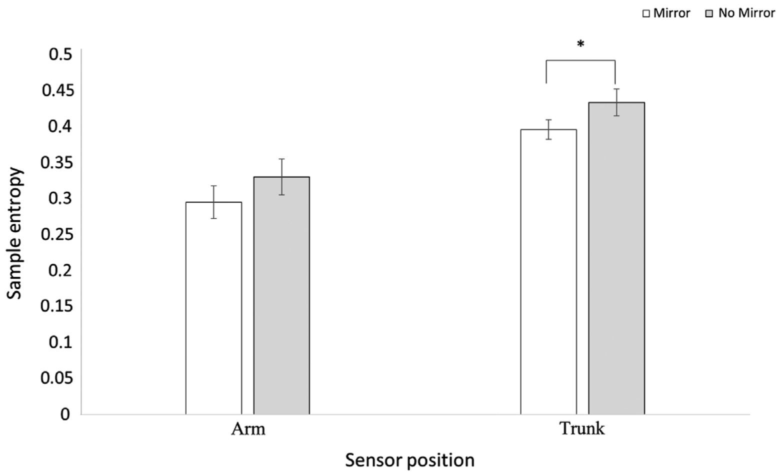

Figure 4 — Mean SEn of the arm accelerations as a function of mirror and metronome. Error bars represent *SE* of the mean. $*p < .05$. SEn = sample entropy.

Discussion

The aim of the current study was to investigate and characterize the effects of mirror and metronome use on the polar frequency distributions of realized movement acceleration directions and SEn measure capturing the predictability of upper body movement variation patterns in dance improvisation. To this end we conducted kinematic analyses of self-generated, maximally diverse upper body movement sequences in preprofessional dancers. Our findings support a constraint-based analysis of variability and motor control (Newell & Corcos, 1993).

In particular, anatomical and geometric and environmental constraints (i.e., mirror use) affect directional preferences and biases (Goble, Zhang, Shimansky, Sharma, & Dounskaia, 2007; Meulenbroek & Thomassen, 1991).

Variation in Movement Acceleration Directions

The extent to which the participants generated upper body accelerations in all directions, expressed by our AIM, was larger when observing their mirrored reflection. However, at the individual level, seen in Table 1 and Figure 2, we can note large between-subject differences with some participants opting for movements more in a mediolateral axis in the transvers plane, whereas others opted for a more anterior–posterior direction in multiple planes. These findings are in line with previous work regarding the influence of task constraints on trunk movement performance (Kaminski, Bock, & Gentile, 1995; Ma & Feldman, 1995), particularly when confronted with multiple constraints seen in whole-body movements (Rosenbaum, Loukopoulos, Meulenbroek, Vaughan, & Engelbrecht, 1995).

Predictability of Movement Variation Patterns

Regarding our measures of entropy, the mean SEn values of generated upper body movements in all conditions ranged between 0.28 and 0.44, with torso movement patterns attaining a larger median entropy than the arm movement patterns. Although improvisation is a highly individualized process as demonstrated by our polar frequency analysis of realized acceleration directions at the trunk and wrist (Figure 2), dancers ardently practice codified genre-specific techniques (e.g., ballroom, ballet, Graham). Nevertheless, the preprofessionals in this study showed variation in SEn values. In this context, we emphasize that SEn is not a simple measure of complexity of a time series but reflects the quality of variability (e.g., Silva & Murta, 2012). Here we consider the SEn values observed to reflect predictability of improvised movement patterns. Improvisation is shaped by the flexibility of choice within a decidedly iterative process of trial and error (Stanton, 2011). Particularly in dance education, the experimental process of being spontaneous involves ignoring learned highly codified movement patterns (e.g., classical ballet), which first need to be deconstructed and circumnavigated before spontaneous, improvised movement emerges. Nonetheless, as reflected by the individual differences of the mean SEn values across participants, nonscripted and spontaneous movement choices were shown to vary across preprofessional dancers.

Mirror Use

Congruent with our hypothesis, the mirror did not affect improvisation dramatically in this cohort. These findings support previous research with regard to the mirror facilitating coordination of planned movement in codified dance techniques (Dearborn & Ross, 2006), such as in dance duets (Brown & Meulenbroek, 2016). Furthermore, our results support previous work describing different models of mirrored self-recognition. In particular, the inductive theory of kinesthetic–visual matching posits that via a frontal mirror a mover can match their proprioceptive–kinesthetic experience with the visual images of their own movement (Mitchell, 1993). Experimental studies have also reported that limb disownership or somatoparaphrenia can be altered using self-observation in a mirror (Fotopoulou et al., 2011). The aforementioned studies detail varying types of clinical research, whereas our results represent, to our knowledge, a novel investigation of mirror use in emergent, spontaneously generated movement behavior in expert individuals.

Metronome Use

We also sought to reveal the role of entrainment in the form of a metronomic beat on our assessments of dance improvisation. Here, the role of the beat had no pronounced effect on the predictability, style, or quality of dancers' creation of arm and torso movement variation patterns as reflected by the absence of a main effect of rhythm on our SEn measure. The use of rhythm has been shown to enhance the learning of samba, for example (Matsumura et al., 2011), which embeds a strong rhythmic pattern. However, in the creation of torso movements, some dancers in this cohort may have considered the external beat a distracting secondary task and, thus, ignored the stimulus, whereas others may have exploited the temporal structure with maximum use of space and full movement variation (Figure 2) without statistically entraining to the metronome. Similar results have been shown when participants attempted to entrain rhythmic arm-swinging movement to a metronome signal (Washburn, Coey, Romero, Malone, & Richardson, 2015). However, syncing with the beat is not a requisite in dance improvisation as in more planned codified dance. Observationally, two dancers appeared to ignore the metered timing, demonstrating increases or decreases in tempi, amplitude, and magnitude of movement choice characteristic in the process of improvising. Future studies on movement improvisation may quantify the level of entrainment to the presented acoustic structure to gain more insight into this potentially important constraint.

Conclusion

In this study, we sought to identify sources of information that would modulate upper body improvisation in dancers. Even though mirror use prompted a moderate increase in variation of upper body movement acceleration directions, metronomic beat was less effective in changing the predictability of the realized upper body movement variation patterns.

Note

1. The data analysis showed that there were no differences due to the instructions to attend to either the trunk or the arms.

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