Empathy, Entrainment, and Perceived Interaction in Complex Dyadic Dance Movement

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The current study explores how individuals' tendency to empathize with others (trait empathy) modulates interaction and social entrainment in dyadic dance in a free movement context using perceptual and computationally derived measures. Stimuli consisting of 24 point-light animations were created using motion capture data selected from a sample of 99 dyads, based on self-reported trait empathy. Individuals whose Empathy Quotient (EQ) scores were in the top or bottom quartile of all scores were considered to have high or low empathy, respectively, and twelve dyads comprised of four high-high, four low-low, and four high-low empathy combinations were identified. Animations of these dyads were presented to 33 participants, who rated the degree of interaction and movement similarity for each stimulus. Results showed a significant effect of empathy combination on perceived interactivity and perceived similarity. High-low stimuli were rated as significantly more interactive than either high-high or low-low stimuli, while high-high stimuli were rated as significantly less similar than high-low and low-low. Dyads' period-locking, bodily orientation and amount of hand movement were all significantly correlated with rated amount of interaction, while rated similarity only related significantly to period-locking. Results suggest that period-locking is important for social entrainment to be perceived, but that other signals such as bodily orientation and hand movement also signal social entrainment during free dance movement.

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Moving in synchrony to music with others feels good (Solberg & Jensenius, 2017), promotes well-being (Quiroga Murcia, Kreutz, Clift, & Bongard, 2010), may increase pro-social behavior (Rabinowitch & Meltzoff, 2017) and group affiliation (Rabinowitch et al., 2015; von Zimmermann, Vicary, Sperling, Orgs, & Richardson, 2018), and can even increase tolerance to pain (Tarr, Launay, & Dunbar, 2016) and our memory of social stimuli (Woolhouse, Tidhar, & Cross, 2016). It is therefore unsurprising that, from the rocking of an infant to the coordinated movements of a rowing team, physical entrainment is not only essential to many human experiences (Laland, Wilkins, & Clayton, 2016; Wang, 2015), but a response so natural that—in the presence of a rhythmic stimulus—it can even been difficult to avoid some degree of motoric entrainment (Repp, 2005; Repp & Su, 2013; Richardson, Marsh, Isenhower, Goodman, & Schmidt, 2007).

It may seem self-evident to say that we entrain with one another socially when we dance together. Nevertheless, what is obvious in the context of the choreographed steps of a country line dance or the precisely timed pirouettes of a balletic chorus is somewhat more abstract when considering free, improvised dancing such as commonly takes place in a club or at a wedding reception. In many cases, dancers may not make identical movements, necessitating the question of what constitutes entrainment in such a movement context. Although the term *entrainment* is sometimes used interchangeably with the term *synchronization,* they are more usually used to describe somewhat differing, although overlapping, concepts. Both relate to concepts of rhythm and beat, which at their most basic can be considered the division of time into regular intervals by some marker, such as the tick of a metronome. Two metronomes with the same interval of time between ticks are said to have the same period, while two metronomes whose ticks happen at the exact same moment are said to have the same phase. Repp (2005) defines synchronization as the timed coordination of an action (such as the tap of a finger) with an event (such as a tick of the metronome), which is usually, but not necessarily, predictable by virtue of occurring at regular, periodic intervals. The Oxford English Dictionary defines the verb *entrain* as follows: "(of a rhythm or something which varies rhythmically) cause (another) gradually to fall in synchrony with it" ("entrain," see en.oxforddictionaries.com/en/entrain). Clayton (2012) emphasizes that synchrony of two rhythmic signals is not necessarily entrainment, as

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this could happen accidentally; rather, the adjustment of at least one signal towards the other in the presence of perturbations or errors is a hallmark of entrainment. Thus, entrainment implies a stronger, more stable relationship between two rhythmic signals than synchronization alone. In their detailed theoretical discussion of the topic, Phillips-Silver, Aktipis, and Bryant (2010) define entrainment as "spatiotemporal coordination resulting from rhythmic responsiveness to a perceived rhythmic signal" (p. 5) and further delineated social entrainment as a special case in which the rhythmic signal is generated by another individual.

Our impressively flexible and cross-modal ability to entrain to a signal seems to have ancient evolutionary roots. Clayton (2012) notes the entrainment of our bodily clocks to the time of day, an example of one-sided entrainment, while Phillips-Silver et al. (2010) point to predator avoidance and hunting as contexts in which the ability to detect rhythmic signals could be important, and argue that the ability to produce rhythmic output is fundamentally implied by the evolutionary adaptation of locomotion. Studies of various non-human species who show some ability to physically entrain with a rhythmic pulse indicate that the ability may have evolved in relation to social functioning, acoustic communication, or vocal mimicry (Large & Gray, 2015; Patel, Iversen, Bregman, & Schulz, 2009; Schachner, Brady, Pepperberg, & Hauser, 2009). Hagen and Bryant (2003) have suggested in that vein that music and dance may have evolved as a system of signaling social coalition, supported by their finding that participants found listening to examples in which musical ensembles were more closely synchronized to be indicative of better group cohesion than less synchronized examples of ensemble playing. Merker, Madison, and Eckerdal (2009) furthermore highlight synchronous chorusing, a behavior seen in various species involving simultaneous signaling to an isochronous beat to amplify a signal as a possible social origin for human rhythmic entrainment. The idea that music and dance evolved to support social functioning within and between groups is supported by the fact that moving in synchrony with others, often through dance, still plays a pervasive and essential role in meaningful social interactions across many cultures (Giurchescu, 2001; Laland et al., 2016; Phillips-Silver, 2009; Vicary, Sperling, Von Zimmermann, Richardson, & Orgs, 2017).

There already exists a large body of literature dealing with human entrainment via sensorimotor synchronization (SMS), much of which employs the paradigm of finger tapping to a rhythmic pulse. It is well established, for example, that we are able to entrain to stimuli present at regular intervals as small as 120 ms and as large as about 1.8 seconds, and that, when asked to tap at a comfortable tempo, humans tend to choose a tempo of around 2 hz, similar to the usual preferred walking tempo (Bohannon, 1997; Repp, 2005; Zatsiorky, Werner, & Kaimin, 1994), and that entrainment to rhythmic auditory stimuli is generally more accurate than for visual stimuli (Repp & Su, 2013). Although noticeable variability exists between individuals' abilities to entrain while tapping to a metronome, the physiological impossibility of sustaining perfect synchronization has led much of SMS research to focus on error correction. There is evidence that individuals can adjust both the phase and period of their movements in order to remain synchronized with a rhythm; the former is thought to be an automated process while the latter may be more intentional, although both rely on the perception of the ongoing, consistent period of the rhythmic stimulus. It has also been shown that when dyads are asked to tap in synchrony together, both partners adjust the period of their taps to one another, though this effect is mediated by individual ability (Repp & Su, 2013). Individuals have also been shown to be able to entrain to each other while rocking in rocking chairs, using the visual information of each other's movements (Richardson et al., 2007).

The relevance of such studies to full-body dance movement, however, may be somewhat limited, especially when considered freely improvised dance as previously described. Outside of the lab, both rhythmic stimuli and our range of possible motoric responses to them are much more complex than the unadorned metronomic tick or the tap of a finger. The presence of multiple instruments, varied divisions of the beat, tempo changes, and even complex devices such as syncopation and hemiola do not prevent the majority of us from detecting a steady pulse in music (Phillips-Silver, 2009; Repp, 2005; Repp & Su, 2013), and we are not limited to simple finger tapping or other overt beat-keeping movements (toe-tapping, head-bobbing) when we dance, although these movements may form a part of our dancing. Guided by the music's qualities, our own personalities, our emotions, and our social context (Burger, Thompson, Luck, Saarikallio, & Toiviainen, 2013; Luck, Saarikallio, Burger, Thompson, & Toiviainen, 2010; Saarikallio, Nieminen, & Brattico, 2012; Solberg & Jensenius, 2017), we seem to be able to use our bodies' full range of motion in dance to draw on an endless vocabulary of movements while still, at a fundamental level, entraining to the beat (Burger, Thompson, Luck, Saarikallio, & Toiviainen, 2014; De Bruyn, Leman, & Moelants, 2008), and presumably to each other. It is therefore necessary to explore social entrainment in complex full-body settings in order to fully understand this human ability and its role in our everyday functioning.

A few recent studies of dance have indeed begun to do just that. Using a naturalistic Electronic Dance Music (EDM) setting, Solberg and Jensenius (2017) identified that group motion increased corresponding to musical structures, and that the presence of other dancers increased enjoyment of the experience. De Bruyn et al. (2008) found that dance movements in nine-year-old children were more intense during social engagement but were not more synchronized with the music. In an eye-tracking study, Woolhouse and Lai (2014) found that observers spent more time looking at dancers who were synchronized to music compared to those who were not, suggesting an individual's ability to entrain to music may affect how others perceive and possibly interact with him on the dance floor. von Zimmermann, Vicary, Sperling, Orgs, and Richardson (2018) investigated the effects of entrainment on group cohesion using a choreographed movement task and found that movement similarity between dyads in a group predicted group affiliation better than unison synchronization of the full group. Notably, this similarity was defined not by exact synchronization; instead the authors identified what they named *distributed coordination*, in which dyads' movements resembled each other after a time lag, suggesting that dyads may have been responding to and imitating each other.

Research has shown that we can perceive a range of information from a person's movements, from the emotions they might be feeling (Camurri, Lagerlöf, & Volpe, 2003; Dittrich, Troscianko, Lea, & Morgan, 1996), to their personalities (Fink et al., 2012), to the tempo of the music to which they are dancing (London, Burger, Thompson, & Toiviainen, 2016). We can even identify our friends by only their walk (Little & Boyd, 1998; Loula, Prasad, Harber, & Shiffrar, 2005). We also make judgements about rapport between dyads based on observed entrainment between dyad members (Lakens & Stel, 2011; Miles, Nind, & Macrae, 2009), consistent with theories that group dance may have evolved partly to signal group affiliation (Hagen & Bryant, 2003).

Although exactly how we are able to infer such abstract things from movement has not yet been clarified by research and is even debated philosophically (Baldwin & Baird, 2001; Goldman & de Vignemont, 2009; Zahavi, 2011), a factor that may affect our actions in social context is empathy. A multi-faceted and still disputed concept, empathy may be broadly defined as a complex psychological process including cognitive and affective components that allows for the understanding of others' emotions and perceptions, which is important to social interaction (Decety & Jackson, 2004; Harari, Shamay-Tsoory, Ravid, & Levkovitz, 2010; Shamay-Tsoory, Tomer, Goldsher, Berger, & Aharon-Peretz, 2004; Zahavi, 2010). Individual differences seem to exist between individuals in empathic abilities (Davis, 1983; Lawson, Baron-Cohen, & Wheelwright, 2004); the tendency a person has to empathize with others has been defined as trait empathy.

Motoric mimicry of others' actions—both overtly and internally through mental representation—was originally proposed by aesthetic philosophers as a mechanism that allows us to empathically understand others' thoughts, feelings, and intentions (Zahavi, 2010, 2012), and empirical research has indeed shown links between mimicry and social functioning. Chartrand and Bargh (1999) showed that humans tend to automatically imitate each other's movements, and furthermore that such mimicry improved the quality of social interactions and participants' liking of task partners. Automatic mimicry highlights the close relationship between what we perceive and how we behave, a link that has been corroborated by neuro-imaging studies identifying "mirror neurons" that activate both when observing a movement and performing it (Rizzolatti & Craighero, 2004). Such "internal" or "covert" imitation has been hypothesized to related to how we perceive and comprehend heard music (Godøy, Song, Nymoen, Haugen, & Jensenius, 2016; Leman, 2008). This view is in line with the perspective of embodied cognition, the supposition that our bodily movements and sensations play an important role in how we understand and make sense of the world around us (Wilson, 2002). Cox (2016) embraces an embodied cognition framework in arguing for a "mimetic hypothesis" in which our comprehension of music is influenced not only by mirroring of a performer's movements, but also through cross-modal mirroring; for example, imagining singing a part that we hear being played by a flute or violin. Somewhat more abstractly, Leman (2008) describes music as consisting of "moving sonic forms," which we can physically and internally imitate, and which allows us in turn to empathically understand the affective content of a given piece of music.

Perhaps more obviously, our experience of watching others dance appears to be influenced by embodied processes. When trained dancers watch video clips of dance or dance-like gestures, their own premotor and motor brain areas are activated (Sevdalis & Keller, 2011), and watching live dance increases the corticospinal excitability even of novices; notably this excitability was increased in more empathic participants (Jola & Grosbras, 2013). In exploring why audiences would seek out dance in order to experience pleasure, Reason and Reynolds (2010) describe the concept of "kinesthetic empathy," a process that they note involves the "translation from the visual to the muscular and also from the muscular to the emotional" (p. 54), which is similar to the process of empathic engagement with music described by Leman; their interviews with audience members at a dance concert indeed gave rise to many explicit descriptions that participants felt or imagined that the observed dancer's movements were their own.

However, there are currently few studies exploring the relationship between empathy and physical engagement in dance movement, although some have conceptualized dance as a form of mimicry of music (Godøy et al., 2016; Leman, 2008). Bamford and Davidson (2017) found that higher trait empathy was associated with better adjustment to abrupt tempo changes, while Carlson et al. (2016) found no relationship between empathy and adjustment to small tempo differences across stimuli. Carlson, Burger, and Toiviainen (2018) found that, in a dyadic free dance context, more empathic participants made greater adjustment to their movements when dancing with different partners, suggesting that empathic dancers may mimic their partners more.

Research of nonmusical, nonverbal interaction may also provide some direction for research into social entrainment during improvised, free dance. Krauss, Chen, and Chawla (1996) note that one main category of communicative hand gesture is defined by " . . . repetitive, rhythmic movements, that bear no obvious relation to [. . .] semantic content" (p. 6), which McNeill (1992) defines as "beats," giving these at least metaphoric relationship to musical context. The other category consisting of varied and complex, non-repetitive movements that seem to relate to semantic meaning in speech. Using Gaussian Mixture Modeling applied to motion capture data of dyadic interactions, Metallinou, Katsamanis, and Narayanan (2013) identified movement features related to perceived affective content of the interaction, many of which were related to hand gestures, as well as to dyad members' postural orientation relative to one another. Head orientation and gaze particularly have previously been related to interaction quality in dyadic and small group social interactions (Ambrosini, Pezzulo, & Costantini, 2015; Emery, 2000; Garau, Slater, Bee, & Sasse, 2001; Vertegaal, Van der Veer, & Vons, 2000).

Current Study and Hypotheses

The literature discussed above shows that synchronization and entrainment are important human skills that may reflect or support broader social functioning, including empathy. However, previous research into dyadic entrainment has focused mainly on simple oscillatory movements (e.g., Richardson et al., 2007), choreographed dance movements (e.g., von Zimmermann et al., 2018), or the movement of single markers (e.g., De Bruyn et al., 2008). Research has not yet explored how social entrainment appears in full body movements in free movement dance settings, how such entrainment is perceived, or how trait empathy might affect such entrainment. To begin to address these issues, a study was designed to combine quantitative movement data with perceptual data of dyadic movement. First, motion capture data were collected of the free dance movements of participants moving in dyads, from which kinematic features relating to periodic movement, bodily orientation, and hand movement were extracted. Animated stimuli derived from these data were then used to gather perceptual ratings of dyads' movement similarity and interaction, to explore how these are perceived in dyadic dance movement and whether this is related to trait empathy of the dancers observed. Considering previous research, the following hypotheses were made:

- H1) Higher levels of trait empathy within dyads will relate to higher levels of perceived interactivity and similarity of movement dyads.
- H2) Higher levels of period locking between dyad members, greater amounts of hand movement, and dyad members' orientation towards each other will relate positively to perceived interactivity and similarity of dyadic movement.
- H3) Higher levels of trait empathy within dyads will relate positively to higher levels of period locking, hand movement, and dyads' orientation towards each other.

Method

MOTION CAPTURE STUDY

The current study is related to a larger project involving several data collections and analyses, an overview of which is given in Figure 1. An initial motion capture study was designed to collect free dance movement data from participants in a dyadic setting, using naturalistic (commercially available) stimuli. Full details of the experiment can be found in Carlson et al. (2018).

Participants. Participants were recruited using social media and University e-mail lists. Seventy-three (52 female) participants, aged 19–40 years ($M = 25.75$, $SD = 4.72$) completed the motion capture experiment. Participants were of 24 different nationalities and

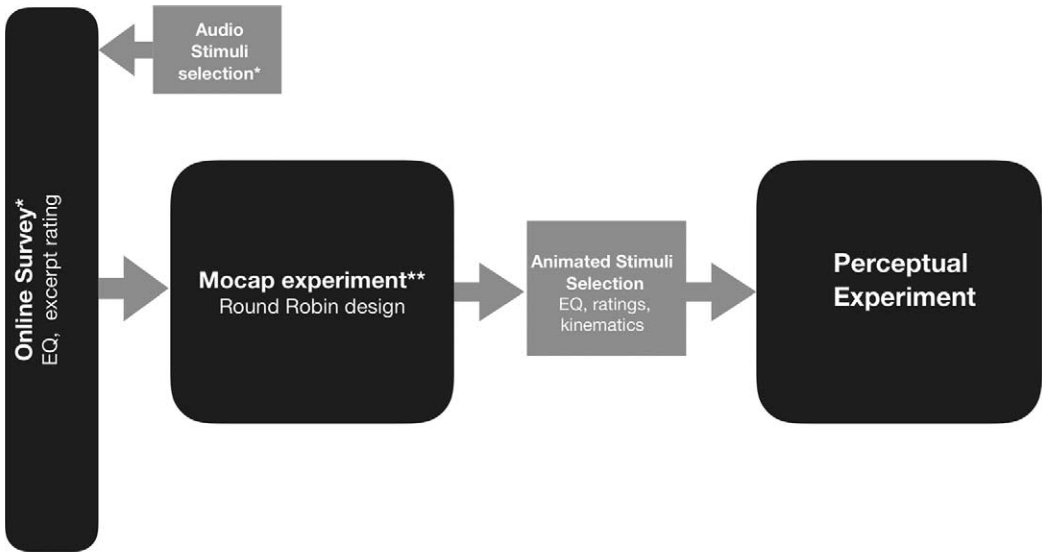

FIGURE 1. Overview of previous data collections and analyses related to the current study. *Full methods and results found in Carlson, Saari, Burger, and Toiviainen (2017). **Full methods and results found in Carlson, Burger, and Toiviainen (2018).

received two movie ticket vouchers in exchange for their participation.

Trait empathy measure. The Empathy Quotient (EQ), developed by Baron-Cohen and Wheelwright (2004), measures trait empathy as a whole, including both cognitive and affective aspects. It has been used particularly in studying autism spectrum disorders and potential deficits of empathy (Baron-Cohen, 2009; Baron-Cohen & Wheelwright, 2004). For the current study, trait empathizing was measured using a short-form (22-item) version of the EQ, developed and validated by Wakabayashi et al. (2006). Participants filled out this test using an online platform prior to the motion capture experiment (see Figure 1).

Apparatus. Participants' movements were recorded using a twelve-camera optical motion capture system (Qualisys Oqus 5+), tracking at a frame rate of 120 Hz, the three-dimensional positions of 21 reflective markers attached to each participant. Markers were located as follows (L = left, R = right, F = front, B = back) 1: LF head; 2: RF head; 3: B head; 4: L shoulder; 5: R shoulder; 6: sternum; 7: stomach; 8: LB hip; 9: RB hip; 10: L elbow; 11: R elbow; 12: L wrist; 13: R wrist; 14: L middle finger; 15: R middle finger; 16: L knee; 17: R knee; 18: L ankle; 19: R ankle; 20: L toe; 21: R tow, visible in Figure 2A. The musical stimuli were played in a random order in each condition via four Genelec 8030A loudspeakers and a sub-woofer. The direct (line-in) audio signal of the playback and the synchronization pulse transmitted by

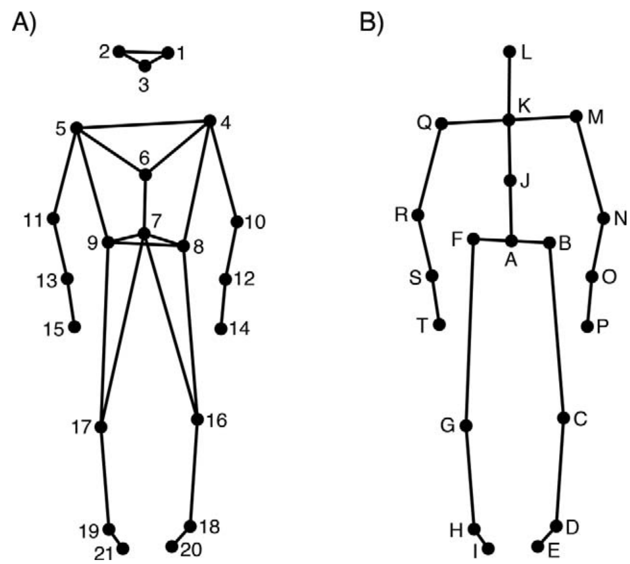

FIGURE 2. Marker and joint locations (A) Anterior view of the marker locations a stick figure illustration. (B) Anterior view of the locations of the secondary markers/joints used in animation and analysis of the data.

the Qualisys cameras when recording were recorded using ProTools software so as to synchronize the motion capture data with the musical stimulus afterwards.

Procedure. Prior to the motion capture experiment, participants completed an online survey that included both self-report personality and empathy measures, as well as rated preferences for heard musical excerpts (see

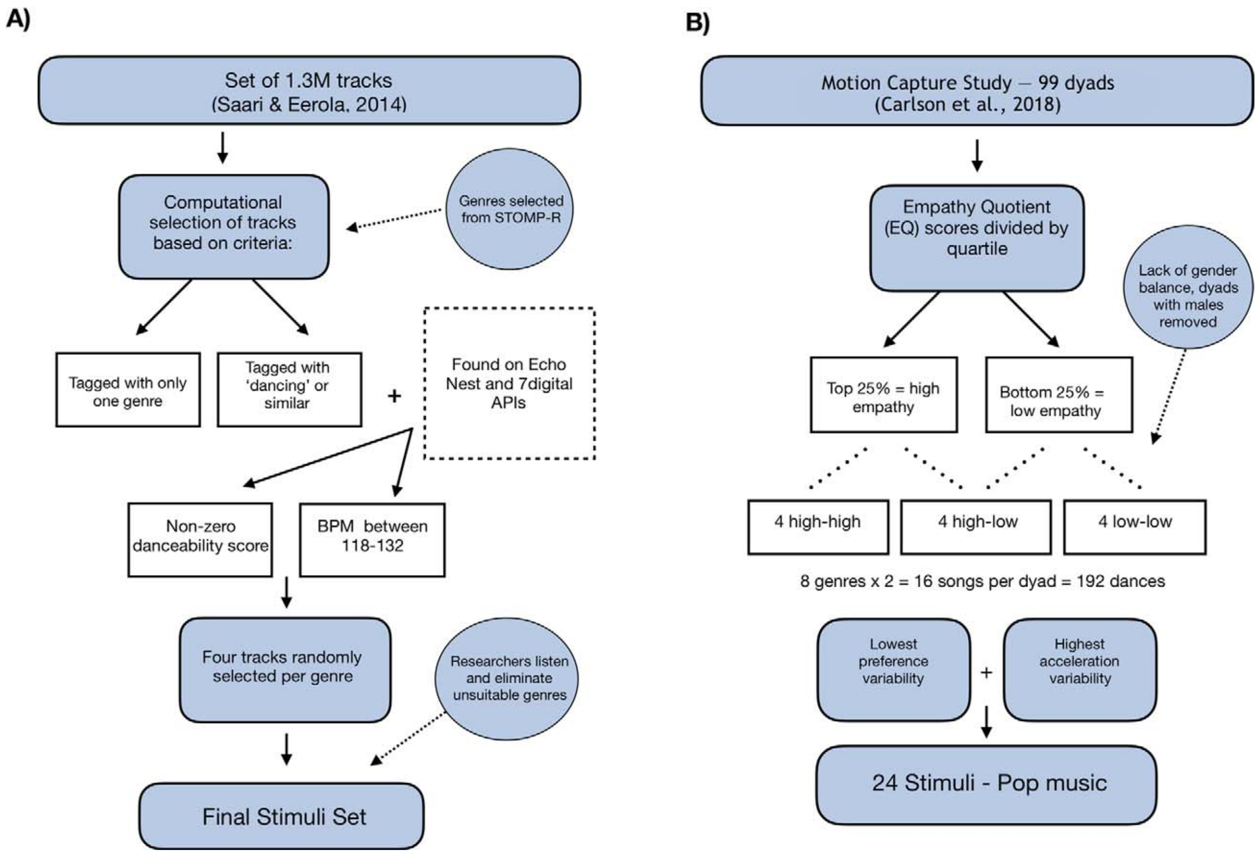

FIGURE 3. The stimuli-selection processes for the audio stimuli (A) and the animated perceptual stimuli (B).

Figure 1). The stimuli comprised sixteen 35-second excerpts from eight genres, in randomized order: Blues, Country, Dance, Jazz, Metal, Pop, Rap, and Reggae. Dancers were instructed to move as they felt comfortable, allowing interaction between dyad members to happen (or not happen) naturally. Stimuli for the experiment were selected computationally using social tagging; that is, data derived from music-listening platforms such as Last.fm, where users can freely tag songs with any words they choose, such as "jazz" or "happy" or "summer favorite." These tags, along with audio information from the chosen excerpts, were used to select excerpts clearly representative of the chosen genres (see Figure 3A for overview, and see Carlson et al., 2017, for a full description), suitable for dancing, and ranging from 118–132 BPM. Participants were allocated to groups of four based on a principal component analysis of their reported preferences for the chosen music stimuli. Groups were designed such that each group member should have both some similar and some dissimilar preferences with each of the others, such that unusually similar or dissimilar preferences between a given pair of dancers would be less likely to confound variables such as personality and trait empathy. Groups of four attended the experiment together and were instructed to move freely to the randomized musical stimuli, as they might in a dance club or party setting.

Due to several no-shows and late cancellations, 7 of 20 groups included only three participants. Participants first danced individually, and then danced in each possible dyad combination, yielding six dyads in all for groups of four and three dyads for groups of three. The total number of dyads recorded was 99.

PERCEPTUAL STUDY

Using data obtained from the collection described above, a perceptual experiment was designed to gather data to provide insight into how dyadic entrainment is perceived.

Stimuli selection. Stimuli were selected based on dancers' self-reported trait empathy. Figure 3 gives an overview of the processes used to select both the audio stimuli for the motion capture study (Figure 3A) and the animation stimuli for the current study (Figure 3B).

EQ scores in the sample ranged from 51 to 73. Although these scores represent healthy individuals (Baron-Cohen & Wheelwright, 2004), participants whose EQ scores were in the top or bottom quartile of all scores were considered—for the purposes of the current study—to have high or low empathy, respectively. Dyads including male dancers were eliminated from this subset, because the smaller number of male compared to female participants in the full sample would make it difficult to achieve an appropriately balanced stimuli set including both male and female dancers. Previous work has suggested some differences in males and females in terms of empathy (Baron-Cohen & Wheelwright, 2004; Schulte-Rüther, Markowitsch, Shah, Fink, & Piefke, 2008), and that there may be differences between males and females in dyadic dance behavior related to empathy (Carlson et al., 2018). Therefore, it was considered prudent to eliminate gender as a potentially confounding factor in the stimuli.

From the remaining data, twelve dyads were selected comprising four high-high, four high-low and four low-low empathy combinations. An effort was made to ensure no overlap of individual dancers between dyads, but in a single case this was unavoidable due to the other constraints mentioned above, such that one dancer was included in both a high-low and a low-low dyad (with different partners). This resulted in a set of twelve dyads dancing together to each of 16 stimuli. To keep the experiment sufficiently short and remove as many confounding variables as possible, it was decided to further reduce the set by only including recordings in which the dyads were dancing to a single genre; as there were two stimuli per genre, this resulted in 24 recordings for animation.

To determine which of the eight genres would be least likely to cause noticeable differences between dyads due to music preference (and thus confound the effects of empathy), variability of stimuli preference was assessed for the twelve selected dyads. On a seven-point scale, mean stimuli preferences ranged from 2.5 to 4.6, while mean variabilities of preference ranged from 1.5 to 5.3. Compared to other stimuli, the two Pop stimuli were moderately liked ($M = 3.33$ and 3.91 respectively), showed low mean variability in preference ratings ($M = 2.26$ and 2.42 respectively), suggesting that dancers' preference or disliking for the excerpts would not be a confounding factor. To ensure that there would, however, be discernable differences between the visual stimuli, mean acceleration across all joints per stimuli was used as a measure of overall amount of movement (Carlson, Burger, London, Thompson, & Toiviainen, 2016). Standard deviation across dyads in amount of movement (in m/s^2) was found to range from 0.78 to 5.53, with Pop excerpts showing comparatively high standard deviations (4.07 and 5.53 respectively). Pop music was also expected to elicit fewer stereotypical dance movements compared to other genres, such as Jazz or Metal, and thus was determined to be the appropriate and most generalizable of the available genres to include as stimuli.

Stimuli processing and animation. Using the Motion Capture (MoCap) Toolbox (Burger & Toiviainen, 2013) in MATLAB, movement data of the 42 markers (21 per dyad member) were trimmed to match the exact duration of the musical excerpts and gaps in the data were linearly filled. Data were then trimmed a second time to comprise a range of the 5th through the 25th second of the recording from the start of the music, resulting in excerpts of 20 seconds each. Following this, the data were transformed into a set of 40 secondary markers, subsequently referred to as joints, of which there were 20 per dyad member. The locations of these 20 joints are depicted in Figure 2B. The locations of joints B, C, D, E, F, G, H, I, M, N, O, P, Q, R, S, and T are identical to the locations of one of the original markers, while the locations of the remaining joints were obtained by averaging the locations of two or more markers; Joint A: midpoint of the two back hip markers (referred to as the root marker in the further analysis); J: midpoint the shoulder and hip markers (midtorso); K: midpoint of shoulder markers (manubrium); and L: midpoint of the three head markers (head). Joint structures were identical for each member of the dyad.

Data were animated at a rate of 30 fps. Data were color-coded such that one dyad member was animated in blue, and the other in green. To avoid the possibility that these colors would affect participants' perceptions, two sets of data were created such that in one set, the dancer on the left was animated in blue while the dancer on the right was animated in green, while in the second set these were reversed. Animations were otherwise identical. For each stimulus, a viewing angle was chosen manually to eliminate or minimize any appearances of overlap between the dancers, to avoid visual confusion. Animations were created without audio so that participants would focus on movements and dancers' entrainment to each other rather than to the music.

Participants. A total of 33 (25 female) participants ranging in age from 23 to 56 ($M = 30.1$, $SD = 7.2$) were recruited via social media and University e-mail lists and had participated in an average of 3.8 years of formal

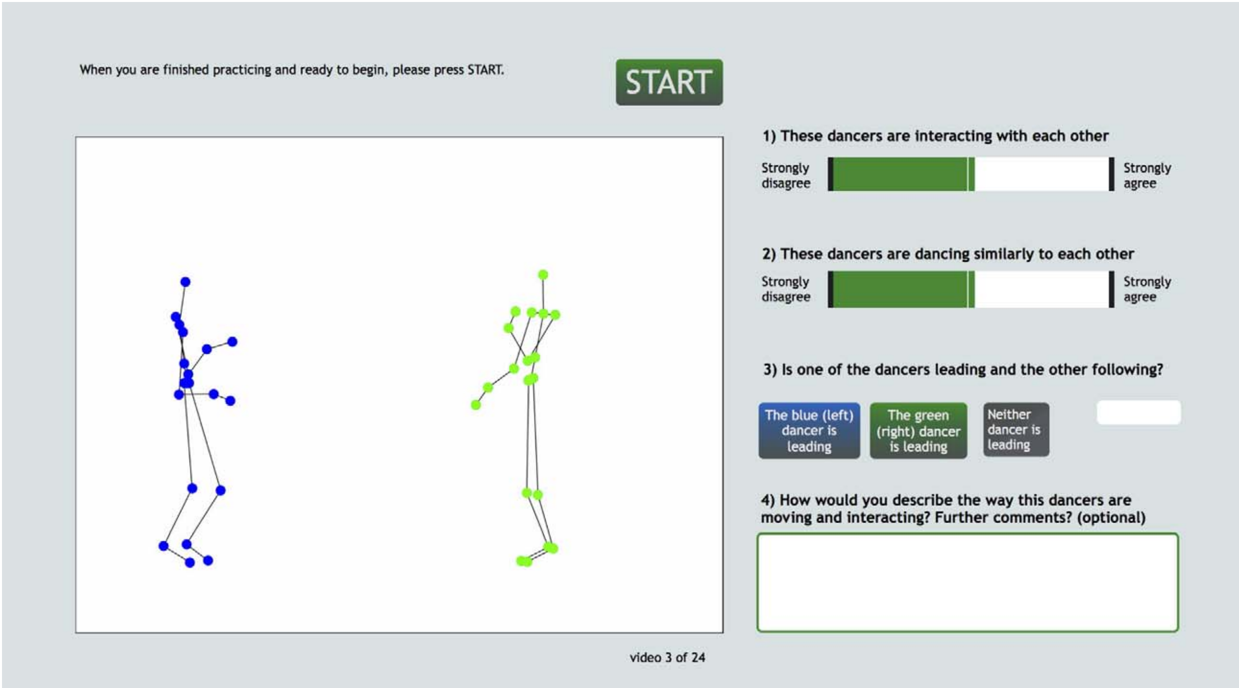

FIGURE 4. Perceptual study self-guided interface. For the experiment, this was rendered in color such that blue and green dancers were indicated by blue and green buttons.

music education ($SD = 6.2$), and 1.6 years of formal dance education ($SD = 3.5$). They represented a broad range of nationalities, with the most represented nationalities being Finnish and Indian. Participants received a movie ticket voucher in exchange for their participation in the study. Exclusion criterion was participation in the motion capture study described above.

Procedure. Animations were presented using an interface created in Max 7 (www.cycling74.com) running on a Macbook Pro laptop, which was set up in a private office on a quiet corridor. Participants signed a consent form and were informed that they could take a break, stop the experiment, or ask the experimenter for clarification at any time. Using a self-guided interface (see Figure 4) participants first answered several demographic questions and completed a practice round before viewing and rating the 24 randomized stimuli. Each 20-second stimulus was looped such that the participants could observe the dyad as long as they wished before making judgments. Participants rated their level of agreement with the statements that dancers were "interacting with each other" and "dancing similarly to each other" on a scale from 0 to 100 using sliders. These terms were chosen over "entrainment" or "synchronization" as they did not require special knowledge of musical terms, following Vicary et al., (2017) who also used general terms. Pilot testers reported that these terms were clear and relatively easy to judge in the stimuli.

Participants additionally were given a space to write freeform observations about the dancers and were allowed to change their answers as many times as they liked before clicking 'Save.' The experiment took between 30 and 50 minutes to complete. After the experiment, participants were debriefed about the purpose of the study, and given the opportunity to ask questions. No participants reported confusion or difficulty with the interface or task. Perceptual participants additionally filled out the Empathy Quotient.

Movement data processing. Motion capture data used to create the perceptual stimuli were further analyzed for comparison with perceptual results using the Mocap Toolbox. Subsequent to transformation from markers to joints and gap-filling, each of the 24 data structures of 40 markers was split into two structures of 20 markers, corresponding to each of the two dyad members or 48 data structures. Data were rotated such that the hip joints (F, A, and B) paralleled the x-axis, with joint A representing the origin of the new coordinate system. Three-dimensional velocity data were extracted from each of the 20 markers, and one-dimensional instantaneous speed data for each joint of each stimulus was obtained using the Euclidian norm. This resulted in 48 structure of 20-dimensional time series data (two structures per stimuli corresponding to two dancers per stimuli), which were trimmed to 20-seconds each for further analysis.

Following this, each of the 20-dimensional time-series were divided into 17 windows of 4 seconds each with a one second hop between windows. The periodicity for each joint was then estimated using autocorrelation, within each window. Following this, the difference in estimated periodicity between dancers for each stimulus was assessed by taking the absolute difference between estimated periodicity per window, per joint. To obtain an overall measure of similarity between dyad members in periodic movement, these differences were then averaged and subtracted from 1 (1 - mean difference) such that larger numbers related to greater levels of similarity between partners in periodic movements. This measure is referred to as *period locking*. As a control, the same measure was calculated using data from the dancers' dancing alone rather than with each other, in order to determine the degree to which periodic movement was related to dyadic effects rather than simply to entrainment with the music.

Additionally, given that hand gestures are commonly used and implicated in spoken communication (Bernardis & Gentilucci, 2006; Goldin-Meadow, 2006), the presence of more hand movements could conceivably be linked to greater levels of interaction. The overall amount of hand movement was assessed using velocity data. For each stimulus the instantaneous magnitudes of velocity were estimated for each hand, and the average taken over time and across the left and right hands for each member of the dyad and summed across the dyad. This measure is referred to as *hand movement.*

Finally, because participants in the motion capture study were not given instructions on whether or how to orient their bodies to their partners, dyads moved together in a range of orientations from facing to non-facing, which could have affected their ability to interact and the perception of interaction. To provide a quantitative measure of this, the absolute angle between the orientation of the hips of each dyad member relative to the orientation of the other dyad member as a function of time was calculated, using markers 7, 8, and 9 prior to transformation to joint data. The mean of this measure was taken across time, and then averaged across dyad members, to obtain a general measure of orientation angle, and subtracted from 180 degrees such that larger numbers indicated that dancers were turned towards each other. This measure is referred to in the analysis as *orientation.*

Results

Independent sample *t*-tests were run comparing period locking, hand movement, orientation and rated interaction and similarity between the two musical stimuli, to check that results were not related to the specific Pop song heard by the dancers. Results showed no significant differences between musical stimuli in any of the variables (p ranged from .23 to .72). Cronbach's alpha showed good interrater reliability for both interaction ($a = .84$) and similarity ($a = .86$) measures. There was a positive correlation between rated interaction and rated similarity, $r = .51$, $p < .05$, suggesting that they measured as similar but non-identical constructs. There was additionally a significant correlation between period locking and hand movement, $r = .51$, $p < .01$, and between orientation and hand movement, $r = .43$, $p < .05$. Following this preliminary analysis, data were *z*-scored to account for the multiple scales used and averaged across raters.

COMPARISON OF PERCEPTUAL RATINGS AND DANCERS' EMPATHY

To assess our first hypothesis, one-way repeated measures ANOVAs were conducted comparing the effect of empathy combinations (high-high, high-low, and low-low) on perceived levels of interaction and similarity. As shown in Figure 5, there was a significant effect of empathy combination on perceived interaction, $F(1, 32) = 527.34$, $\eta^2 = .09$, $p < .001$, and perceived similarity, $F(1, 32) = 614.65$, $p < .001$. Bonferroni-corrected pairwise comparisons showed that, for interaction, high-low stimuli ($M = 56.44$, $SD = 22.12$) were rated as significantly more interactive than either high-high ($M = 38.34$, $SD = 23.62$) or low-low ($M = 41.30$, $SD = 20.62$) stimuli, $p < .001$. For perceived similarity, pairwise comparison showed that high-high stimuli ($M = 50.42$, $SD = 17.73$) were rated as significantly less similar than high-low ($M = 61.44$, $SD = 13.29$) and low-low ($M = 57.58$, $SD = 20.80$), $p < .05$.

COMPARISON OF PERCEPTUAL RATINGS AND MOVEMENT VARIABLES

There was no significant correlation between dyads' period locking scores when they danced alone compared to when they danced together, suggesting the measure is indeed related to dyadic processes ($r = .10$). To assess our second hypothesis, correlation analysis was used to compare perceptual ratings with movement features. These results are displayed in Table 1.

Rated interaction correlated significantly with all three movement variables, with moderate effect sizes. Rated similarity only correlated significantly with

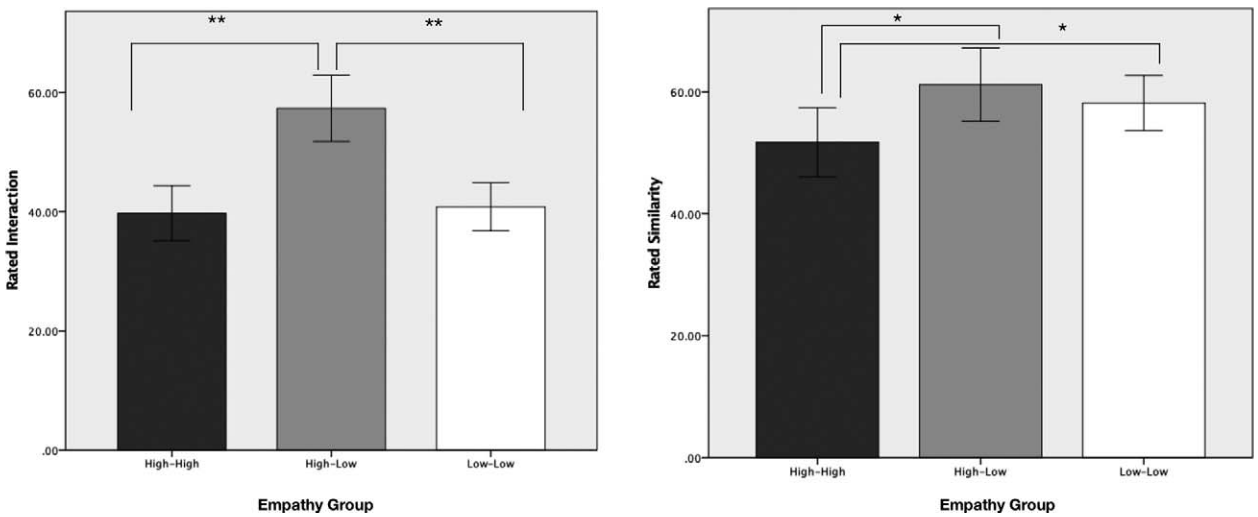

FIGURE 5. *p < .05 **p < .001. Mean rated level of interaction (left) and similarity (right) by empathy pairing, 95% CI.

TABLE 1. *Correlations Between Rating and Movement Variables (n = 24)*

	Interaction	Similarity
Period Locking	.48*	.45*
Hand movement	.64**	.30
Orientation	.49**	.32

*$p < .05$ **$p < .01$

period locking. There were no significant relationships between raters' music or dance experience and their ratings of dancers' interaction or similarity. There was also no relationship between raters' EQ scores and their ratings of dancers' interaction or similarity. There were also no significant correlations between the control measure of period locking from dancers' individual data and any of the other measures.

COMPARISON OF MOVEMENT CHARACTERISTICS AND DANCERS' EMPATHY

To assess our third hypothesis, one-way repeated measures ANOVAs were conducted comparing the effect of empathy combinations (high-high, high-low, and low-low) on movement variables. There was a significant effect of empathy combination on hand movement, $F(2, 21) = 4.18$, $\eta^2 = .28$, $p < .05$, but no significant effect on either period locking or orientation. Bonferroni-corrected pairwise comparisons showed that, for hand movement, high-low stimuli (M = 23154.11, SD = 8598.92) had significantly greater hand movement than high-high stimuli (M = 14605.92, SD = 3886.87), $p < .05$. There were no other significant differences between groups. Figure 4 displays bar plots of movement variables by empathy pairing.

Discussion

The current study sought to explore the nature of dyadic entrainment in free, improvised dance movement using perceptual and computational measures of dance movement. This study also explored the relationship of these measures to dancers' self-reported trait empathy. Results showed that dancers' trait empathy had a significant effect on perceived interaction and similarity with their dance partners. However, against our expectations, dyads consisting of one highly empathic and one less empathic dancer were rated as significantly more interactive than dyads where both dancers were high or both dancers were low in empathy. Also, against our expectations, dyads in which both dancers rated themselves as high in empathy were perceived as moving less similarly than other dyads. In line with our expectations, period locking of full body movements related significantly to greater perceived interaction and greater perceived similarity. Greater amounts of hand movement and orientation of the body towards the dance partner, however, related significantly only to perceived interaction. Dyads with one dancer high in empathy and one low in empathy used significantly more hand movements than dyads with two highly empathic dancers. There were no other significant differences between dyads based on empathy pairing, although

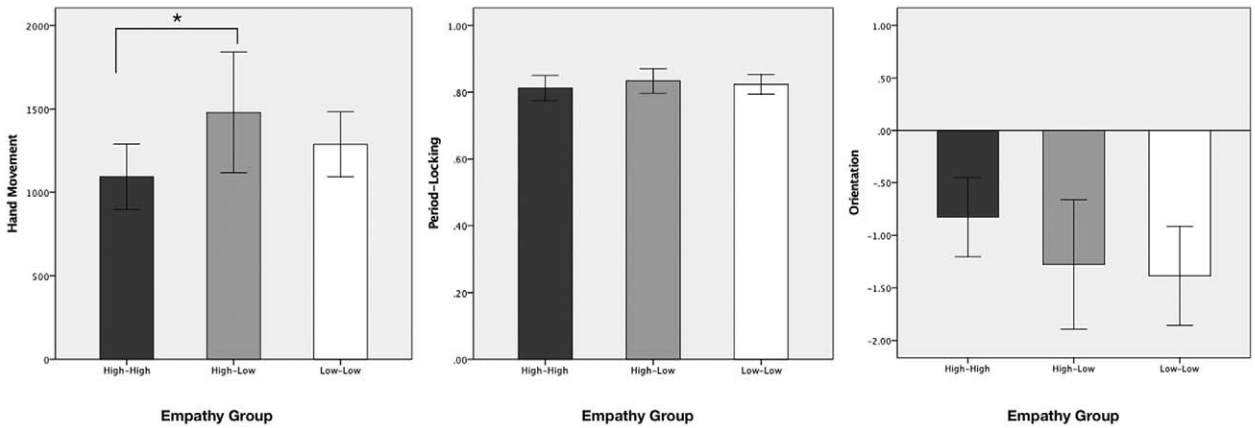

FIGURE 6. *$p < .05$. Mean movement variables extracted from stimuli, by empathy pairing, 95% CI.

a pattern of nonsignificant differences can be seen in Figure 4, which may shed some light on perceptual results, specifically that high-low pairings were above the others in all of the tested movement characteristics.

Low empathy has previously been related to lower levels of automatic facial mimicry, (Sonnby–Borgström & Sonnby-Borgstrom, 2002), to lower levels of interpersonal citizenship behavior (Taylor, Kluemper, & Mossholder, 2010), and to various psychiatric and developmental disorders, including autism spectrum disorder, in which disturbances of social functioning are implicated (Baron-Cohen, 2009; Decety & Moriguchi, 2007; Dziobek et al., 2011; Ritter et al., 2011; Schulte-Rüther et al., 2011). It is therefore not surprising to find that dyads in which both participants reported low levels of trait empathy were perceived as significantly less interactive than dyads in which one participant reported high empathy, as we might expect the empathic participant to be more likely to adjust their movements to mimic or imitate their partner (Iacoboni, 2005; Koehne, Behrends, Fairhurst, & Dziobek, 2016; Sonnby-Borgström, Jönsson, & Svensson, 2003). However, in the current results, dyads with two highly empathic participants were rated as less interactive and less similar than dyads in which only one dancer was highly empathic. Previous work into the effect of similarity of disposition between social partners on interactions have yielded mixed results. Cuperman and Ickes (2009) found that participants with similar personality traits had better interactions (unless both participants reported low levels of Agreeableness) while Isbister and Nass (2000) found that, in the domain of Extraversion, participants preferred interacting with interactive characters with opposite rather than similar personality types to their own. To the authors' knowledge, such research has not been carried out on trait empathy, limiting how well the current result can be interpreted, but it may be that a similar phenomenon as found by Isbister and Nass (2000) is present here. Although more research with bigger sample sizes is needed to support and clarify this finding, one speculative interpretation is that interaction was more efficient if one dyad member was primarily adjusting their movements to the other. This may be supported by the results found in Carlson et al. (2018), that empathic dancers overall change their own movements more in response to dancing with different partners. Paired with the current results, this may indicate that empathic dancers were concerned about putting their partner at ease, which in some cases could have meant reading their partner's desire *not* to interact and adjusting accordingly; that is, two empathic dancers may have tended to be more cautious regarding each other's desire for interaction. Another possibility is that highly empathic dancers tended to seek a connection with their partners, which was easily established with other empathic dancers but required a greater amount of effort with less empathic partners, leading to more active and obvious attempts at interaction. Finally, it is possible that a factor other than trait empathy that was not measured in this study—such as social dominance or extraversion—contributed to the current findings.

That movement with stronger overall period-locking across the whole body, overall amount of hand movement, and orientation towards the dance partner all related to perceived interaction suggests that these movement characteristics may provide a starting point for defining dyadic entrainment in a free movement setting as a multi-dimensional phenomenon. Only similarity in periodic movement related to perceived similarity across dancers, indicating that hand movement and orientation were not as important to participants' judgements of similarity. This could suggest that, in some circumstances, dancers moved similarly in response to the music rather than to each other, and that participants were able to perceive such similarity as distinct from intentional interaction. However, as there was no significant relationship between dyads' period locking when they were dancing alone and when they were dancing together, it is likely that the presence of another dancer affected their periodic entrainment in one way or another.

Phillips-Silver et al. (2010) define social entrainment as a special case of entrainment where the rhythmic signal is generated by another person. Since in this case the rhythmic signal would be the dance movements of a participants' partner, it stands to reason that such social entrainment is more likely to take place when a dancer is oriented towards their partner, which could account for the high correlation between dyads' orientation and their perceived levels of interaction. This is in line with previous research showing that the presence of shared visual information altered participants' movements when interacting (Vesper, Schmitz, Safra, Sebanz, & Knoblich, 2016). It is likely that dyads' orientation towards rather than away from each other was perceived as more interactive, which is in line with previous research (Burgoon & Le Poire, 1999; Burgoon, Manusov, Mineo, & Hale, 1985). Although intention cannot be measured directly, the perceived intention or intentionality of an action is often considered a key factor in social perception (Baldwin & Baird, 2001; Sartori, Becchio, Bara, & Castiello, 2009). Reddish, Fischer, and Bulbulia (2013) found that in dance, participants felt stronger group cohesion and engaged in more prosocial behaviors when they were explicitly instructed to synchronize their movements, suggesting that intention may play an important role in social entrainment in dance. Orientation towards a partner may not only afford possibility of social entrainment in dance by increasing visual information, but may function to communicate the intention to socially entrain.

Similar reasoning can be applied to the significant positive relation of overall amount of hand movement to perceived interaction. Dyads with one dancer with high empathy and one with low empathy—who were judged as more interactive than other dyad types—were shown to use significantly more hand movements than dyads where both dancers were high in empathy, suggesting that hand movement increases the likelihood that observers will perceive interaction. Hand gestures can be expressive and communicative (Goldin-Meadow, 2006; Krauss et al., 1996), possibly leading to the perception of greater intent to communicate in dyadic dance. Hands also have more freedom of movement in dance than the torso or lower body, so it may be that, in this case, increased hand movement reflected more complex and individualistic movements that could be specifically imitated, rather than, for example, more passive movements resulting from bodily sway. However, the current measure is a very broad one and cannot speak directly to whether hand movements were being used for imitation or communication. The development of more finely-tuned analysis methods could shed further light on this topic.

Taken together, these results show that periodic entrainment between individuals can be present in complex movements that may not be identical to each other, but that this alone is not sufficient for social entrainment to be perceived. One interpretation of these results could be that interaction, or social entrainment, may be perceived when periodic entrainment is present along with orientation towards a dance partner and a greater amount of hand movement than average. It may be that these features afford greater opportunity to entrain to the visual signal of another dancer, as bodily orientation towards a partner could increase visual contact, and increased hand movement could provide grounds for explicit imitation or signal the social intention to entrain to the partner (Phillips-Silver et al., 2016; Vesper et al., 2016). However, as the relationship between empathy, the extracted kinematic features, and the raters' perceptions of interaction were not straightforward, there are almost certainly a number of other kinematic features not captured by the current analysis but influential regarding how social entrainment is perceived, highlighting the need for further research on this topic.

The current study aimed to explore how entrainment can happen in a dyadic, free dance setting using a naturalistic paradigm to collect dance data. Future work could develop the insights gained here by using experimental study designs—for example, through manipulating dancers' bodily orientation towards one another, including conditions with and without full musical stimuli, providing deliberate leader-follower instructions, and for motion capture, recruiting participants who are well-acquainted with each other. The development of more sophisticated computational measures of interaction could also provide new insights. For example, a measure that captures the perception of interaction over time, rather than as a single overall judgement, could provide new insights and a richer ground for comparison with kinematic features. Future work may also benefit from collecting information on dancers' own perceptions about interaction and entrainment with their dance partners. The results of the current study could be supported and expanded by replication with larger sample sizes, the specific recruitment of high and low scorers in trait empathy, and possibly the use of a performance-based rather than a self-report measure of empathy (e.g., Baron-Cohen, Wheelwright, Hill, Raste, & Plumb, 2001). Although the study sample included participants from a wide range of countries, the majority were from Western cultures and all were currently living in Finland and thus exposed to Western culture. The degree to which the current results can be generalized across cultures, therefore, is uncertain, and requires further investigation. It is also possible that more conclusive results could be gained by restricting the sample to members of a single cultural tradition, and similarly that more generalizable results could be gained from seeking a gender-balanced sample. Finally, further study can explore how the whole-body aspects of social entrainment and interaction shown here to be significant within dyads may manifest in settings with a greater number of dancers.

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