MUSIC AND MIRRORING:
HOW MUSIC AFFECTS THE MIRROR GAME

Megan Buchkowski
Master’s Thesis
Music and Social Bonding
Department of Music
16 August 2018
University of Jyväskylä

JYVÄSKYLÄN YLIOPISTO

Tiedekunta – Faculty Humanities	Laitos – Department Music Department
Tekijä – Author MEGAN BUCHKOWSKI	
Työn nimi – Title MUSIC AND MIRRORING: HOW MUSIC AFFECTS THE MIRROR GAME	
Oppiaine – Subject Music, Mind & Technology	Työn laji – Level Master's Thesis
Aika – Month and year APRIL 2018	Sivumäärä – Number of pages 77

Tiivistelmä – Abstract

Social bonding and intersubjectivity are basic human necessities, but have been notoriously difficult to measure. Recently, there has been an increased interest into research that utilises tools such as the mirror game (where two or more participants mirror each other's arm movements) as a possible measure for these phenomena. The mirror game is a means to enter into shared leadership, a state where there is no designated leader of the movement and when intersubjectivity can be experienced. In the current study, the mirror game's potential as a measure was investigated using music to facilitate social bonding between stranger dyads of equal musical standing. Participants were collected from the international community of the University of Jyväskylä, Finland, and were divided into pairs based upon a questionnaire. The dyads generated creative, synchronous motion jointly before and after one of three musical interventions (turn-taking, entrainment and solo). To determine if a relationship between the mirror game and social bonding was possible the velocity, acceleration and jitter of the arm movements in the shared leadership mirror game were analyzed. Social bonding was measured with the Inclusion of Other in Self scale (IOS, Aron, et at., 1992). The study found, through windowed cross-correlation, that the musical condition did have an impact upon how the shared leadership mirror game was played: turn-taking dyads showed more regulated, longer turns of leadership, whereas entrainment dyads showed an increase in periodic movement and solo dyads displayed no consistent relationship. The amount of jitter calculated in the post-intervention turn-taking mirror game trials was found to be significantly related to the IOS scores. A novel measure of social bonding using physical proximity was also investigated, but was not successful. It was concluded that the mirror game is able to capture some of the nonverbal aspects of human interaction and its sensitivity to changes in social bonding could lead to its use as a measurement tool.

Asiasanat – Keywords
MUSIC, SOCIAL BONDING, INTERSUBJECTIVITY, SYNCHRONY, MIRRORING

Säilytyspaikka – Depository	
Muita tietoja – Additional information	

Acknowledgments

First, I would like to heartily thank my two advisors, Dr. Marc Thompson and Dr. Tommi Himberg, for their patience and kindness throughout this process. I came into this degree with little to no background in scientific research, and I am eternally grateful for all they have taught me and how they have helped me grow. Second, I would like to thank all of the students in my MMT programme who inspired me and motivated me every day to do better. I am so proud of everyone. Third, a thank you to Finland and those in Jyväskylä who took the time to get to know me and made the two years I have spent here unbelievably enriching. Fourth, thank you to Kylahop, Improkampus, Off Script, hiking and saunas for providing me with laughter, joy and relaxation while completing this degree. Fifth, thank you to Kerry for reading and editing all my writings—you have helped me become a better writer. And final thank you to my friends and family back home who, although at far distance physically, supported me in my journey.

"Life is a continual improvisation."
—Agre & Chapman (1987, pg. 287)

"It is perhaps for good reason that 'minds make bodies synchronize'"
—Sebanz et al. (2006, p. 73).

CONTENTS

1 INTRODUCTION

Social bonding is an evolution-based human phenomenon that is vital to humanity. As humans, we have all felt spontaneous connections to other people. The bonding can be immediate, described as a “spark”, or it can take time to build the trust and understanding required to feel the bond. It is common knowledge that social bonding is dependent upon many factors: personality, empathy levels, opinions, sense of humour, hobbies, physical appearance, and various others. There are many books and movies that tell stories of likely and unlikely friendships or romantic relationships and many maxims that describe human relations, such as “like attracts like” or “opposites attract”. The ways by which humans bond is as mysterious as the phenomenon of bonding itself. Bonding appears to occur under many different kinds of interaction without one clear and consistent common denominator, aside from the amount of time spent together.

Synchronous behaviour is suggested to assist bonding because of humans’ strong tendency to synchronize (Richardson, Marsh, & Schmidt, 2005; Schmidt & O’Brien, 1997; Sebanz et al., 2006). Previous studies have explored the effectiveness of synchrony and joint action to facilitate feelings of togetherness in humans, and these two phenomena have been shown to increase social bonding (Demos, Chaffin, Begosh, Daniels, & Marshl, 2011; Wiltermuth & Heath, 2009). Nonetheless, measuring bonding is difficult given the vast complexity and uncertainty of social bonding. Many approaches have been employed to capture it (Demos et al., 2011; Kreutz, 2010; Sayette et al., 2012; Wiltermuth & Heath, 2009), but none have been confidently accurate, aside from one scale that has been consistently used with promising results: The Inclusion of Other in Self Scale (Aron, Aron, & Smollan, 1992). With this measurement difficulty in mind, the mirror game (Noy, Dekel, & Alon, 2011) has been investigated as a possible addition to the plethora of social bonding measures. Previous research into the mirror game (Himberg, Laroche, Binge, Buchkowski, & Bachrach, 2018) indicates that the relationship between social bonding and synchrony might be bi-directional: could an increase in social bonding lead to better synchrony or ability to perform joint action?

The mirror game began to be studied in greater depth because of its ability to lead to synchronized motion between individuals (Noy et al., 2011). In the mirror game, two or more people attempt to improvise synchronized movement together. Previous research has demonstrated that the mirror game can help people enter into joint action or shared leadership (Himberg et al., 2018). This joint improvisation also takes place in daily activities, such as musical interactions or in conversation (Issartel, Gueugnon & Marin, 2017), and is also connected to humans' feelings of togetherness (Knoblich, Butterfill, & Sebanz, 2011). In social interaction, these moments of togetherness (Hart, Noy, Feniger-Schaal, Mayo, & Alon, 2014; Noy, Levit-binun, & Golland, 2015) are the merging of the individual with the collective and can be described as moments of "being in the zone" (Issartel et al., 2017, p. 2). Such feelings are common in the phenomena of synchrony and entrainment, both of which are important in the current experiment.

The terms synchrony and entrainment are used and focused on as connected but unique phenomena. In this study, entrainment is defined as a consistent relationship (Clayton, Will & Sager, 2005), whereas the definition of synchrony, while encompassing both true synchrony and behavioural matching (Chartrand & Bargh, 1999), is understood as true synchrony. This perspective is chosen because social bonding can be measured through the time delay found between the dyad's movement; the closer to synchrony their movements are, the more bonded they are (Yun, Watanabe, & Shimojo, 2012). Entrainment is conceptualized in how the participants relate to their dyad partner during their movement, or simply, their relationship to one another. As the mirror game is a game of imitation, behavioural matching will be inevitable, and therefore not of great importance in this study. Out of the three main characteristics of joint interactions (subjective, physiological and kinematic; Issartel et al., 2017), the current study focuses upon the subjective measures and the kinematic measures.

Given the results of previous studies of the mirror game (Noy et al., 2011; Himberg et al., 2018; Gueugnon et al., 2016a) in relation to studies of synchrony (Chartrand & Bard, 1999; Chartrand & Jefferies, 2003) and entrainment (Clayton et al., 2005), this study assumes the mirror game measures the amount of social bonding between players. To explore this relationship, the study uses music to investigate what parameters the mirror game uses to capture different types of interactions.

Music is another common human behaviour that assists social bonding and has attracted interest in research (Cross, 2001; Kirschner & Tomasello, 2010, Tarr, Launay, & Dunbar, 2014). Humans use entrainment, turn-taking and synchrony, all of which are important in this study, in order to be successful in music. Since music is enjoyed by, and is quite accessible to, the majority of people, it could be employed for its social bonding ability to examine the mirror game. Music was chosen as the intervention because, although it has many similar elements to the mirror game, it is an activity that does not solely use synchrony to assist bonding. Given this, musical interventions could manipulate social bonding without directly impacting the mirror game or teaching the players synchronization strategies that could be applied to the mirror game.

Based upon the connection synchrony has to positive affiliation (Demos et al., 2011; Wiltermuth & Heath, 2009), and the mirror game's potential for triggering the natural human processes of mimicry, the current study combines these ideas to investigate if, and in what ways, the mirror game measures social bonding between humans.

1.1 Intersubjectivity, Synchrony and Shared Leadership

The main focus of the study is human intersubjectivity, which is defined as "mutual engagement and participation between independent subjects, which conditions their respective experience." (de Quincey, 2000). Simply, to measure intersubjectivity would be to measure how bonded and committed a person is to another in a given moment. Intersubjectivity may be measured through interpersonal coordination (Marsh, et al., 2007), which, according to Hove and Risen (2009), can be divided into two parts: behaviour matching, such as mimicry, and interactional synchrony. For example, behaviour matching can occur through spontaneous synchronization of body posture in conversation (Shockley et al., 2003) or in the tendency of humans to synchronize their limbs while walking together (Mottet et al., 2001). Unconscious mimicry, similar to mirroring and imitation, has been suggested to improve social bonds, increase affiliation and rapport (Chartrand & Bargh, 1999), and incite customers to be more generous in tipping (van Baaren, Holland, Steenaert, & van Knippenberg, 2003). Both mirroring and imitation occur spontaneously (Chartrand & Bargh, 1999), and are very important tools in social interactions (Shockley, Satana & Fowler, 2003; Meltzoff & Moore, 1994). Synchrony has also been shown to have social benefits: to heighten rapport between people (Valdesolo & DeSteno, 2011; Hove & Risen, 2009) and to increase cooperation (Wiltermuth & Heath, 2009). According to Valdesolo and DeSteno (2011), a primary function of synchrony is to see how similar others are to oneself, and those who are perceived to be more similar are given more compassion and altruistic behaviour. If it is possible to incite bonding through interpersonal interaction such as mirroring, mimicry and synchrony, perhaps it is also possible to measure the level of bonding by means of this type of interpersonal interaction.

The interpersonal interaction of interest in this study is shared leadership, otherwise known as joint action. Joint action is commonly found in the performing arts due to their high improvisatory nature. It is described as, "the creative action of two or more people without a script or designated leader" (Noy, Dekel, & Alon, 2011, p. 20947). There are two types of joint action, according to Knoblich, Butterfill, & Sebanz (2011). The first is planned coordination: when the players' behaviour depends upon what they wish to achieve (such as playing an instrument). The second is emergent coordination: when "coordinated behaviour occurs due to perception action couplings that make multiple individuals act in similar ways; it is independent of any joint plans or common knowledge (which may be altogether absent)" (Knoblich, Butterfill, & Sebanz, 2011, p. 62). The strength of this togetherness is measured by how well people mutually coordinate their actions (Bolt, Poncelet, Schultz, & Loehr, 2016). Joint action can be learned through practice by learning how to communicate bodily with one's interaction partner (Gueugnon, et al., 2016a). This may be illustrated through a comparison of a study by Noy, et al. (2011) to one by Feniger-Schaal, Noy, Hart, Koren-Karie, Mayo, & Alon (2016). Expert improvisers are players that have an extensive history in dance, improvisational theatre or another similar art form (Noy et al, 2011). The novices, in the study by Feniger-Schaal et al. (2016) were not able to enter joint action as readily as the experts in Noy et al.'s study. In the current study, joint action is a key aspect because the participants can enter into a joint state through playing the mirror game.

1.1.1 The Mirror Game

Mirroring, in the form of spontaneous sensory-motor synchronization, is common between humans (Knoblich et al., 2011; Repp & Su, 2013); therefore, the employment of this communication device could enlighten aspects of human interaction previously masked by other, more obvious, forms of communication.

The mirror game (MG) is an improvisation-focused theatre game. It is used as a warm-up exercise for actors to help them experience moments of togetherness (Schechner, 1973; Spolin, 1999). Within the MG, players enter into a state where the possibility of creating synchronized, complex motions together is heightened. The MG was first introduced as a possible measure of intersubjectivity by Noy et al. (2011). These authors looked at expert improvisers playing a one-dimensional MG with two rounds: leader-follower (LF) and joint-improvised (JI). The results showed that the experts completed the JI round with much less jitter (small corrections of follower oscillating around the leader's movements), and could make improvised, complex movements together. This lower amount of jitter suggests a coupling of movement or an experience of togetherness between the players.

Since its induction into research, the MG has been used to study various human phenomena, such as attachment type, shared leadership, posture and individuality. Feniger-Schaal et al. (2016) used the MG to study adult attachment type and ability to synchronize in one dimension with novice-expert gender matched dyads. In this study, amount of synchrony was related to attachment type. Then, in a preliminary study on shared leadership, Himberg, Niinisalo, & Hari (2015) extended the mirror game to three-dimensions, using expert improvisers. Participants, facing each other, were instructed to mirror each other's fingers, either drawing a circle or creating free movements for one minute, in either LF or JI conditions. Similar to Noy, et al. (2011), they found that in the JI round, participants were more likely to mutually adapt to each other's movements, and had less jitter, achieving smoother movements (Himberg, et al., 2015). Gueugnon et al. (2016b) used a one-dimensional version of the mirror game to study how interpersonal coordination effects postural movements in a medial-lateral and an anterior-posterior direction. They found that interpersonal coordination led to in-phase movement in the medial-lateral direction and antiphase movement in the anterior-posterior direction. In another study, Gueugnon et al. (2016a) evaluated how movement synchrony and richness evolved over time and whether it could improve improvisational abilities. They found that movement synchrony contributes strongly to improvisation ability and can help predict movement richness in an improvisatory setting. They calculated synchrony through temporal delay between the participants' movements, and richness through the number of frequency values present in the movement. Gueugnon et al. (2016a) determined that both synchrony and richness of movement could indicate the quality of, and ability for, joint action. Synchrony between participants was an integral aspect of the current study's focus, but richness was not greatly involved.

In a study examining how togetherness is related to individuality within the mirror game, Hart et al., (2014) found that, in fifty percent of the games, participants in moments of togetherness or joint action changed their characteristic movements towards a universal stroke shape or universal co-confident movement. In a more recent study, Noy, Levit-Binun, and Gollard (2015) investigated the relationship between physiological markers, such as heart rate, and the one-dimensional MG. Through kinematic and subjective ratings, they found moments of togetherness in the MGs and compared the resulting heart rates of the participants during these times. They found that games that had higher amounts of togetherness showed higher correlation between the player's heart rates. If the MG can induce moments of togetherness enough to couple stroke shape (Hart et al., 2014), heart rate (Noy et al., 2015) and neural patterns (Yun et al., 2012), then this implies that the mirror game could be a means to investigate how this relationship is developed when the players are subjected to different interventions, such as those based on music.

All of these studies demonstrate the wide-ranging interest and usefulness of the MG to study human phenomena through a non-verbal physical medium. Up until this point, and to best of the author's knowledge, previous studies have not intentionally investigated how the MG could measure social bonding.

In the next two sections, attention and gaze will be discussed in order to provide clarity on these important aspects.

1.2 Synchrony and Heightened Attention

Attention or focus upon an interaction partner can be viewed as essential to play the MG. Like most tasks, the MG requires one's full attention in order to be successful. This is due in part to the importance of attention in social bonding, a behaviour that is commonly shown with gaze (Knapp & Hall, 2010), discussed in Section 1.3. Synchrony has been investigated as an human ability that is influential on attention (Macrae, Oonagh, Lynden, & Miles, 2008). When one moves together with another, the interaction partner gains a relevance because s/he may have pertinent social knowledge to provide (Sebanz et al., 2006). The relationship between synchrony and attention emerges in infancy (Deák et al., 2000), and continues on to be important in complex social interactions, such as conversations (Condon, 1976; Paxton & Dale, 2003). Some studies looking at synchrony have focused on how synchrony and mimicry are able to lead to heightened affiliation (Chartrand & Jefferies, 2003; Demos et al., 2011; Wiltermuth & Heath, 2009) or attention on an area of focus, whether that is a person or a task (Khalil, Minces, McLoughlin, and Chiba, 2013). In the Khalil, et al. study, participants who were found to be better rhythmic synchronizers were also more attentive, suggesting a relationship between synchrony and attention. Such previous studies provide support with attention-forming and synchrony-based tasks, such as music, to help with bonding. This will be discussed in greater detail below.

1.3 Gaze and Eye Contact

In the experiment, the participants were told to maintain eye contact as much as possible. Gaze is the eye movement made in the general direction of a face (Knapp & Hall, 2010). It has been shown to help with person perception, which suggests mutual eye contact is a core aspect of social cognition, and can help direct attention to the interaction partner (Macrae, Hood, Milne, Rowe, & Mason, 2002; Mason, Hood, & Macrae, 2004; Vuilleumier, George, Lister, Armony, & Driver, 2004). Eye gaze is an important social-communicative signal, and can provide information about the gazer's perceptions, desires, emotions, and intentions (Brooks & Meltzoff, 2014), as well as information about cognitive activity, feedback, flow of communication and the nature of the interpersonal relationship (Kendon, 1967). In previous studies, eye contact was found to have an effect on ratings of attentiveness, competence, liking and attraction, social skills and mental health, dominance credibility and expression of feelings (Kleinke, 1986). It was found that when a partner looked away this behaviour indicated that s/he was thinking about something, losing interest or avoiding intimacy (Argyle & Cook, 1976; Kendon, 1990). This finding provides support for the importance of eye contact in connecting with another person. Furthering this concept, Mehrabian (1968a, 1968b) reported an increase in gaze when participants moved towards an imaginary person they liked in comparison to one they disliked. Therefore, the maintenance of mutual eye contact would lead to more affiliation towards another person (Knapp & Hall, 2010), and that would lead to a heightened awareness of the other person, as felt when one is romantically interested in another. Nevertheless, in previous studies (Himberg et al., 2015; Himberg et al., 2018), the authors observed the participants would focus upon the finger that was making the motion, rather than their face, which created a lack of focus on the person outside of the moving body part. For the current study, it was hypothesized that this had an impact upon the process of bonding and connecting. Due to the findings from the studies and observations from the pilots, eye contact was determined to be an important addition to the study.

In the next few sections, some history and information regarding social bonding and social bonding measures will be provided.

1.4 Measures of Social Bonding

As a difficult human phenomenon to measure, various studies have used different approaches in attempts to capture social bonding: Likert scales (Demos et al., 2011), self-report (Sayette, et al., 2012), hormones (Kreutz, 2010), cooperative tasks (Wiltermuth & Health, 2009), questionnaires (Mueller, Agamanolis, & Picard, 2002), informal observation of body language with intercoder confirmation (Mueller, Agamanolis, & Picard, 2002), and trust as a measure of cooperation in the Prisoner's Dilemma (Poundstone, 1992). One of the most well-used measures is the Inclusion of Other in Self Scale (IOS, Aron, Aron, & Smollan, 1992). The current study used the IOS scale as the established measure of social bonding by which to validate the other measures under investigation, such as the MG and physical proximity.

1.4.1 Physical Proximity

In research into nonverbal communication, there have been investigations into physical proximity and intimacy between humans. Knapp and Hall (2010) completed an extensive compilation on nonverbal communication, and discussed the creation of intimacy within friendships and romantic relationships. They argue that intimacy can be shown by various nonverbal behaviour, including physical closeness, such as leaning forward, touching and direct body orientation. Moreover, this change in behaviour (change in closeness) happens in the beginning stages of the relationship between two individuals. Clore, Wiggins & Itkin (1975a, 1975b) monitored observer reactions to the behaviour of a female's action toward a male that she either likes or dislikes. The female was played by an actress, and observers were asked to rate how "warm" or "cold" her behaviours were. The observers rated a movement toward the male as "warm" and a movement away from the male as "cold". This study suggests that physical proximity is related to one's opinion or liking of another. The current study explored the use of physical proximity as another measure of the participants feeling of closeness towards each other.

1.5 Music and Social Bonding – Why Use Music as a Social Bonding Intervention?

Many tasks, games and situations promote social bonding and human connection (Launay, 2015), however, in this study, music was chosen as the intervention to facilitate the participants' bonding experience. Theories of music as a facilitator of social bonding began with Darwin (1871), who was the first recorded academic to comment upon music and social bonding within evolution. Since then other researchers have proposed theories, such as Merker (2001) and Miller (2001). Cross (2001), another primary researcher in music and evolution, proposed that music as a facilitator of social bonding may have evolved to teach children cognitive flexibility to help children learn the rules of their society, which benefits long-term social bonding. David Huron (2001)'s theory stems from Robin Dunbar's Grooming and Gossip Theory (1996): music may have been beneficial in bringing together large groups of people when other human behaviours have failed. There are many examples in history: indeed, music is integral to many large group activities related to religion, military and sexual rites (Roederer, 1984) and builds coherency between those involved. National anthems are an excellent example of this. Finally, Hagen and Byrant (2003) offered a hypothesis that music and dance were used as a coalition system for tribes to show their coherence and trust in one another.

Although these theories argue for music as an evolutionary adaptation, there are some strong arguments suggesting that music is non-adaptational, and merely an exaptation, or a pleasurable side effect of evolution (see Pinker, 1987; Fitch, 2000). However, regardless of whether music is an adaptation or not, researchers on both sides of the dispute agree that it seems to facilitate social bonding, giving support to further research in this field and to the use of music as an intervention in this study.

1.6 Evidence of Music as a Facilitator of Social Bonding

Empirical studies have examined the proclivity of music to assist in social bonding between humans. They have done so through synchrony, behaviour, hormonal measures and neural measures. During this section, I will briefly examine the literature demonstrating support for this suggestion.

1.6.1 Through Synchrony

Studies on synchronization to music have shown an increase in cooperation after a musical experience. For example, Wiltermuth and Heath (2009) found that after synchronized singing, adults worked more cooperatively in situations that required personal sacrifice. Demos, et al. (2011), in a study looking at synchrony in rocking chairs, found that even without perfect physical synchrony, music could act as a kind of "social glue" (p. 4). Although the presence of music actually interrupted the synchrony of the dyad, the use of music resulted in greater feelings of connection between partners, and showed that, "[t]he power of music to unite people may lie more in its ability to provide them with a common experience than in its ability to coordinate their movements" (p. 4). Consequently, music allows for bonding when full synchrony is not present (Tarr, Launay & Dunbar, 2014). This statement also relates to the study of synchronized singing by Wiltermuth and Heath (2009) and the Shared Affective Motion Experience (SAME) model of Overy and Molnar-Szakacs (2009), discussed later, which indicates that it is the feeling of being together in a shared experience that leads to cooperation.

1.6.2 Through Behaviour

Beyond bodily synchrony, Kirschner and Tomasello (2010) demonstrated that combined music making can increase prosociality in four-year-old children. Between a musical condition and non-musical condition, in which the authors attempted to keep every aspect identical except for the music, it was found that there was an increase in helpful behaviour in both genders after making music together. Furthermore, even if the children were not helpful, the ones in the musical condition gave more verbal excuses, showing greater empathy. In addition to assessing helpful behaviour, the authors also measured another game where the children could choose to solve a problem together or separately. They found the children in the musical group were more likely solve the problem together in comparison to the non-musical group. The periodic pulse of the music might have also influenced the results as music incites the synchrony of bodies, which has been shown to increase affiliation (Marsh et al., 2009, and Richardson et al., 2007).

1.6.3 Through Neural Measures

Overy and Molnar-Szakacs (2009) argue that music is a multisensory social activity that, one, always involves body movement (clapping, singing, etc.), two, occurs in groups, and three, involves synchronization in physical and mental means. In their paper, the authors discuss their model: Shared Affective Motion Experience (SAME), which suggests that humans not only perceive the auditory signal from music, but also “the intentional, hierarchically organized sequences of expressive motor acts behind the signal” (Overy & Molnar-Szakacs, 2009, p. 492). Expressive motor acts are based on the mirror neuron system (MNS) that activates during the performance and the observation of a task (Gallese, Fadiga, Fogassi, & Rizzolatti 1996; Rizzolatti & Fabbri-Destro, 2008), which could allow the sharing of a musical experience. The MNS has also been implicated in emotional synchronization: for example, neurological studies have shown the recruitment of the anterior insula when experiencing and observing pain. This dual activation indicates the overlapping of self and other, which might increase emotional empathy (de Waal, 2008), and lead to greater bonding.

1.6.4 Through Hormones

More recent studies have shown evidence for a hormonal basis of music and social bonding. Kreutz (2014) looked at the potential of oxytocin to help social cohesion during singing. The outcomes indicated that between chatting and singing, oxytocin was released while singing, but not while chatting. Therefore, group singing, through oxytocin release, may result in increased positive affiliation to other members of the group. Tarr et al. (2014) completed a review on music, social bonding and the endogenous opioid system (EOS). The EOS includes oxytocin, vasopressin, dopamine, serotonin and endorphins, and is recently being studied in greater detail with regards to social bonding as it can relate to non-sexual and non-kin relationships (Tarr et al., 2014). EOS has also been shown to increase an individual's pain threshold, to help better an individual's mood, to activate during entrainment (Blood & Zatorre, 2001), to be connected to pleasure in music and to be linked to musical chills (Goldstein, 1980). Although, hormone levels were not measured in this study, the ability of music to release these pleasure-related hormones provides support to the author's choice to use music as a social bonding intervention.

In summary, empirical studies investigating music, hormones, synchrony, neural processes and behaviour show support for a relationship between music and social bonding. Moving forward, the next section, will provide support for the musical interventions in this study.

1.7 Human Behaviour Support for the Creation of the Musical Interventions

Three musical interventions were created for the experiment: turn-taking, entrainment and solo. Since the solo condition was the control, it will not be discussed here. The interventions were created to be very similar with small differences between the participant experiences.

1.7.1 Turn-Taking

The phenomenon of turn-taking (*TT*) is important and based in fundamental human cognitive processes (Issartel, et al., 2017). Turn-taking is a regulated process that requires practice, which we learn from social interactions, such as in conversation, since infancy (Bloom, Russell, & Wassenberg, 1987). Successful turn-taking needs highly coordinated timing that may be thought to be caused by endogenous oscillators in the brain (Wilson & Wilson, 2005).

Since turn-taking is a natural human process, it is possible that turn-taking could be used to study human movement behaviour. Implementing an intervention with turn-taking could influence human movement behaviour which could be captured within the MG.

1.7.2 Entrainment

Entrainment (*E*) is another natural behaviour, and is "the process in which the rhythms displayed by two or more phenomena become synchronized" (Bluedorn, 2002, p. 149). Often, one rhythm is dominant and conquers the other, pulling it into true entrainment. However, contrary to first thought, the two entraining rhythms (pendulums, people, rocking chairs, etc.) do not have to match exactly, but rather have a "*consistent relationship*" (Bluedorn, 2001, p. 149). A consistent relationship means that their processes are related in some way. For example, the first rhythm taps every beat and the second taps once every third beat; this is not necessarily entrainment in its truest form, but rather a consistent relationship, showing these two rhythms are related. Previous studies examining entrainment between humans have demonstrated that better entrainment does lead to heightened feelings of bonding and togetherness (Demos, et al. 2011); however, entrainment that is too "perfect" or too tight is perceived as less positive than imperfect entrainment (Clayton, Will, & Sager, 2005). Music is a common and natural means by which to achieve imperfect entrainment that is enjoyable and beneficial for social bonding in humans. Since entrainment would lead people to a tendency to be more tightly in sync with each other, an intervention facilitating entrainment could have a synchronizing effect upon the MG. Moreover, Gueugnon et al. (2016a) showed that synchronization predicted more movement richness, so it is possible that the greater synchrony experienced in the entrainment condition could lead to greater creativity of movement.

1.8 Motion Capture

Motion capture is a means to record the movement of objects and people that is used in sports, movies, video games, the military, scientific and medical applications and research, and various other areas. It is most commonly known for its use in film, for example, *The Lord of the Rings: The Two Towers* (2002), for computer-generated characters like Gollum or the Orcs. In motion capture, the movements of a person are recorded in frames per second in the x-, y-, and z-axes, and this vector data is stored into a computer program, and can be analyzed and worked with at a later time.

The types of 3D motion capture systems fall under two main categories: optical and non-optical. The non-optical systems are inertial, mechanical and magnetic. Non-optical systems do not use cameras to record the movement. The inertial systems use sensors, such as gyroscopes and accelerometers, placed on the body (Scheffer & Cloete, 2012). The mechanical systems use a structure similar to an exoskeleton that estimates the angles of the joints (Bodenheimer, B., Rose, Rosenthal, & Pella, 1997). The magnetic systems measure changes in a magnetic field created by a transmitter (Norton, 2008). One benefit of these systems is that they do not require cameras and are therefore more mobile.

Optical systems use cameras that emit infrared light to triangulate the position and movement of a person wearing markers on their body. To triangulate the position of a marker, at least two cameras need to “see” the marker to gather to necessary x-, y-, and z-axes data (Kurihara, Hoshino, Yamane, & Nakamura, 2002). The markers are placed on the major joints or areas of interest on the body. Passive markers have a reflective coating that reflects the infrared light back to the cameras that then triangulates the positons of all the markers. Active markers emit their own light, which the cameras then use to triangulate the positions of the markers.

The system used in this study is an eight-camera Qualysis optical motion capture system with passive markers. The cameras record movement at 120 frames per second (Qualysis Oqus, https://www.qualisys.com/). The reflective markers were attached to suits that the participants are wearing. The markers’ movement trajectories are captured by the cameras, and recorded into a computer programme, Qualisys Track Manager, where the markers are then labeled to create a reconstruction of the body (Kurihara, Hoshino, Yamane, & Nakamura, 2002).

1.9 Instructions

The creation of the instructions for the participants was an important focus in the development of the study. In pilots, participants expressed confusion regarding the MG and how it was meant to be played, especially in the shared leadership condition. This indicated that the instructions given were not clear and consistent enough to acquire the understanding and response intended. During the formation of this study, the precise instructions were determined and then executed to great success. The confusion and misunderstanding of the participants was significantly less than seen in previous pilots and studies (Himberg et al., 2018). The only issues observed in the current study was language barriers for those with a lower level of English comprehension. Below is a normalized version of the explanation transcript.

> Next, we are going to build upon the *circle mirror game* (see Section 2.4.2.2). We can now move away from drawing only circles and explore. You can make any movement that you would like using only one arm. Like before, the arms need to be mirroring arms, so if one of you is using your right arm, the other must use his/her left arm. The structure will be the same as in the *circle mirror game*. You will lead (*indicates Person 1*) in the first game. Then you both will stop, switch the arms you are using if you want, and then in the second game, you will lead (*indicates Person 2*). I will tell you when you will change. Finally, you will stop again, and for the third game, both of you will create elegant, enjoyable movements together as a unit. Remember to think slow, elegant, smooth movements, rather than jerky and quick movements. Remember to maintain eye contact as much as possible and remember that there is no talking while playing the game. Do you have any questions?

1.10 The Current Study

The aim of this study was to examine how dyadic music performance could lead to enhanced social bonding and how that is measured by the mirror game. The study was a between-subject design where the participants took part in one of three musical interventions. The musical interventions were intended to induce social bonding (see Cross, 2001, Hagen & Byrant, 2003, Huron, 2001) that would then be measured in the MG. Three interventions were used: *entrainment, turn-taking* and *solo*. These interventions were intended to manipulate how the participants attuned to one another. Since joint action can be improved by learning bodily communication with a partner (Gueugnon, et al., 2016a) through time and practice, the solo condition was included to provide a base line of practice effects. The *experimental mirror game* was played before and after the musical intervention. The study investigated movement parameters (velocity, acceleration, jitter, etc.) of the MG to explore if these aspects could predict the participants' rating of how they felt in relation to their partner (via Inclusion of Other in Self scale). The hypotheses were as such:

1) The mirror game would display a measurable change between the pre- and post-intervention measures that indicated a relationship between the level of social bonding experienced by the players and the effects measured in the mirror game.

2) The mirror game would demonstrate an effect particular to the musical interventions:

    a. In the turn-taking condition, the participants would show a tendency towards the switching leadership strategy found in a previous study (Himberg et al., 2018).

    b. In the entrainment condition, the participants would demonstrate a heightened level of creativity and greater proclivity towards shared leadership.

    c. In the solo condition, only practice effects were expected. The dyads would increase in synchrony simply because they became familiar with the game, but no distinct pattern will emerge.

3) In the paired musical interventions (turn-taking and entrainment), higher correlations between the kinematic variables of the finger markers were expected in comparison to the solo condition.

As a sub-investigation, the study examined physical proximity as another possible measure for human social bonding. It was expected to find a correlation between the distance the participants chose to stand from each other and their ratings on the IOS.

2 METHODOLOGY

To test the hypothesis that the mirror game could predict the IOS response, a study was designed that used music as a social bonding intervention. Participants completed a questionnaire to determine their pairs, and then participated in the main study that consisted of six overarching sections: warm-up, pre-musical intervention mirror game, musical intervention, post-musical intervention mirror game, social bonding measures, and final measures and debrief. The procedure was created based on the results of two pilot studies. In this section, the procedure and materials will be explained.

2.1 Participants

Sixty-four participants were recruited (68.4% female, 29.8% male and 1.8% other via Facebook and mailing lists. The participants were aged between 19 and 36 (*M* = 25.4, *SD* = 3.91). The majority of the participants were international students of the University of Jyväskylä, Finland. Dyads were the same or mixed gender; this was not important to the study and thus not controlled. Participants reported their musical expertise (45.6% non-musicians, 31.6% amateur, 19.3 semi-professional, and 3.5% professional), and were placed with another participant of equal musical standing. As compensation, participants were given home-baked goods and a free movie ticket. All participants gave informed consent (see Appendix 2) and were unaware of the purpose of the study during the experiment. The participants were debriefed after the study was completed and agreed that their data be used. During, they wore a motion capture jacket and hat with reflective markers attached. The participants were from a convenience sample, and thus generalizations could be an issue.

2.2 Apparatus

An eight-camera Qualisys Motion Capture System (Qualysis Oqus, https://www.qualisys.com/) was used to capture body movements. Twenty reflective markers were attached to the participants, and the cameras recorded their movements at a rate of 120 fps. Four Black Magic video cameras were used to record the sessions in addition to the motion capture system. Protools (Version 11.03, Avid Technology, 2018) recorded the audio of the experiment and Max/MSP (Version 7.3.2, Cycling 74'/IRCAM, 2017) was used to record the basic rhythmic skills of each participant. The motion capture data was exported into MATLAB (2016b, The Mathworks, Inc., Natick, MA, USA) with the MoCap toolbox (Toiviainen & Burger, 2003). Analysis of the movements was performed in MATLAB (www.mathworks.com).

2.3 Procedure

2.3.1 Recruitment and Pairing of Participants

The study required a specific organization of the pairs due to the intended measurement of social bonding. The participants, were initially sent a questionnaire to complete, which consisted of demographic and musical background questions (see Appendix 1), the Big Five Index (John & Srivastava, 1999) and the Interpersonal Reactivity Index (Davis, 1980). Based on the questionnaires, pairs were created based upon three criteria: i) both participants shared a similar musical background, ii) that they did not know each other, and iii) that they were available at the same time. For example, a semi-professional musician would only be paired with another semi-professional musician. If a non-musician was paired with a semi-professional musician, this disparity in skill could create a power difference, potentially causing the non-musician to feel inadequate, leading to displeasure, and thus interrupting the bonding that is meant to occur. These requirements were followed as closely as possible. The author attempted to ensure the pairs did not know each other, however, on occasion the participants had some previous level of familiarity. The potential for familiarity was unavoidable due to the small size of the university and the international community of city of Jyväskylä. The familiarity was assessed through a simple Likert scale in the post-questionnaire in which the participants were asked: “How well did you know the other participant? (1 = not at all; 5 = we’re best friends)”.

2.3.2 Warm-Up

The purpose of the initial warm-up was to allow the participants to become comfortable with the space and the motion capture suits. The warm-up consisted of two parts: *Movement and Imagination Task* and the *Introduction to the Concept of Mirroring* (see *warm-up* in Figure 1).

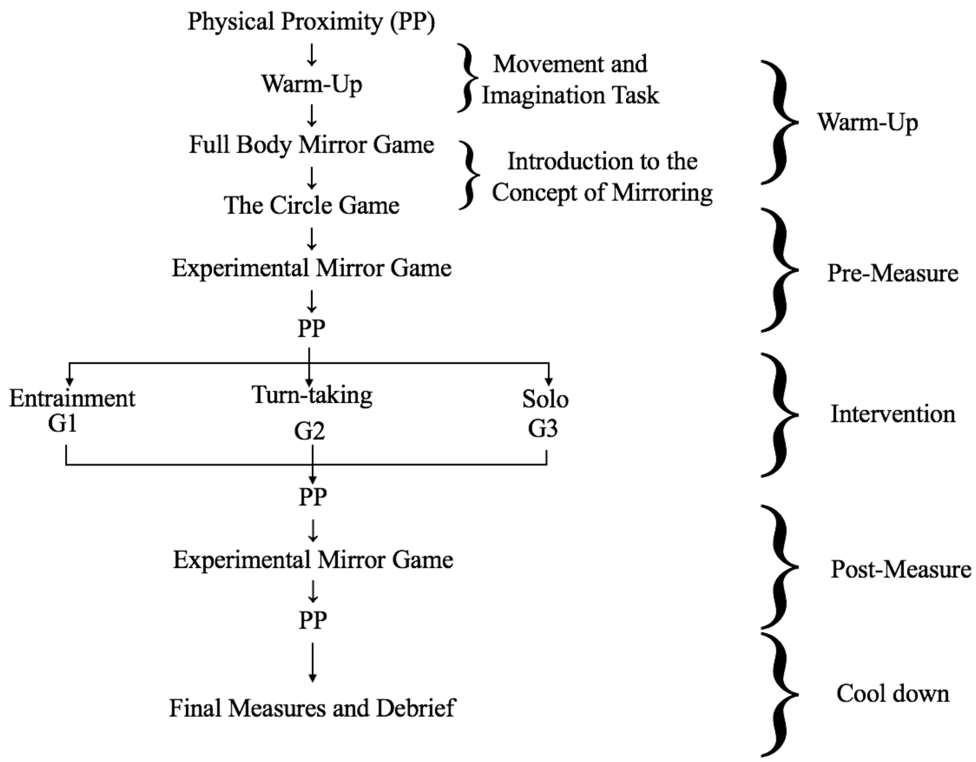


FIGURE 1. Overview of experiment procedure. Group 1 (G1) only completed the Entrainment condition, Group 2 (G2) only completed the Turn-Taking condition, and Group 3 (G3) only completed the Solo condition.

2.3.2.1. Movement and Imagination Task

The *Movement and Imagination Task* consisted of moving around the motion capture space, tossing the ball between the pair and the author. During this time, the author asked two questions. The first was, “Can you come up with a new toy for a five-year-old child?”, and the second was, “What are all the things you can do with a coat hanger that isn’t hanging clothes?”. The questions were intended to provoke out-of-the-box thinking, ideally to help the participants regard the upcoming experience with an open mind. A high degree of openness in the participants was important to this study because the author wanted the participants to explore in both the MGs and the musical interventions. Therefore, the inclusion of a warm-up that could stimulate out-of-the-box thinking might be beneficial in solving this lack of understanding.

2.3.2.2. Introduction to the Concept of Mirroring

The next section was the introduction to the concept of mirroring. This part of the warm-up consisted of three sections: the *full body mirror game*, *the circle mirror game* and *the static pose*. All of these were meant to increase the participants’ comfortability with the experience of mirroring. Throughout all mirroring games the participants were asked to maintain eye contact as much as possible. Some participants expressed an awkwardness in maintaining eye contact, but they often said that the eye contact led to a greater feeling of connection with their partner. The author did remind dyads to maintain eye contact whenever she noticed they were focused on the moving body part.

Full Body Mirror Game. The participants were asked to mirror each other’s full body movements for 30 seconds. They did this by standing face-to-face, pretending that the other person was a full-length mirror. Playing the *full body mirror game* gave the participants an opportunity to experience the feeling of mirroring another person in a more natural way, potentially simulating dancing.

The Circle Game. The participants were then asked to mirror circles. They stood, face-to-face, and drew circles in the air in front of them with one arm. They could choose the arm, as long as the arms were on the same side (one using his/her left arm, the other using his/her right arm and vice versa). The size and shape of the circles drawn remained the same, but the speed could change. In *the circle mirror game*, there were two conditions: leader-follower (*LF*) and shared leadership (*SH*). In LF, each person led for 30 seconds. In *SH*, played for 1 minute, there was no designated leader, and the pair was instructed to “create the circles together”.

The Static Pose. The final part of the warm-up was a static pose. The participants were asked to point at each other in the mirror game pose (Figure 2) and maintain eye contact for 30 seconds. Since eye contact has been shown to have a relationship with connection and affiliation (Knapp & Hall, 2010), asking the participants to focus solely on maintaining eye contact might lead to a greater awareness and liking of each other. This completed the warm-up.

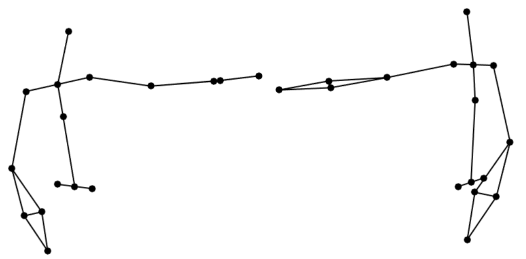


FIGURE 2. The mirror game pose.

2.3.2.3. The Experimental Mirror Game

The main focus of the study was to examine the experimental mirror game, and thus the process of the warm-up led to the playing of the experimental mirror game. The version of the game was taken from Himberg (2016) and Himberg, et al. (2018). The pair stood face-to-face, and used "mirroring" arms (one participant used his/her right arm and the other used his/her left arm, and vice versa). The participants were once again asked to maintain eye contact. They were instructed to "make enjoyable movements together as a unit". Two conditions were used: *LF* (1 minute each) and *SH* (2 minutes). The game was also repeated after the musical intervention. See *pre-measure* and *post-measure* in Figure 1.

2.3.3 Musical Interventions

This study was a between-subject design; therefore, the participants took part in one of three musical interventions, see *interventions* in Figure 1. All interventions used pentatonic xylophones as the musical instrument. The author chose the pentatonic scale because, regardless of what the participants played, the music would still sound "good" or "harmonious" as there would be no "wrong" notes due to the lack of dissonant harmonies. Since many of the participants were non-musicians, the author believed that this would encourage them to continue playing. This assumption was correct from the responses of the non-musicians, however, a number of the musicians commented that they would have preferred the ability to have more dissonant sounds.

In all of the interventions, the author encouraged the participants to explore many different musical parameters: dynamics, rhythms, tempo, timbre, etc. These were explained in terms understandable to a non-musician. The author also encouraged the participants to explore away from the traditional uses of the instrument and use the wood, the metal parts, the table and their hands to make music rather than being constrained to the mallet and keys. While the participants played, the author suggested changes in musical parameters if she felt that the participants lacked exploration.

Condition 1: Entrainment (E). The first intervention was based upon synchronous playing. Hart et al. (2014), looking at the specific movement of togetherness in improvised dancing, found that a high level of togetherness was related to smooth and symmetric movement properties. A higher degree of smoothness is a result that we expected to see from this entrainment-based musical intervention.

In the study, participants stood across from each other at a xylophone. The author explained that they were to play a duet together. Both were given a simple starting rhythm that interlocked with each other (Figure 3). The rhythms were intended to give participants a starting point from which to explore. At the end of the duet, the author told the participants to "find an end to their piece".

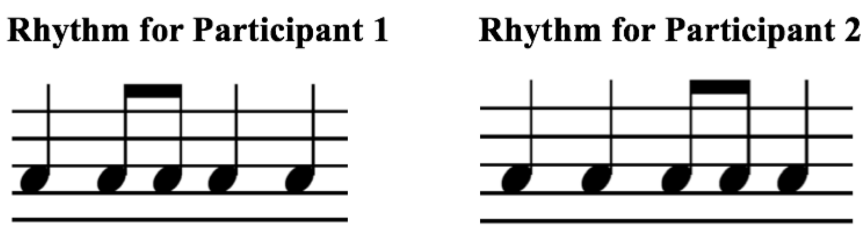


FIGURE 3. Rhythms introduced to the participants to facilitate improvising.

Condition 2: Turn-Taking. The second intervention was based upon turn-taking (*TT*). However, in this study, it was hypothesized that engaging in a musical turn-taking intervention would lead to a tendency of using a strategy of switching leadership to maintain the shared leadership MG. In addition, the author hypothesized *TT* would lead to a more regular or rhythmic-based approach to leader switching because the musical intervention is a rhythmic exercise.

In this task, the author referred back to the questions in the warm-up. This musical task emulated a conversation, where the participants took turns to "speak". In music, the conversation proceeded as a normal spoken conversation would: one person played a musical "sentence" and the other responded with another musical "sentence". They continued like this: making comments, posing questions or arguing through music. The participants played for approximately five minutes, until the author told the participants to "find an end to their conversation".

Condition 3: Solo. The final intervention, solo (*S*), acted as the control condition. The task was completed solo, while the other participant waited in the hall. Each participant was asked to improvise a soundtrack to a five-minute Buster Keaton silent movie scene (Classics, 2017). They were told what the premise of the scene was and allowed to become acquainted with the instrument before starting the condition.

2.3.4 Social Bonding Measures

The study used two measures of social bonding. First, in the debrief questionnaire, the participants filled out the Inclusion of Other in Self Scale (IOS; Aron, Aron, & Smollan, 1992) to assess their bonding, see Figure 4. The IOS includes seven images with circles of varying levels of overlap that indicate how close the participant feels to their partner. The second, and novel, measure of social bonding was based on *physical proximity* (*PP*). To ensure that the participants would not guess the motives of the study, the author explained that the motion capture system needed to be calibrated in order to check the occlusion of markers. This measurement occurred four times throughout: at the beginning, after the first experimental mirror game, after the musical intervention and after the second experimental mirror game, see Figure 1. In the measurement, the author asked the participants to stand side by side, then move closer, while measuring their movement with motion capture, see Figure 5. Since physical comfortability is a trait of intimacy (Knapp & Hall, 2010), it is possible the more comfortable they felt, the closer they would stand, without noticing the change themselves. Furthering this, because this measure is exploratory, it is unknown in what stage the change in *PP* could measure their level of social bonding. For example, the important change might be in how close they stood initially or in how close they moved together once asked to do so.

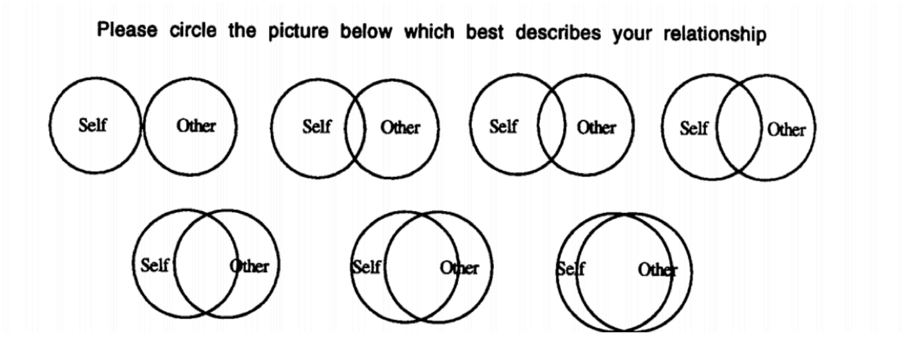


FIGURE 4. The Inclusion of Other in Self Scale used in the post-experiment debrief questionnaire.

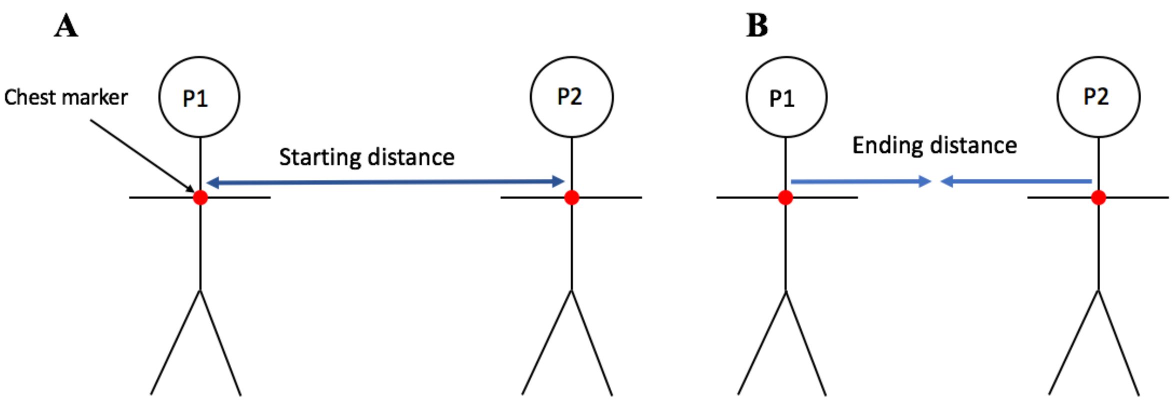


FIGURE 5. Physical Proximity measure of social bonding. The distance was measured by calculating the total distance between the chest markers of each participant. a) How far apart the participants are at the start of the measure. b) How far apart the participants are at the end of the measure.

2.3.5 Final Measures and Debrief

Finally, the participants repeated the *experimental mirror game*, exactly as before, see *post-measure*, Figure 1. The participants then did a short continuation-synchronization task to assess their basic rhythmic skills, and filled out a short debrief questionnaire (see Appendix 3). The questionnaire included the IOS and questions regarding their impressions of the musical interventions and the mirror game. Finally, the author asked a few short questions to gain insight about their feelings regarding the pre-intervention mirror game in comparison to the post-intervention mirror game, see *cool down*, Figure 1.

2.4 Data Analysis

The motion capture data was labelled in Qualysis Track Manager; each marker represented a specific body part and was labelled accordingly. The data was then exported to tab-separated value (tsv) files as time series data that represented the motion of each marker. The data was preprocessed in preparation for analysis in Matlab. The analysis was performed using the MoCap Toolbox (Toivainen & Burger, 2010). One of the dyads was removed due to data failure, leaving a data set of thirty dyads. Ten dyads completed TT, eleven dyads completed E and nine dyads completed S.

The *experimental mirror game* and the *physical proximity* measure were analyzed with more depth as these were the main focus of the study. First, these files were trimmed to create separate files for the *LF* games and the *SH* games. The *physical proximity* files were trimmed so the participants were at their farthest distance at the start of the file and at their closest distance at the end of the file. For most of the analysis, the finger marker of the hand used in the mirror game was analyzed. The marker was selected based on a function that found the cumulative distance of both finger markers, and then selected the marker that moved the most. Since this study was exploratory many measures were investigated in order to achieve a broader view of what the MG could possibly show.

The analysis of the *experimental mirror games* focused only on the *SH* games. The analysis centred around five movement parameters: quantity of motion, complexity of motion, velocity, acceleration and smoothness/jitter.

2.4.1 Kinematic Measures

Norming: In all of the analyses, the data was first normed and the finger markers were measured. Norming is a process by which the absolute distance is taken from each data point in the 3D space to the origin (0,0,0). By this method, the three columns of data (x, y, z-axis) are normed into one column of data: the distance from the origin. The structure remains identical to the motion capture structure.

Velocity: First derivative of a change in action. The difference in velocity between pre-intervention MG velocity and post-intervention MG velocity was plotted by condition. The same was done with average velocity. Since the data rejected the assumption of normality, kurtosis and homogeneity, a Kruskal-Wallis test was run to compare the change in velocity from pre- to post-intervention MG per condition. A cross-correlation and windowed cross-correlation was also completed with velocity data; this is explained below in section 2.5.3 and 2.5.4. See Figure 6a for an example.

Acceleration: Second derivative of a change in action. The same process as was done with velocity was completed with acceleration. A cross-correlation was also calculated on the acceleration between the dyads in each condition. See Figure 6b for an example.

Jerk: Third derivative of a change in action. The same process as was done with velocity and with acceleration was completed with jerk. No cross-correlation was completed with jerk. See Figure 6c for an example.

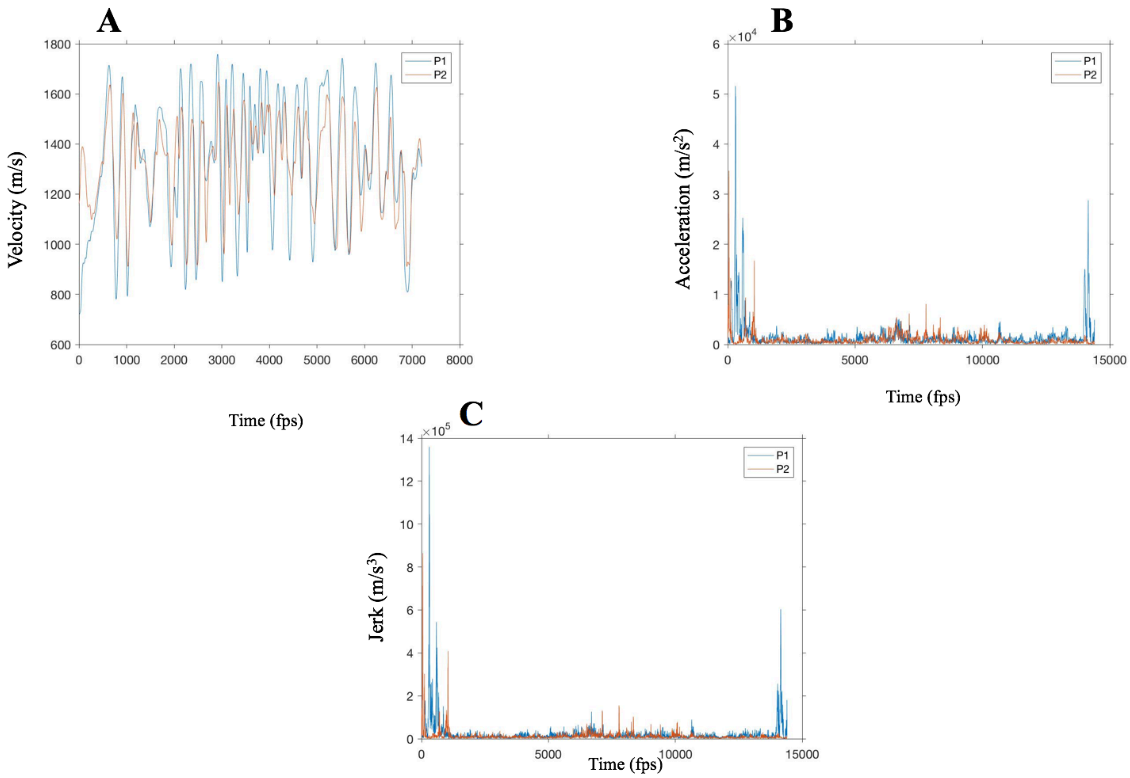


FIGURE 6. Examples of velocity, acceleration and jerk.

2.4.2 Quantity of Motion

The quantity of motion was calculated as another parameter to measure the effects of the musical intervention. The cumulative distance of the two finger markers were calculated and then the maximum distance of each dyad per condition was selected and plotted.

2.4.3 Complexity of Motion

A preliminary measure of complexity was calculated. Complexity was defined as a measure of velocity: the combined velocity of both finger markers. When there was greater velocity, this suggested that there was a higher likelihood the participants moved more and were using potentially more complex movements. There are many limitations to this conceptualization, such as the slowness of the movement and amount of jitter, however as a preliminary measure the use of total velocity was decided as acceptable. The overall average velocity of the finger markers and the average velocity of the finger markers per condition were also calculated.

2.4.4 Smoothness/Jitter

Jitter is defined as an oscillation of 2-3 Hz around followed movement (Noy, Dekel & Alon, 2011). For example, when one participant leads and the other follows, the leader will have little jitter because they know where the motion will go, however the follower does not have this knowledge, and thus will have to make small corrective movements as the leader changes directions or speed. See Figure 7. The average jitter of the pre-intervention MG and the post-intervention MG was calculated, plotted (see Figure 8), and compared through a dependent t-test. The change in average jitter from the pre- to post-intervention MG was calculated and compared in the same way. Jitter and smoothness are related as the greater the smoothness of a movement, the less jitter will be calculated. Dyads with low amounts of jitter, therefore, had overall smoother movements than dyads with higher amount of jitter.

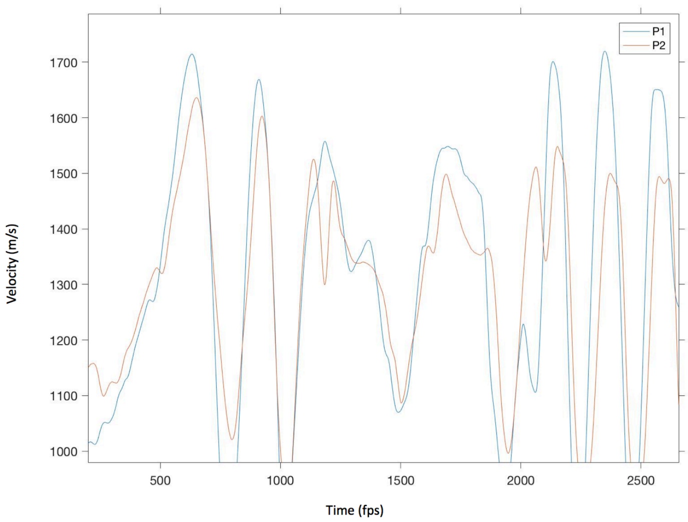


FIGURE 7. The orange line is the leader (P1) and the blue line is the follower (P2). As can be seen the leader's motions are much smoother than the follower. The follower displays characteristic correction movements that are identified as jitter.

\

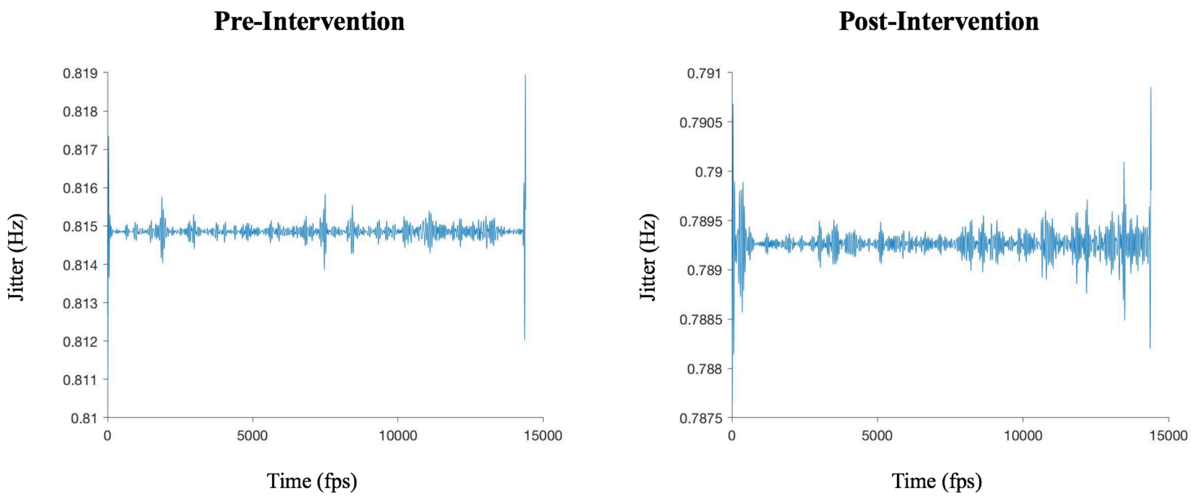


FIGURE 8. Dyad 14 (*E*). An example of pre-intervention and post-intervention jitter plots.

2.4.5 Cross Correlation

Cross-correlation is a measurement used to compare two signals. Simple correlation compares two signals exactly as they are in time; however, a cross-correlation adds in the dimension of time and finds where the two signals are most correlated by sliding one signal across the other. Two signals could have a low correlation at lag 0, but could be highly correlated at lag 30, meaning that the one signal was merely behind the other. A maximum lag is set in order to ensure the association is not too distant and thus potentially spurious. Once the cross-correlations were calculated, a Kruskal-Wallis test was run to compare the correlations, split by condition. The same was done with the lags. To compare the pre-intervention MG cross-correlations and lags with the post-intervention MG cross-correlations and lags in each condition, a Wilcoxon signed rank test (Wilcoxon, 1945) was run, since the data rejected the assumption of normality, kurtosis and homogeneity. See Figure 9.

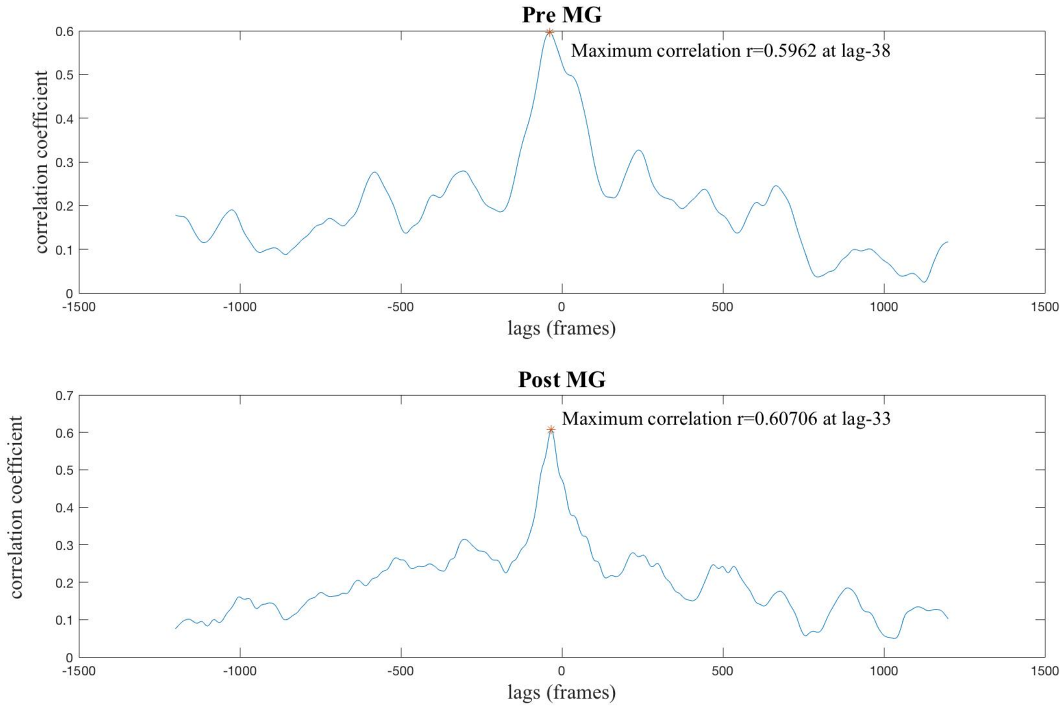


FIGURE 9. An example of cross-correlation plot.

2.4.6 Windowed Cross-Correlation

Windowed cross-correlation (WCC) is running a cross-correlation within a window. The window is the number of observations (in this case number of frames) chosen from each time series being measured (Boker, Rotondo, Xu, & King, 2002). WCC is a measurement used when it is suspected that the relationship between the measured variables may not be stationary (Boker et al., 2002), such as in the MG. WCC was used to observe if there was any association over the course of the MGs that could not be observed in the global score found in the cross-correlation of velocity. Taking an overall cross-correlation will provide a general view of the association, but a WCC will show how the relationship developed over time. For example, if the pair switched leadership, this can be seen in the plot of WCC along with the strength of the correlation at each window.

In each window, the signals were slid over each other to find the peak correlation and the lag at which that happened. The hop factor is the number of observations or time elapsed between the resulting correlations (Boker et al., 2002); it is the distance the window moves before another cross-correlation is calculated. Another aspect that is chosen in completing a WCC is the maximum lag. The max lag is the longest amount of time between the behaviours being compared (Boker et al., 2002). For example, a max lag of 10 seconds in motion capture data of this kind would not indicate anything but a spurious relationship between the behaviours and likely indicate that the behaviour was repeated rather than mirrored. A window length of 480, a hop factor of 20 and a max lag of 240 (two seconds) was chosen based upon previous literature using motion capture data (Himberg, 2016). See Figure 10.

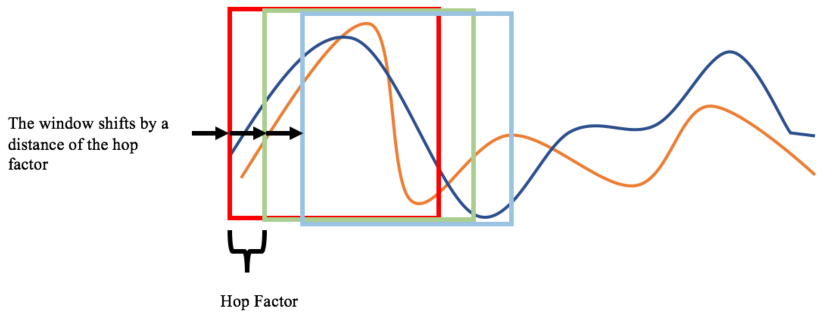


FIGURE 10. Windowed cross-correlation. The window is the number of observations within the cross-correlation. The hop factor decides how far the window steps before calculating another cross-correlation.

Leader Changes: Switching leadership is one of the strategies used to maintain the shared leadership mirror game. To obtain an understanding of how the participants maintained the *SH* MG, another calculation was completed to investigate how often the leadership changed between participants.

On the windowed cross-correlation plot, the maximum lag per window was plotted, which created a line to show which person lead in that window: a positive lag meant participant 1 lead and a negative lag meant participant 2 lead. This was plotted as a red line on the windowed cross-correlation plot (See Figure 11). Since small changes around the zero line are possible, a threshold was determined to discretize the value of the lag. The threshold was set to 20 frames, which meant that any lag time that was above +20 frames became a +1, any lag below -20 frames became a -1, and any lag between +20 and -20 frames became a 0. In this way, leader change line was plotted as a blue line on the windowed cross-correlation plot A zero line as a black line was plotted as a reference (See Figure 11).

Changes in leadership were plotted as any slight change of valence in lag, which meant that the “turn” could be only a few frames or milliseconds, which was determined to be too short to be a true change of leadership. A second threshold was added to restrict how long the leader changes could be. The process was run three times with the lowest thresholds set at two, four and eight seconds. The average number of switches was taken for each of these time thresholds.

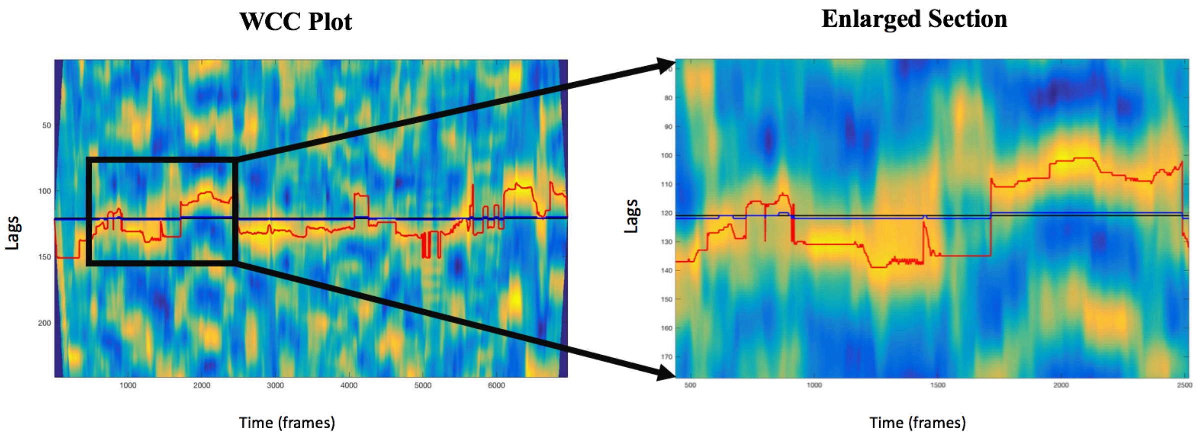


FIGURE 11. Dyad 10, *TT*. Example of the plots determining leader switches. The red line traces the max correlation per window. The black line is the zero line. The blue line traces the leader switches.

2.4.7 Physical Proximity

To investigate the novel measure of social bonding through *PP*, the chest markers were selected because they were along the centre of the body, and thus were likely to give an accurate measure of distance between the participants. The total distance each chest marker moved within the four *PP* measures per dyad was calculated. Based upon the idea that people who do not know each other would stand farther apart than people who do know each other, the starting distance of *PP1* and the ending distance of *PP4* were chosen as a plausible measure of social bonding. The difference in distance between chest markers were taken at start *PP1* and end *PP4*.

A second distance comparison occurred between start of *PP1* and start of *PP4* because the proximity change may have occurred in how close the participants chose to stand at the beginning and each *PP* measure. Therefore, the distance between chest markers was taken at start *PP1* and start *PP4*.

Both of these measures were plotted by condition in order to observe any possible patterns in the changes between conditions. A dependent t-test was run on the change in distance. A correlation was also run to compare the change of distance with the IOS scale.

2.4.8 Debrief Questionnaire and Post-Experiment Interviews

Both the debrief questionnaire and post-experiment interviews were analyzed through a data-based approach. The author digitized the questionnaires and transcribed the interviews. Initially, the author read through the qualitative data and created codes based upon trends observed. The author did another coding after two weeks had passed in order to provide a new perspective on the data. Finally, a second rater was recruited. The second rater was given the codes and proceeded to code the questionnaires and interviews. These results were reviewed by the author and are presented below. The author is aware that recruiting more raters would have increased the validity of the coding, however, due to time and resource restriction, only one was enlisted.

3 RESULTS

3.1 General observations

3.1.1 Overall Experiment

In both the *TT* and *E* conditions, the participants expressed having an overall better and more stimulating experience. They communicated that they had "a lot of fun" and enjoyed their participation. The *TT* and E condition participants seemed to interact better and more openly, and would more readily offer their opinion of the experiment. In contrast, the participants in the *S* condition showed a lower level of connection from the view of the author, corroborated with the interviews and questionnaires discussed below. In the *S* condition, participants would enter excited, and leave significantly less energetic and less excited. This did not happen within the other two conditions. These observations are consistent with the post-experiment debrief questionnaire.

The analysis of the motion capture data yielded somewhat confusing and contrasting results, but also some general patterns demonstrating that musical interventions do have some measureable effect upon the MG. These results can be investigated further in future studies.

First, the results from the motion capture data will be discussed, followed by the qualitative data from the interviews and questionnaires.

3.2 Kinematic Measures

3.2.1 Velocity

Observations: Velocity and average velocity (see Figure 12a) were plotted. Overall, the average velocity decreased in TT and E, but increased in S. No significance was found.

3.2.2 Acceleration

Observations: Average acceleration (per dyad, split by condition) of the pre-intervention and post-intervention MG were plotted. Seventy percent of *TT* dyads, thirty-six percent of *E* dyads increased in acceleration and forty-four percent of *S* dyads increased in acceleration. Overall average acceleration of each condition showed an increase in acceleration in *TT* and *S* a decreased in *E*. See Figure 12b. No significance was found.

Cross-Correlation of Acceleration: The maximum cross-correlation and minimum lag were calculated and split by condition: 45% of *E* decreased in lag and 63% increased in correlation, 70% of *TT* decreased in lag and 70% increased in correlation, and 77% of *S* decreased in lag and 66% of *S* increased in correlation. See Figure 9 for an example of a cross-correlation plot.

3.2.3 Jerk

Observations: Average jerk of the pre-intervention and post-intervention MG plotted in each dyad by condition. Seventy percent of *TT* dyads, twenty-seven percent of *E* dyads, and thirty-three percent of *S* dyads increased in jerk. Overall average jerk of each condition showed an increase in jerk in *TT* and a decrease in *E* and *S*. No significance was found from pre- to post intervention or between conditions. See Figure 12c.

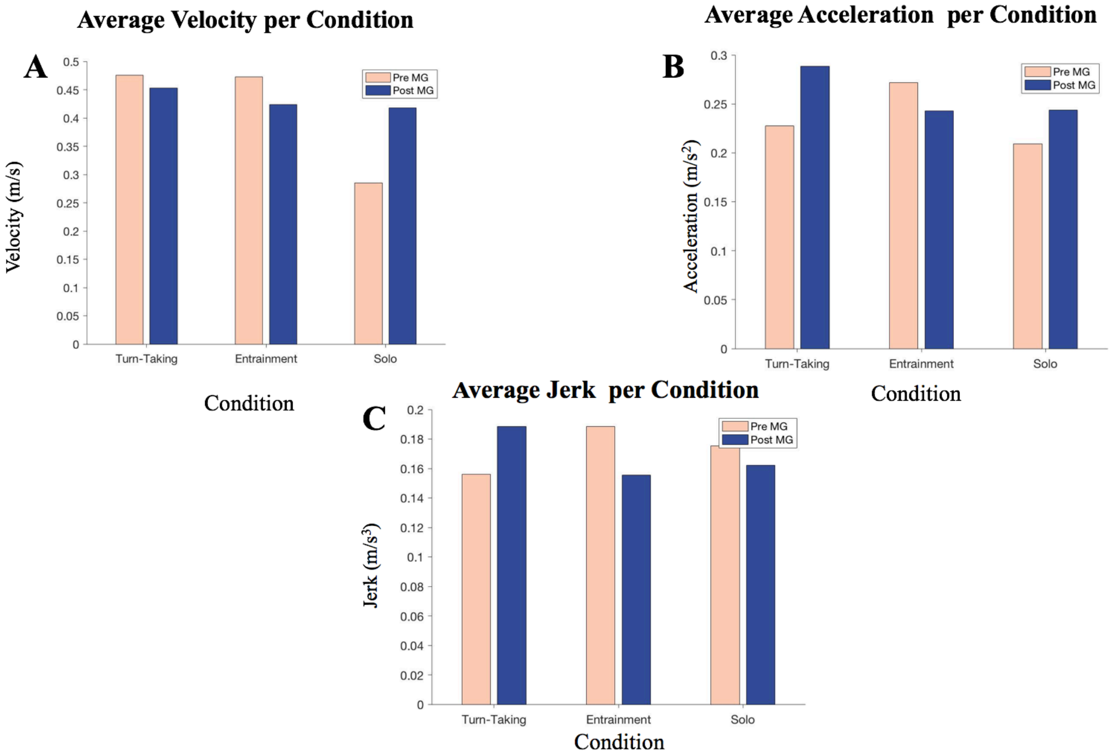


FIGURE 12. a) average velocity per condition; b) average acceleration per condition; c) average jerk per condition

3.2.4 Quantity of Motion (QOM)

In *TT*, sixty percent of dyads increased in QOM in the post-intervention MG. In *E*, fifty-four percent of dyads increase in QOM in the post-intervention MG. In *S*, forty-four percent of dyads increased in QOM. Average QOM of the fingers showed that *TT* had the greatest amount of movement, followed by *E* and then *S*. *TT* decreased slightly in QOM from pre-intervention MG to post-intervention MG. *E* and *S* increased slightly in QOM from pre-intervention to post-intervention MG. See Figure 13.

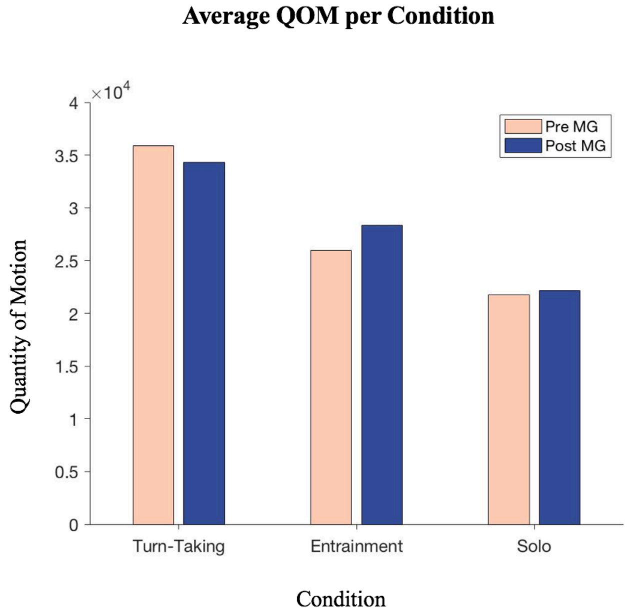


FIGURE 13. Average Quantity of Motion per condition.

3.2.5 Complexity

Overall complexity of motion (overall average velocity) showed a slight non-significant increase from the pre-intervention to post-intervention MG. Complexity of movement per condition displayed a general increase from pre-intervention and post-intervention MG in all conditions, but *TT* had overall a higher complexity score than *E* or *S*.

3.2.6 Jitter

Observations: Amount of jitter per dyad split into condition was calculated and plotted. Forty percent of *TT*, forty-five percent of *E*, and thirty-three percent of *S* dyads decreased in jitter from pre-intervention to post-intervention MG, see Figure 14. Overall average amount of jitter of each condition showed a decrease in jitter in *TT* and *S*, but an increase in *E*. No significance was found between pre- to post or between conditions. The difference between amount of jitter from pre-intervention to post-intervention MG was calculated and plotted. This showed that in *TT* and *E*, there were greater changes in amount of jitter than there was in *S*. The *E* condition showed the smallest amount of overall jitter in post-intervention game, even though jitter increased from pre-intervention to post-intervention MG.

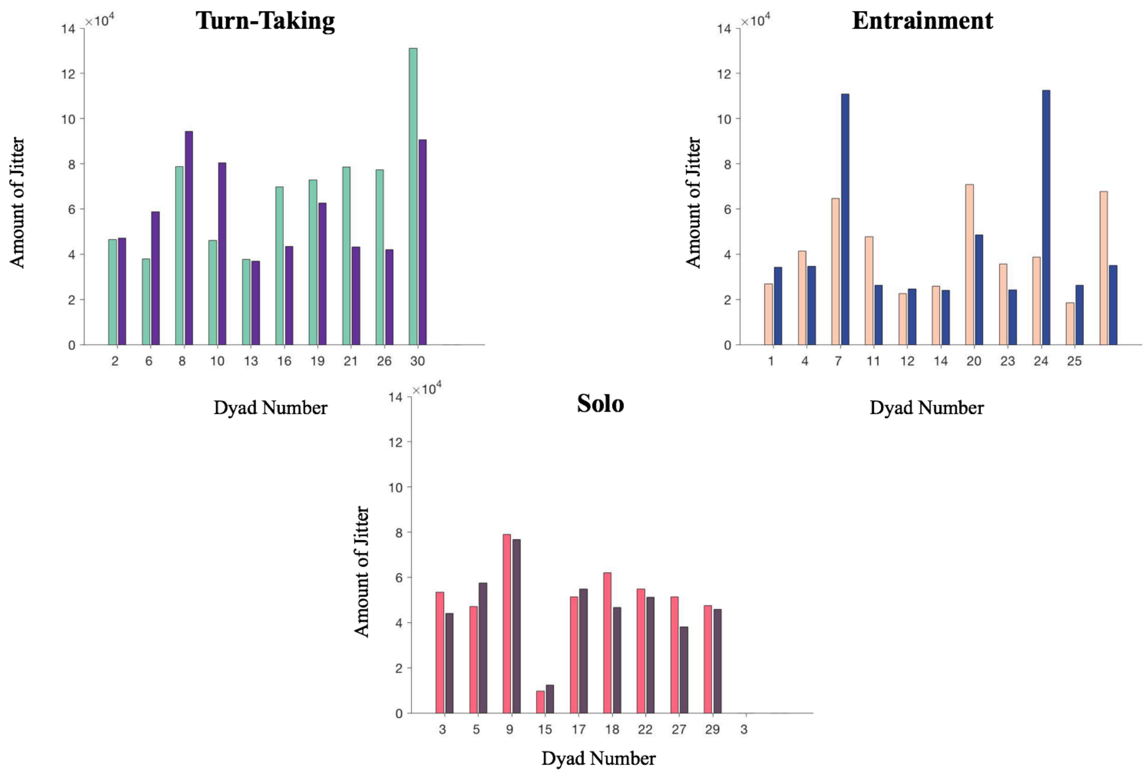


FIGURE 14. A comparison between the amount of jitter per dyad between pre-intervention and post-intervention, split by condition.

3.2.7 Jitter and IOS scores

Correlations were run on average jitter and average IOS scores, see Table 2. For all conditions, the correlations increased towards positive correlation. The only significant result was found in the post-intervention *TT* condition ($r = .66$, $p = 0.04$).

Table 2. The correlational relationship between jitter and IOS by condition.

	Turn-Taking		**Entrainment**		**Solo**	
	Pre	Post	Pre	Post	Pre	Post
***r*-value**	-.20	.66*	-.43	.01	.37	.39

Note: * $p = < .05$.

3.2.8 IOS and Physical Proximity

The exploratory measure of physical proximity as a measure of social bonding was not successful. A number of correlations were run between a variety of possible changes in proximity and the IOS scale. First, the difference between the starting distance of the first measure and the starting distance of the last measure was examined. Second, the difference between the starting distance of the first measure and the ending distance of the last measure was examined. Neither of these correlated significantly with the answers of the IOS scale in the debrief questionnaire.

3.2.9 Cross-Correlation of Velocity:

The maximum cross-correlation and minimum lag were calculated and split by condition: 45% of *E* decreased in lag and increased in correlation, 50% of *TT* decreased in lag and 60% increased in correlation, and 100% of *S* decreased in lag and 88% increased in correlation. See Figure 15 for an example of cross-correlation. The maximum cross-correlation by minimum lag of velocity of each condition was plotted on a scatter plot, see Figure 16. The *TT* condition showed a general decrease in correlation and a slight increase in lag, but the correlations stay close around the 0-lag line. The *E* condition displayed an overall decrease in correlation and general maintenance of the lag length, minus one outlier, Dyad 11. Finally, the *S* condition, although there was a general increase in correlation and decrease in lag. However, in *S*, there was a higher variability in both pre-intervention and post-intervention MGs than in both the *TT* and *E*.

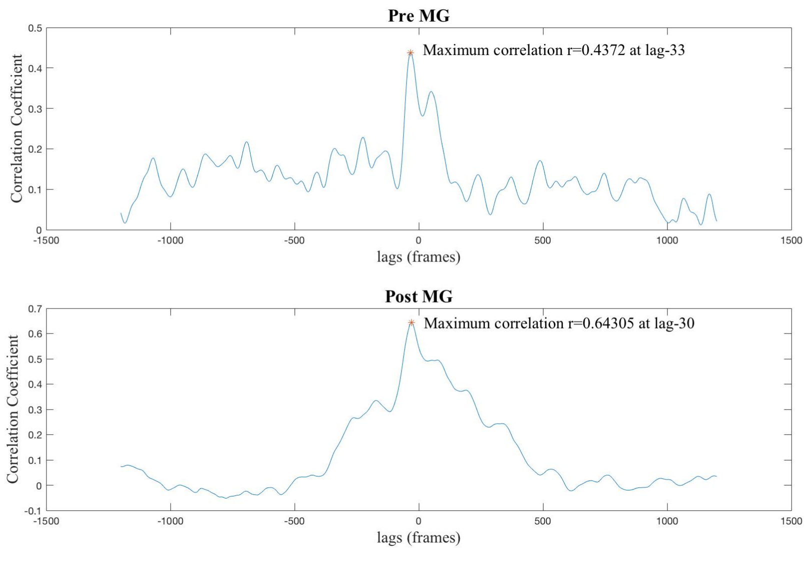


FIGURE 15. Dyad 21 (TT). An example of cross-correlation of velocity.

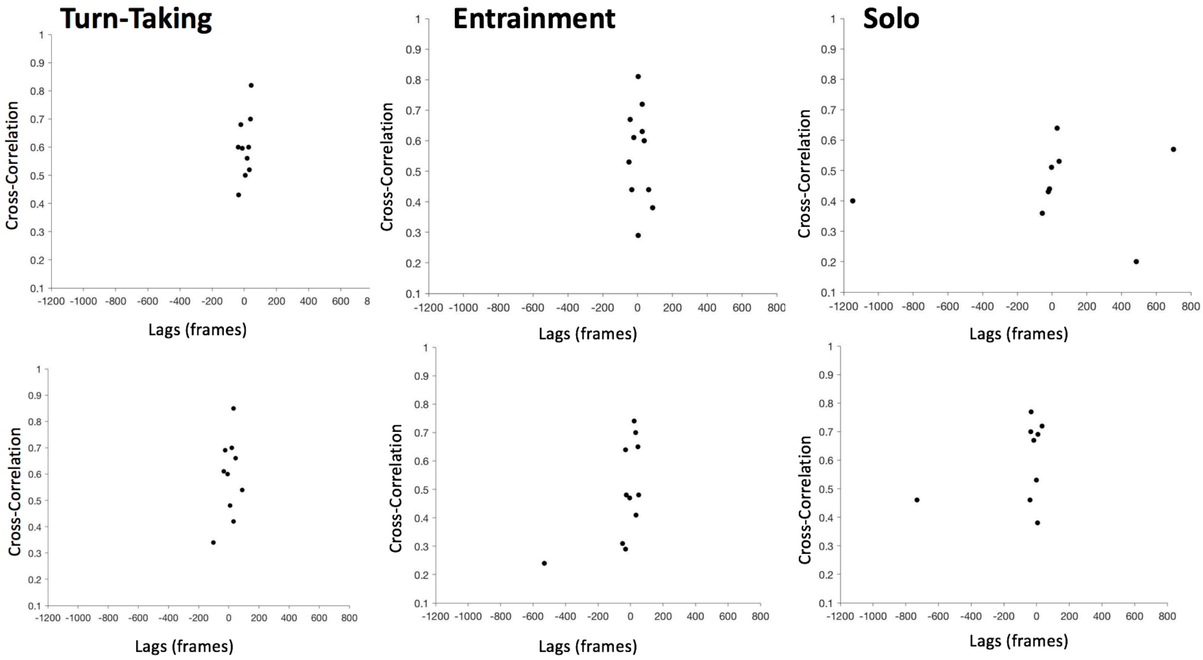


FIGURE 16. Scatter plots showing maximum correlation by minimum lag per dyad, separated by condition.

Average Cross-Correlation of Velocity: The overall average cross-correlation lag-by-lag was taken for each condition. *TT* showed little to no change between pre-intervention to post intervention MG. *E* showed an overall slight decrease in correlation, but a smoothing of the peak. *S* showed a large increase in correlation. See Figure 17.

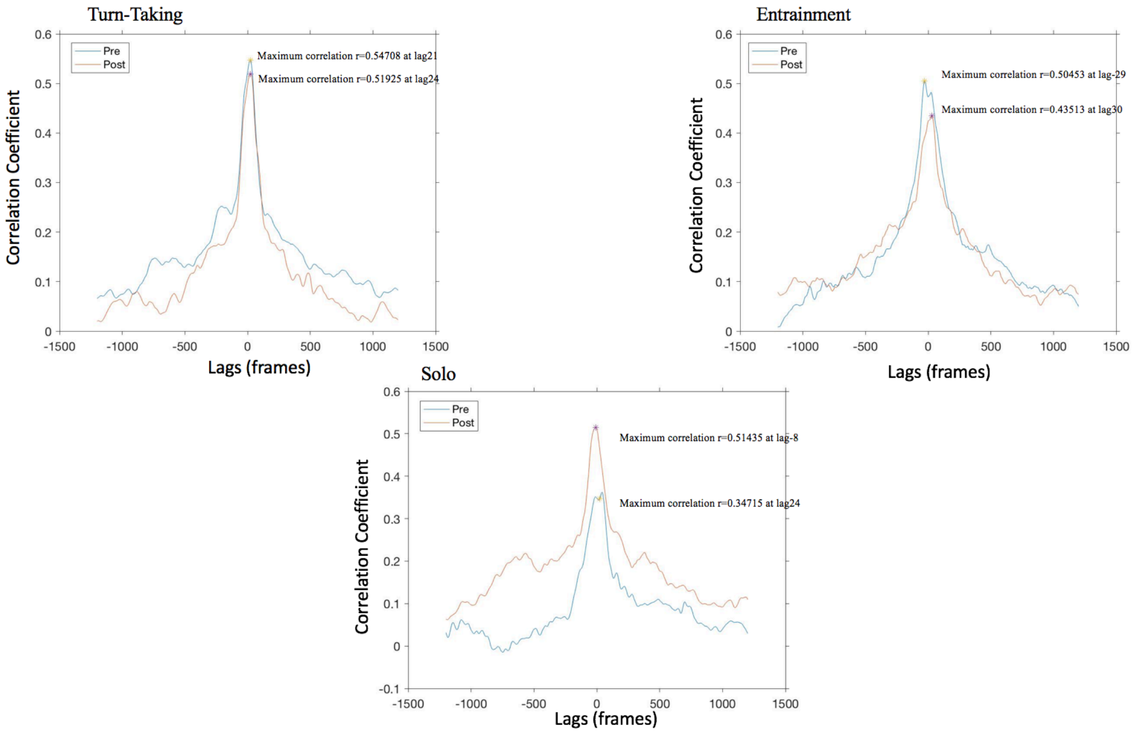


FIGURE 17. Average cross-correlation of velocity. Both *TT* and *E* decreased in correlation, whereas S increased in correlation.

3.2.10 Windowed Cross-Correlation of Velocity:

The windowed cross-correlation plots are plots of correlation. In these plots, lag is on the y-axis, time is on the x-axis, and correlation is shown by the colour: high correlation is yellow and low correlation is dark blue. See Figure 18.

The post-intervention MG of *TT* condition plots showed an emergence of a pattern of switching leadership. Dyad 6, 10, 14, 19 show this quite clearly in the plots. In the MG post, a sinusoidal pattern can be seen that indicates a regular switching of leadership between the pairs. See Figure 18a. In seven of the dyads, the switching leadership pattern emerged in the post-intervention MG and the lag got closer to 0.

The *E* plots did not show a very clear pattern, as found in the *TT* condition. In four of the plots, there was a tightening of the correlation around 0 (see Figure 18b). The *E* plots showed an increase in periodic movements. The periodic movements are shown by a consistent section of stacked lines from top to bottom of the plot. See Figure 19. In two of plots, the switching leadership behaviour disappeared in the post-intervention MG, but in three of the plots, there was somewhat of the switching pattern seen in *TT*; however, the pattern was not as clear as in the *TT*.

The *S* plots display no specific pattern. Dyad 16 shows an increase in the switching leadership pattern, and Dyad 3 and 5 demonstrate a tightening of the correlation around lag 0, but there is no consistent pattern as seen in the paired musical intervention conditions. Sometimes the dyads increase in correlation, but most decrease in correlation, shown by the smaller amount of high correlation areas. In a few of the dyads, there is a strengthening of the correlation pattern from pre-intervention to post-intervention MG, but the pattern itself remains essentially the same. See Figure 18c.

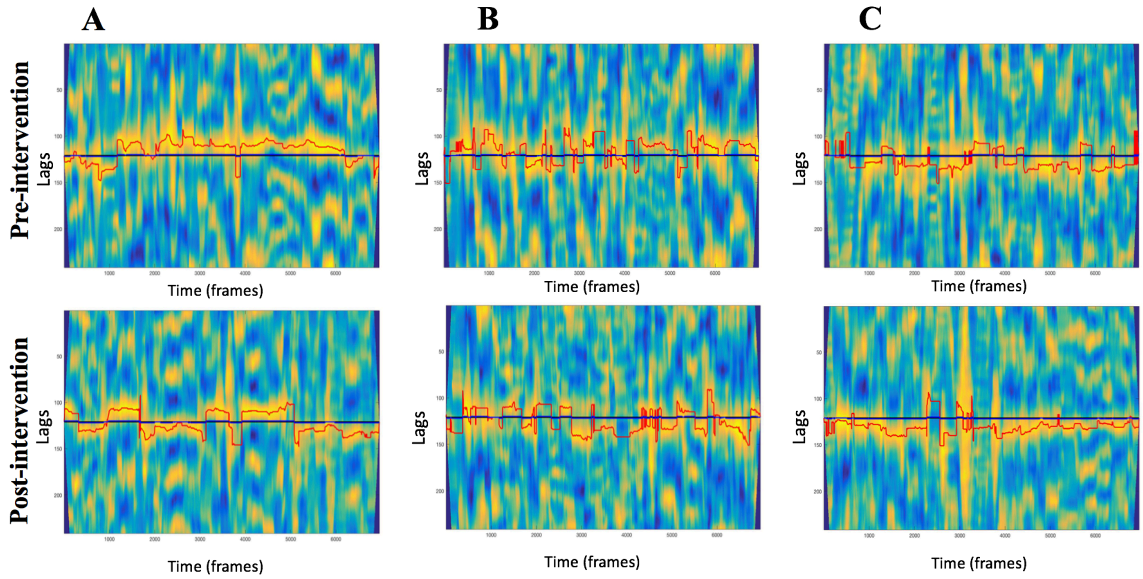


FIGURE 18. Examples of windowed cross-correlation. A) Dyad 6, *TT*. Between the pre-intervention MG and post-intervention MG, a clear turn-taking behaviour can be seen to emerge in the second plot. B) Dyad 26, *E*. In the post-intervention MG, the plot demonstrates a closer oscillation around lag 0. C) Dyad 18, *S*. The post-intervention MG plot shows an increased lag, and no emergent pattern.

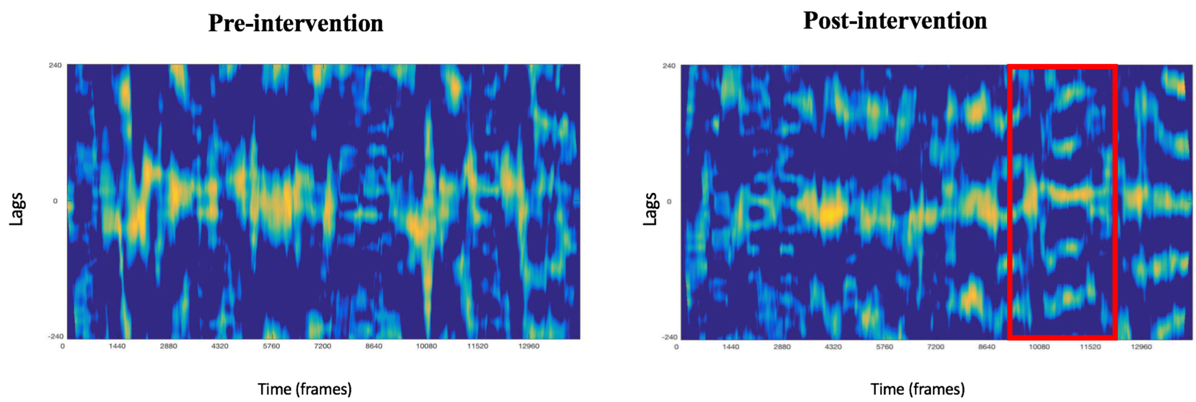


FIGURE 19. Example of periodic movement emergence. Dyad 25 (*E*). A larger amount of periodic movement emerged in the post-intervention mirror game. Periodic movement is characterized by the pattern shown in the red box.

Leader Switching: The average number of turns taken in each condition. Figure 20 gives an example of a windowed cross-correlation plot with the calculations of leader switches plotted on top of the plot. The minimum time between turns was set at two seconds, four seconds and eight seconds (see Table 1). In each calculation, the solo condition had the smallest number of average switches occur. At two seconds, all conditions decrease from pre- to post-intervention MG, but *TT* decreases the most. At four seconds, *S* decreases in switches the most, and at eight seconds, *E* decreases in switches the most. At two seconds, *E* has the highest number of switches in both pre- and post-intervention MG, at four second, *S* has the highest, and at eight seconds *TT* has the highest number of switches.

Table 1: Average number of leader switches per condition.

Condition/Minimum Time	**Two Seconds**		**Four Seconds**		**Eight Seconds**	
	Pre	Post	Pre	Post	Pre	Post
Turn-Taking	15.7	13.8	9.7	9.0	3.6	3.6
Entrainment	16.4	16.1	10	10	3.5	2.9
Solo	10.1	7.8	15.6	14.8	2.7	2.4

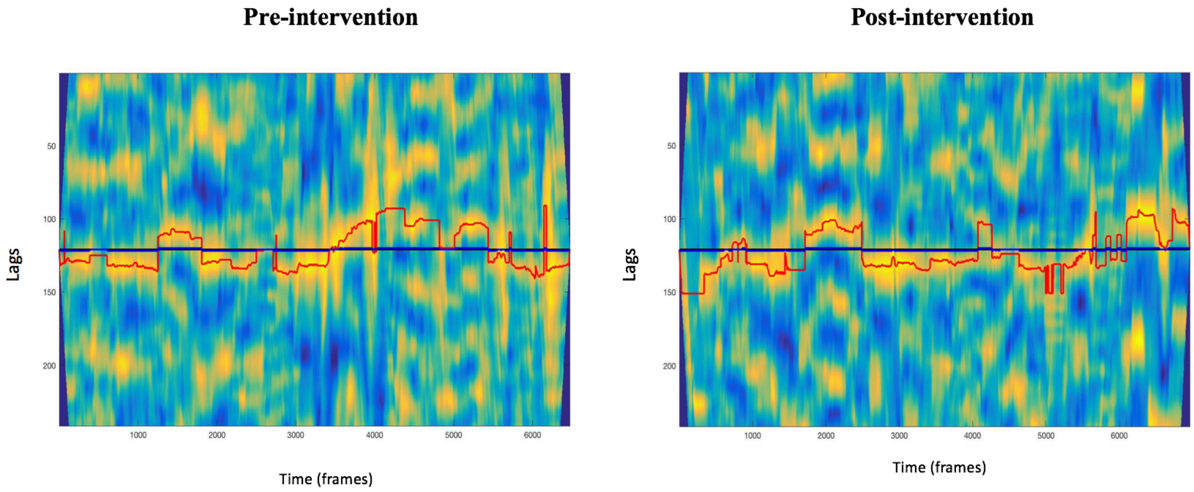


FIGURE 20. Dyad 10, *TT*. Example of the plots determining leader switches. The red line traces the max correlation per window. The black line is the zero line. The blue line traces the leader switches.

3.3 Overall Trends

A possible, weak relationship between the kinematic measures and the conditions appears to have emerged. A study with more dyads may be able to show a stronger relationship. In the *E* condition, the three derivatives of kinematics decreased, whereas QOM and complexity of movement (measures potentially relating to creativity of movement) increased. *E* had the highest average reported level of bonding. See Table 3 for overview.

Table 3. Overview of kinematics

		Avg. Velocity (m/s)	**Avg. Acceleration (m/s^2)**	**Avg. Jerk (m/s^3)**	**Avg. Jitter 1.0e+04***	**Avg. max QOM 1.0e+04***	**Complexity**	**IOS**
TT	Pre-In	0.52	0.25	0.17	6.9	6.9	379.6	
	Post-In	0.50	0.31	0.21	5.0	4.9	385.1	3.5
E	Pre-In	0.47	0.27	0.19	4.2	4.9	248.3	
	Post-In	0.42	0.24	0.16	4.6	6.8	274.0	4.0
S	Pre-In	0.35	0.26	0.21	5.1	6.9	271.7	
	Post-In	0.51	0.30	0.20	4.7	4.3	283.5	3.3

Note: "In" = Intervention

3.3.1 Post-Experiment Interviews and Debrief Questionnaire

During the post-experiment interviews, the participants discussed what changes they observed in the two *experimental mirror games*. In the *TT* and *E* conditions, the participants were more likely to mention a stronger feeling of change than in *S*. For example, one pair, in E, found that during the post-intervention *SH* MG, they were unable to know who was leading and who was following. This suggests that they entered a state of emergent movement. In general, however, almost all of the participants expressed that they used a switching leader strategy to maintain the shared leadership game. Only two dyads expressed their inability to know who was leading and following in the shared leadership game. Regardless of this, only four of the 63 participants said they did not feel a clear difference in the post-intervention MG. Most of the fifty-nine who expressed they could feel the difference could not describe specifically what it was. Therefore, overall, the participants felt a change in connection with their partner.

With regards to gaze, sixteen people expressed an awkwardness in keeping eye contact, but ten of them wrote that maintaining eye contact became easier, even crucial to the partner-partner connection, and their initial nervousness became "okay later". Two people mentioned their surprise in how close they felt to their partner due to their shared decision making found in the *SH* MG.

They stated that the MG was overall easier the second time they played it.

> P31 from Dyad 15 (*E*): "I felt extremely and surprisingly comfortable working with my partner."

> P32 from Dyad 16 (*S*): "The shared leadership led to a surprising closeness somehow. Even though I didn't know my partner at all, there has been some kind of intimacy—maybe because of the eye contact, I would guess that the shared decision making process was more important for that."

They said the changes happened in different aspects of the game: easier to keep eye contact (4 of 31 dyads), easier to read their partner (10 of 31 dyads), and greater overall comfortability (6 of 31 dyads), however, most were unable to discuss what may have created the difference. If the dyads did mention what they thought caused the change, they either said they were "more familiar" with the game (4 of 31 dyads) or that the music helped them relax (5 of 31 dyads).

Generally, participants said it was more likely that simply spending more time together changed their mutual comfortability and the task itself did not necessarily matter.

In terms of a general response to the study, participants in the paired musical conditions had a greater likelihood to use more positive language when describing their thoughts of the study. Eight of the twenty participants in *TT*, eleven of the twenty-two participants in *E*, and only one of the eighteen participants in *S* expressed very positive responses to the study. These comments were in an optional "General comments" section of the debrief questionnaire, therefore, not all participants responded. This creates a limitation in this part of the analysis. In contrast, four of the twenty participants in *TT*, six of the twenty-two in *E*, and twelve of the eighteen in *S* expressed mildly positive or more negative responses to the study. For example, instead of stating it was "very fun!", they said the study was "interesting". This is consistent with the general observations of the author.

IOS Scale: Within the debrief questionnaire, the participants filled out the IOS scale to measure how close they felt to their partner. The average of the responses per condition were taken for *TT* (M= 3.5), *E* (M = 4.0), and *S* (M = 3.3). The difference between conditions was not significant, but the highest bonding occurred in the entrainment condition and the lowest in the solo condition, coinciding with the observations made by the author.

3.3.2 Musical Interventions

All the dyads in the paired conditions said they really enjoyed the music game, but this was not as clear in the solo group. Most of the solo group expressed frustration at the inability to make the sounds they wanted to hear because of the pentatonic xylophone. They felt that the film was too fast to be able to make an effective soundtrack, and this frustration may have affected the bonding, and therefore potentially the MG. The potential consequence may be a limitation that effected the results of the study.

> P36 from Dyad 18 (*S*): "I found this hard, as I didn't know what was coming in the movie, and I couldn't express that I wanted to express on the xylophone as there were limited notes."

When discussing the paired musical interventions, the participants were very positive:

> P44 from Dyad 23 (*TT*): "The musical game was easier and funnier, I felt we could really establish a connection during that part, the only hard part was to improvise. It was the part in which I enjoyed my partner the most."

> P48 from Dyad 24 (*E*): "It was just super fun! Very easy to improvise and making music got me and my partner more in the same level of thinking, I think."

> P53 from Dyad 26 (*E*): "It was super fun. It might have been difficult to synchronize at times, but I felt the task as fun."

These written responses supported the responses heard in the post-experiment interviews as well as observed from the author.

4 DISCUSSION

This thesis investigated the feasibility of using the experimental mirror game to measure how various musical interactions effects intersubjectivity within dyads. In order to study this possibility, three different musical interactions were created to examine the effects of musical interactions upon the MG. The primary hypothesis stated that a change in the MG would be related to the bonded-ness of the pair, measured through the IOS scale (Aron, et al., 1992). This hypothesis was not fully supported, but results provided outcomes that may lead to further studies. The only possible relationship found was in the amount of jitter recorded during a MG. The hypothesis also proposed that the post-intervention MG would demonstrate an effect particular to the musical condition. This section of the hypothesis was somewhat supported. Finally, a secondary investigation examined if physical proximity could be used as another measure of social bonding or intersubjectivity. The secondary hypothesis was not supported, as no pattern or strong relationship was found to exist between physical proximity and the IOS-measured level of bonding.

4.1 Kinematic Patterns are Complex

While investigating basic measures of velocity, acceleration, jerk, QOM and complexity of movement, significant results were not found within the analysis of the pre-intervention and post-intervention MG. It appears that each dyad responded to the musical interventions in a different way. It was expected to find some trend within these kinematic measurements to demonstrate the effects of the musical interventions, however, this did not occur with the strength and clarity anticipated. The high correlation and small lag pattern found in *S* velocity cross-correlation calculations did not align with the expected results; however, a pattern emerged in acceleration cross-correlation (*TT* had the highest number of dyads increase in correlation and decrease in lag) and the windowed cross-correlation of velocity that provides some indication that the relationship may lie in deeper aspects of human movement.

Acceleration: A change in the correlation of acceleration is conceptualized as either an improvement or a worsening in the participants' ability to predict each other's manipulations of acceleration. For example, if dyads are unconnected, then they would not be attuned to their partner's movements, and thus would miss changes in accelerations or directions, leading to a decrease in correlation and an increase in lag. However, if the dyad was well-bonded, they would be highly attuned to changes in the partner's actions (Knapp & Hall, 2010) and the attunement would lead to a better ability to predict changes in acceleration and direction. This, in turn, would create an increase in correlation and decrease in lag. The *TT* condition had the greatest number of dyads increase in correlation and decrease in lag, which suggests that practicing turn-taking in the musical intervention led to a heightened attunement between the partners.

Complexity: The measure of complexity was a preliminary one, but the general increase in all conditions shown indicates that each group increased in complexity; this suggests an increase in creativity. *TT* increased the most, and thus potentially had more creative movements. However, limitations, see section 2.5.6 in Methodology, to this measurement could prevent a clear conceptualization of what the results mean.

4.2 Possible Relationship between Jitter and IOS

There appears to be a connection between amount of jitter measured in the mirror game per condition and the subsequent mean rating of the IOS. The correlation increased in a positive direction in all conditions, but showed a significant correlation between the *TT* post-intervention jitter measure and the IOS responses. Furthering this, *E* had the lowest amount of recorded jitter and the highest recorded IOS response. These results indicate a possible relationship between this kinematic phenomenon and social bonding scores. This outcome supports Noy et al. (2011), who showed that true joint action is characterized by the smoothness of movement signal (little jitter). Joint action is also known to increase feelings of affiliation because the brain assimilates that person closer to the self (Sebanz, Bekkering, & Knoblich, 2006). It is possible that jitter could be one of the ways to measure bonding through the MG. However, measuring this effectively may be difficult with novices due to the difficulty they face in entering into *SH* (Gueugnon et al., 2016a).

4.3 Emergence of Movement Patterns in WCC

There were conflicting results with the cross-correlation of velocity and WCC of velocity. From the cross-correlation calculations alone, the solo condition appeared to have the greatest effect upon the synchrony of the dyads, however, this relationship did not appear in the WCC. The results of the windowed cross-correlation on velocity provided a clearer example of the different effects the musical interventions had upon the mirror game. In these plots, there was a fairly clear distinction between the conditions.

In *TT*, the plots showed the emergence of a sinusoidal pattern that suggested the participants switched leadership more regularly. This pattern related to the longer turns, shown by calculating the number of leader switches. The higher number of switches at eight seconds in *TT* indicates that the *TT* condition potentially induced more regular, longer turns. The ‘conversation’ had with music appears to have effected how the participants played the *SH* MG as shown in the windowed cross-correlation plots. The turn-taking from the musical intervention appears to have influenced the mirror game. After such a regular turn-taking experience, it seems that the pair fell into the turn-taking pattern in the mirror game as well. This finding supports the hypothesis that stated that turn-taking would incite a greater tendency towards switching leadership as opposed to the other two interventions.

The *E* plots show some of the switching leadership pattern seen in the *TT* condition, but it is not as prevalent. The tendency for the pattern to disappear from pre- to post-intervention MG is more likely than its emergence, which indicates that the entrainment nature of the intervention did have an effect upon the MG. The *E* plots instead show a higher amount of periodic movement and the correlation of participant’s movements tightening towards the 0-lag line from pre-intervention to post-intervention (see Figure 18b). This finding supports the hypothesis that the participants in the *E* condition would gain a higher attunement to their partner after improvising a duet together. Furthermore, the higher number of turns in *E* seen when the minimum turn-time is two seconds suggests the participants were switching leadership more rapidly. Faster changes in leadership would be consistent with the closer oscillation around lag 0 shown in the windowed cross-correlation plots. When dyads move towards entrainment, they become unable to know who is leading and who is following, as demonstrated in the Noy et al. (2011) study. This confusion suggests that they are so close to joint action that the "leader" and "follower" switch very rapidly. It is natural for the temporal behaviour patterns of interacting humans to synchronize or at least move towards a common phase or period (Clayton, Sager, & Will, 2005), which may explain the periodic movement seen in the plots. Entrainment is defined as an established consistent relationship; therefore, the emergence of periodic movement may be an early stage of entering into entrainment because periodic movement is a consistent pattern. Previous studies have also demonstrated entrainment or synchrony between people increases mutual affiliation and/or liking (Marsh, Richardson & Schmidt, 2009; Richardson et al., 2007; Wiltermuth & Health, 2009) so the closer to lag 0 a dyad is, the higher bonding they would feel. Furthering this, when one feels connected to another person, one tends to be more aware of what s/he does, both emotionally and physically (Knapp & Hall, 2010), as demonstrated with unconscious mimicry (Chartrand & Bargh, 1999). The closer 0-lag oscillation seen in the *E* plots might suggest that the dyad was able to enter into shared leadership because more fully entrained pairs likely have less lag. This phenomenon could explain the higher number of switches at shorter turn times as well. Perfect synchrony or entrainment is virtually impossible in humans because of jitter and the capacities of human movement, however, when a pair nears perfect synchrony their movement will more likely oscillate tighter around lag 0. As mentioned previously, the cross-correlations of velocity of *E* dyads did not show a significant increase in correlation or decrease in lag, and thus conflicts with these WCC findings. This may be due to the complex nature of the relationship in addition to the use of novice improvisers in this study, who have been shown to have greater difficulty entering *SH* than experts (Himberg et al., 2018). Dance is one means by which to learn physical improvisation, and since the majority of the participants (73.5%) had less than five years of dance training, this suggests that none of the participants were highly experienced improvisers. Since the participants were novice improvisers, their inability to reach emergent movement is not surprising. However, because the participants were paired based on musical standing, there could be a relationship between ability to synchronize and musical ability, but this was not investigated in this thesis.

The *S* plots did not display any particular nor consistent pattern, which was expected. The highest number of switches in *S* at four seconds may suggest that four seconds might be the average length of switches without effects from interaction types. This supports the hypothesis which stated that the *S* condition should only produce practice effects.

In summary, the emergence of the leader switching in *TT*, the closer oscillation around lag 0 in *E*, the lack of these patterns appearing reliably in the solo condition, and the consistency of this pattern in counting the leader switches, indicates the musical interventions did have effect and that the MG was able to quantify that effect fairly consistently.

4.4 Playing Together Creates an Effect on Enjoyment

From observations and the questionnaires, the participants in the paired musical conditions appeared to enjoy the experiment to a greater extent than the participants in the solo condition. The heighted enjoyment might relate to how humans bond and how long it takes to bond. It is well-known that spending any amount of time with another person will likely lead to bonding, dependent upon personality and various other factors; therefore, perhaps even the ten minutes the participants in the solo condition spent apart was long enough to disrupt the bonding that had been taking place.

To support this, the participants, in the post-experiment interviews, were more likely to mention a greater feeling of change between the pre- and post-intervention MGs in the turn-taking and entrainment conditions, in comparison with the solo condition. This feeling could be related to the greater amount of bonding that took place in the paired musical intervention as seen in the IOS results.

4.5 Conclusions

Although this investigation into the MG did not yield the clear results expected, the feelings of connection expressed by the participants supports previous findings of the rewarding qualities of joint interaction. Previous studies suggest that in moments of peak joint interaction, players are highly engaged, feel rewarded and experience intense positive emotions (Berliner, 1994). Furthering this, other research has shown coupling of neural circuits (Yun et al., 2012), and coupling of heart rate and breathing patterns (Müller & Lindenberger, 2011) during joint activity**.** Perhaps, further measures of physiological responses, such as heart rate, breathing rate and skin conductance, might be beneficial to measuring the joint responses of the players to gain a broader understanding of their reaction.

The variability of the results suggests that the data needs to be assessed from many different types of analyses and viewpoints, both qualitatively and quantitatively. This study continued the opinions expressed in Himberg et al. (2018) with regard to collecting various types of data, and although the current study increased the gathered amount of structured qualitative data, it might also be beneficial to have more in-depth interviews with the participants into the effects of the musical intervention and the connections between the MG and social bonding. Seeman (2009) states that joint action involves "a sense of acting together" (p. 504), which indicates the importance of the subjective experience. It is possible that having the participants or outside raters view the mirror games and judge the musical interactions for musicality or togetherness could provide more insight into what the effects of the musical interventions are and how the MG and social bonding are connected.

4.5.1 Limitations

There are some limitations in this study. First, there is a difference between the workability of the solo vs. paired musical interventions. The solo condition was found to cause more stress than the paired conditions. This increased difficulty may not have been an equal comparison to the paired interventions. Second, some participants had difficulty understanding how to play the shared leadership mirror game. Sharing leadership is a difficult concept to understand and some language barriers may have confused the issue. Third, the population was quite restricted as the majority of the participants were international students, which limits how widely the results can be applied.

4.5.2 Further Directions

The results reported here demonstrate only a small portion of the data collected in preparation for this study. Many varying directions are possible to explore with this vast date set. Some possible suggestions follow.

One could investigate the improvised musical interactions through their body movement or investigate the musical interactions by comparing musical skill with ability to play the MG. Further work could compare personality and/or empathy with the MG or quality of music or explore postural interaction within music and the MG. One could examine comparisons between *LF* and *SH* games. Finally, one could complete the analysis done in this thesis but looking at all the markers on the body. Many research questions can be asked based on the breadth of data collected.

4.5.3 Summary of Results and Implications

The findings of this study provide further support for the MG as a means to measure aspects of human interaction. The MG's sensitivity creates both apprehension and excitement for future directions. On one hand, it has the sensitivity to capture human interaction in movement, and therefore can be used to understand many nonverbal interactions. On the other hand, the MG's sensitivity also creates difficulty in knowing what the MG is measuring within the interaction. Such difficulties also extend to knowing what MG parameter is measuring the interaction; for example, the MG could measure an interaction through the level of synchrony between players in velocity or acceleration, or else through the differing creativity of their movements.

To summarize the outcomes of the study, hypothesis 1 was partially supported because the MG did show a relationship between jitter and the IOS for the *TT* condition. This provides support to previous ideas in regards to the MG being employed at a measure for intersubjectivity (Himberg et al., 2018). Hypothesis 2 was fully supported: patterns specific to each condition emerged. *TT* showed a sinusoidal pattern and longer leadership turns (Hypothesis 2a), *E* showed more periodic movement, oscillations closer to lag 0 and shorter leadership turns (Hypothesis 2b), and *S* showed no specific patterns and medium length leadership turns (Hypothesis 2c). This finding implies that the MG is sensitive enough to capture behavioural changes unable to be seen by a human observer. Further studies on this subject can carry out more in-depth research on these patterns, given that this study has shown their presence. Hypothesis 3 was not supported as *TT* and *E* did not display higher correlations than *S*. This result was contradictory to the findings of hypothesis 2, however, further research should be done to confirm or refute this result. And finally, the sub-investigation on *PP* was unsuccessful. Overall, this thesis was successful in acquiring new knowledge on the MG and its various abilities with regards to measuring human behaviours. The playing of pentatonic xylophones in a paired musical intervention led to higher bonding, more excitement about the experiment and the emergence of movement patterns.

In conclusion, the wide focus of this study offers the potential to be used as a map to guide future studies that examines the mirror game, synchrony, and social bonding, and their interrelationship. The universal and subjective state known as ‘feelings of togetherness’ is difficult to quantify; however, this study signals one more step towards understanding the phenomena that all humans implicitly know and want.

5 REFERENCES

Agre, P., & Chapman, D. (1987). PENGI: An implementation of a theory of activity. In: *Proceedings of the Sixth National Conference on Artificial Intelligence (AAAI-87)*, Seattle, W.A. (pp. 268-272).

Argyle, M., & Cook, M. (1976). *Gaze and mutual gaze.* Cambridge, English: Cambridge University Press.

Avid Technology. (2018). ProTools (Version 11.03). [Computer software]. Available from http://www.avid.com/pro-tools .

Berliner, P. (1994). *Thinking in Jazz: The infinite Art of Improvisation*. Chicago, IL: University of Chicago Press. doi: 10.7208/chicago/9780226044521.001.0001

Bluedorn, A.C. (2002). *The human organization of time: Temporal realities and experience*. Stanford, C.A.: Stanford University Press.

Boker, S. M., Rotondo, J. L., Xu, M., & King, K. (2002). Windowed cross-correlation and peak picking for the analysis of variability in the association between behavioral time series. *Psychological Methods, 7*(3), 338-355.

Blood, A. J., & Zatorre, R. (2001). Intensely pleasurable responses to music correlate with activity in brain regions implicated in reward and emotion. *PNAS, 98*(20), 11818-11823.

Bloom, K., Russell, A., & Wassenberg, K. (1987). Turn taking affects the quality of infant vocalizations. *Journal of Child Language, 14*(2), 211-227. doi: 10.107/S0305000900012897.

Bodenheimer, B., Rose, C., Rosenthal, S., & Pella, J. (1997). The process of motion capture Dealing with data. In D. Thalmann, M. van de Panne (Eds.). *Computer Animation and Simulation '97*. Eurographics. Springer, Vienna.

Bolt, N.K., Poncelet, E.M., Schultz, B.G., Loehr, J.D. (2016). Mutual coordination strengthens the sense of joint agency in cooperative joint action. *Consciousness and Cognition, 46*, 173-187. doi: 10.1016/j.concog.2016.10.001.

Brooks, R., & Meltzoff, A.N. (2014). Gaze following: A mechanism for building social connections between infants and adults. In M. Mukulincer & P.R. Shaver (Eds.), *Mechanisms of social connection: From brain to group* (pp. 167-183). Washington, D.C.: American Psychological Association.

Burger, B., & Toiviainen, P. (2013). MoCap Toolbox - A Matlab toolbox for computational analysis of movement data. Presented at the *10th Sound and Music Computing Conference*, SMC 2013, Stockholm, Sweden, Logos Verlag Berlin. Retrieved from https://jyx.jyu.fi/dspace/handle/123456789/42837.

Chartrand, T.L. & Bargh, J.A. (1999). The chameleon effect: The perception-behaviour link and social interaction. *Journal of Personality and Social Psychology, 76*(6), 893-910.

Chartrand, T.L., & Jefferis, V.E. (2003). Consequences of automatic goal pursuit and the case of nonconscious mimicry. In J.P. Forgas (Ed.), *Social judgements: Implicit and explicit processes* (pp. 290-305). New York: Cambridge University Press.

[Classics]. (2017, April 27). *Buster as a Monkey Buster Keaton The Play House 1921.* [Video File]. Retrieved from https://www.youtube.com/watch?v=srzYr_gU5WI

Clayton, M., Sager, R. & Will, U. (2004). In time with the music: The concept of entrainment and its significance for ethnomusicology. *ESEM Counterpoint 1*, (1-82). Available at: http://oro.open.ac.uk/2661/?LKCAMPAIGN=it00 1_res&MEDIA=it001_c03.

Clore, G.L., Wiggins, N.H., & Itkin, S. (1975a). Gain and loss in attraction: Attributions from nonverbal behavior. *Journal of Personality and Social Psychology, 31*, 706-712.

Clore, G.L., Wiggins, N.H., & Itkin, S. (1975b). Judging attraction from nonverbal behavior: The gain phenomenon. *Journal of Consulting and Clinical Psychology, 43*, 491-497.

Cross, I. (2001). Music, mind and evolution. *Psychology of Music, 29*(1), 95-102.

Condon, W. (1976). An analysis of behavioural organisation. *Sign Language Studies, 13*, 285 318.

Cycling 74'/IRCAM (2017). Max 7 (Version 7.3.2) [Computer Software]. Available from: https://cycling74.com/.

Darwin, C. (1871). *The descent of man and selection in relation to sex*. London: John Murray, Albemarle Street.

Davis, M. (1980). A multidimensional approach to individual differences in empathy. *Catalog of Selected Documents in Psychology, 10*(4), 1-17.

Deák, G. O., Flom, R. A., and Pick, A. D. (2000). Effects of gesture and target on 12-and 18-month-olds' joint visual attention to objects in front of or behind them. *Dev. Psychol*. 36, 511. doi: 10.1037/0012-1649.36.4.511.

Demos, A. P., Chaffin, R., Begosh, K. T., Daniels, J. D., & Marsh, K. L. (2011). Rocking to the beat: Effects of music and partner’s movements on spontaneous interpersonal coordination. *Journal of Experimental Psychology: General*. Advance online publication. doi: 10.1037/a0023843.

Dunbar, Robert. (1996). *Grooming, gossip and the evolution of language*. Boston, Massachusetts: Harvard University Press.

Feniger-Schaal, R., Noy, L., Hart, Y., Koren-Karie, N., Mayo, A.E., & Alon, U. (2016). Would you like to play together? Adults' attachment and the mirror game. *Attachment & Human Development, 18*(1), 33-34. doi: 10.1080.14616734.2015.1109677.

Gallese, V., Fadiga, L., Fogassi, L., & Rizzolatti, G. (1996). Action recognition in the premotor cortex. *Brain, 119*, 593-609.

Goldstein, A. (1980). Thrills in response to music and other stimuli. *Psychobiology Psychology, 8*(1), 126-129.

Gueugnon, M., Salese, R.N., Coste, A., Zhao, Z., Bardy, B.G., & Marin, L. (2016a). The acquisition of socio-motor improvisation in the mirror game. *Human Movement Science, 46*, 117-128. doi:10.10.16/j.humov.2015.12.005

Gueugnon, M., Salese, R.N., Coste, A., Zhao, Z., Bardy, B.G., & Marin, L. (2016b). Postural coordination during socio-motor improvisation. *Frontier Psychology, 7*(1168). doi: 10.3389/fpsyg.2016.01168.

Hagen, E. H., & Bryant, G. A. (2003). Music as a coalition signaling system. *Human Nature, 14*(1), 21-51.

Hart, Y., Noy, L., Feniger-Schaal, R., Mayo, A.E., & Alon, U. (2014). Individuality and togetherness in joint improvised motion. *PLOS, 9*(2): eB7213. doi: 10.1371/journal.pone.0087213.

Himberg, T. (2016, October). *Four-way mirror game*. Retrieved from: https://wiki.aalto.fi/display/BehSynch/Four-way+mirror+game.

Himberg, T., Niinisalo, M., & Hari, R. (2015). Coordination of Fluent Hand-Movements in Dyads. RPPW15, Amsterdam, Netherlands. Retrieved from: https://www.move.vu.nl/en/Images/RPPW15_proceedings_tcm223-485306.pdf

Himberg, T. Laroche, J., Binge, R., Buchkowski, M., & Bachrach, A. (2018). Coordinated interpersonal behaviour in collective dance improvisation: The aesthetics of kinaesthetic togetherness. *Behavioural Sciences, 8*(2), pii-E23. doi: 10.3390/bs8020023.

Hove, M. J., & Risen, J. L. (2009). It's all in the timing: Interpersonal synchrony increases affiliation. *Social Cognition, 27*(6), 949-961.

Huron, D. (2001). Is music an evolutionary adaptation? *The Biological Foundations of Music, 930*, 43-61

Issartel, J., Gueugnon, M., & Marin, L. (2017). Understanding the impact of expertise in joint and solo-improvisation. *Frontiers in Psychology, 8*(1078). doi: 10.3389/fpsyg. 2017.01078.

Jackson, P. (Producer & Director). (2002). *The Lord of the Rings: The Two Towers* [Motion Picture]. United States: New Line Cinema.

John, O.P., and Srivastava, S. (1999). The big-five trait taxonomy: History, measurement and theoretical perspectives. In L. Pervin and O.P. John (Eds.), *Handbook of personality: Theory and research* (2nd ed.). New York: Guilford.

Kendon, A. (1967). Some functions of gaze direction in social interaction. *Acta Psychologica, 26*, 22-63.

Kendon, A. (1990). *Conducting interaction: Patterns of behaviour in focused encounters*. Cambridge, English: Cambridge University Press.

Kirschner, S., & Tomasello, M. (2010). Joint music making promotes prosocial behaviour in 4-year-old children. *Evolution and Human Behaviour, 31*, 354-364.

Klienke, C.L. (1986). Gaze and eye contact: A research review. *Psychological Bulletin, 100*(1), 78-100).

Knapp, M.L. & Hall, J.A. (2010). *Nonverbal Communication in Human Interaction*, 7th ed. Boston, USA: Wadsworth, Cengage Learning.

Knoblich, G., Butterfill, S., & Sebanz, N. (2011). Psychological research on joint action: Theory and data. In B. Ross, (Ed), *The Psychology of Learning and Motivation, 54*, 59-101.

Kurihara, K., Hoshino, S., Yamane, K., &Nakamura, Y. (2002)

Launay, J. (2015). Music as a technology for social bonding: Comment on “Music, empathy, and cultural understand” by E. Clarke et al. *Phy Life Rev*, 94-95. doi: 10.106/prev.2015.10.004.

Macrae, C.N., Hood, B.M., Milne, A.B., Rowe, A.C., & Mason, M.F. (2002). Are you looking at me? Eye gaze and person perception. *Psychological Science, 13*(5), 460-464. doi: 10.111/1467-9280.00481

Macrae, C.N., Oonagh, K.D., Lynden, K., & Miles, J.L. (2008). A case of hand waving: Action synchrony and person perception. *Cognition, 109*(1), 152-156. doi: 10.1016/j.cognition.2008.07.007.

Marsh, K. L., Richardson, M. J., & Schmidt, R. C. (2009). Social connection through joint action and interpersonal coordination. *Topics in Cognitive Science*, 320-339.

Mason, M.F., Hood, B.M., & Macrae, C.N. (2004). Look into my eyes: gaze direction and person memory. *Memory, 12*(5), 637-643. doi: 10.1080/09658210344000152.

MATLAB and Statistics Toolbox Release 2016b, The MathWorks, Inc., Natick, Massachusetts, United States.

Mottet, D., Guiard, Y., Ferrand, T., and Bootsman, R. J. (2001). Two-handed performance of a rhythmical fits task by individuals and dyads. *Journal Experimental Psychological*

Human Perception and Performance, 27(6), 1275–1286. doi: 10.1037/0096 1523.27.6.1275

Mehrabian, A. (1968a). Relationship of attitude to seated posture, orientation, and distance. *Journal of Consulting and Clinical Psychology, 32*, 296-308.

Mehrabian, A. (1968b). Nonverbal betrayal of feeling. *Journal of Experimental Research in Personality,5*, 64-73.

Meltzoff, A.N., & Moore, M. K. (1994). Imitation, memory, and the representation of persons. *Infant Behaviour Development, 17*(1), 83-99. doi: 10.1016/0163-6383(94)90024-8.

Merker, B. (2001). Synchronous chorusing and human origins. In N. L. Wallin, B. Merker, & S. Brown (Eds.), *The Origins of Music* (315-327). Cambridge, Massachusetts: MIT Press.

Miall, R.C., Weir, D.J., Stein, J.F. (1993). Intermittency in human manual tracking tasks. *Journal of Motor Behavior 25*, 53–63.

Miller, G. (2001). Evolution of human music through sexual selection. In N. L. Wallin, B.

Merker, & S. Brown (Eds.), *The Origins of Music* (329-360). Cambridge, Massachusetts: MIT Press.

Mueller, F, Agamanolis, S., & Picard, R. (2002 April 5-10). Exertion interfaces: Sports over a distance for social bonding and fun. *Proceedings of the SIGCHI Conference on Human Factors in Computing System*. Paper presented at ACM, New York, NY (561-568). doi: 10.1145/642611.642709

Müller, V., and Lindenberger, U. (2011). Cardiac and respiratory patterns synchronize between persons during choir singing. *PLoS ONE* 6:e24893. doi: 10.1371/journal.pone.0024893

Norton J.C. (2008). Motion Capture to Build a Foundation for a Computer-controlled Instrument by Study of Classical Guitar Performance. USA: ProQuest LLC.

Noy, L., Dekel, E., Alon, U. (2011). The mirror game as a paradigm for studying the dynamics of two people improvising motion together. *PNAS, 108*(52), 20947-20952. doi: 10.1073/pnas.1108155108.

Noy, L., Levit-binun, N., & Golland, Y. (2015). Being in the zone?: Physiological markers of togetherness in joint improvisation. *Front. Hum. Neurosci., 9*,187. doi: 10.3389/fnhum.2015.00187

Overy, K., & Molnar-Szakacs, I. (2009). Being together in time: Musical experience and the mirror neuron system. *Music Perception, 26*(5), 489-504.

de Quincey, D. (2000). Intersubjectivity: Exploring consciousness from the second-person perspective. *The Journal of Transpersonal Psychology, 32*(2), 135-155.

Paxton, A. & Dale, R. (2013). Argument disrupts interpersonal synchrony. *Quarterly Journal of Experimental Psychology, 66*(11), 2092-2102. doi: 10.1080/17470218.2013.853089.

Poundstone, W. (1992). The prisoner's dilemma: John Von Neumann, Game Theory and the Puzzle of the Bomb. New York, NY: Knopf Doubleday Publishing Group.

Repp, B.H. & Su, Y. (2013). Sensorimotor synchronization: A review of recent research (2006 2012). *Psychonomic Bulletin & Review*, 20(3), 403-452.

Richardson, M.J., Marsh, K.L., Schmidt, R.C. (2005). Effects of visual and verbal interaction on unintentional coordination. *Journal of Experimental Psychology: Human Perception and Performance, 31*(1), 62-79. doi: 10.1036/0096-1523.31.1.62.

Richardson, M. J., Marsh, K. L., Isenhower, R. W., Goodman, J. R. L., & Schimdt, R. C. (2007). Rocking together: Dynamics of intentional and unintentional interpersonal coordination. *Human Movement Science, 26*(6), 867-891.

Rizzolatti, G. & Fabbri-Destro, M. (2008). The mirror system and its role in social cognition. *Current Opinion in Neurobiology, 18*(2), 179-184. doi: 10.1016/j.conb.2008.08.001.

Roederer, J.G. (1984). The search for a survival value of music. *Music Perception, 1*(3), 350-356.

Sayette, M.A, Cresweel, K.G., Dimoff, J.D., Fairbairn, C.E., Cohn, J.F., Heckman, B.W. … Moreland, R.L. (2012). Alcohol and group formation: A multimodal investigation of the effects of alcohol on emotion and social bonding. *Psychological Science 23*(8), 869-878. doi: 10.1177/0956797611435134.

Sebanz N, Bekkering H, and Knoblich G. (2006) Joint action: bodies and minds moving together. *Trends in Cognitive Sciences, 10*, 70–76.

Schechner, R. (1973). Drama, script, theatre, and performance. *The Drama Review: TDR*, *17*(3), 5-36.

Scheffer, C. & Cloete, T. (2012). Inertial motion capture in conjunction with an artificial neural network can differentiate the gait patterns of hemiparetic stroke patients compared with able-bodied counterparts. *Computer Methods in Biomechanics and Biomedical Engineering, 15*(3), 285-294.

Schmidt, R.C., O'Brien., B. (1997). Evaluating the dynamics of unintended interpersonal coordination. *Ecological Psychology, 9*(3), p. 189-206. doi: 10.1207/s15326969eco0903_2.

Sebanz, N., Bekkering, H., & Knoblich, G. (2006). Joint action: bodies and minds moving together. *Trends in Cognitive Sciences, 10*(2), 70-76. doi: 10.1016/j.tics.2005.12.009.

Seeman, A. (2009). Joint agency: Intersubjectivity, sense of control, and the feeling of trust. *An interdisciplinary journal of philosophy, 52*(5), 500-515. doi: 10.1080/00201740903302634.

Shockley, K., Santana, M.V., & Fowler, C.A. (2003). Mutual interpersonal postural constraints are involved in cooperative conversation. *J. Exp Pscyhol Hum Percet Perform, 29*(2), 326-223.

Spolin, V. (1999). *Improvisation for the theater 3E: A handbook of teaching and directing techniques*. 3rd ed. Northwestern University Press.

Tarr, B., Launay, J., & Dunbar, R. I. M., (2014). Music and social bonding: self-other merging and neurohormonal mechanisms. *Frontiers in Psychology, 5*, 1-10. doi: 10.3389/fpsyg.2014.01096.

van Baaren, R.B., Holland, R.W., Steenaert, K., & van Knippenberg, A. (2003). Mimicry and prosocial behaviour. *Psychological Science, 15*(1), 71-74

Valdesolo, P. & Desteno, D. (2011). Synchrony and the social tuning of compassion. *Emotion, 11*(2), 262-266. doi: 1037/a0021302

Vuilleumier, P., George, N., Lister, V., Armony, J.L., & Driver, J. (2005). Effects of perceived mutual gaze and gender on face processing and recognition memory. *Visual Cognition, 12*(1), 85-101.

de Waal, F.B.M. (2008). Putting the altruism back into altruism: The evolution of empathy. *Annual Review in Psychology, 59*, 279-300.doi: 10.1146/annurev.psych.59.103006.093625.

Wiltermuth, S., & Heath, C. (2009). Synchrony and cooperation. *Psychological Science, 20*(1), 1-5.

Wilson, M., and Wilson, T.P. (2005). An oscillator model of the timing of turn-taking. *Psychonomic Bulletin and Review, 12*(6), 957-968. doi: 10.3758.

Wilcoxon, F. (1945). Individual comparison by ranking methods. *Biometrics Bulletin, 1*(6), 80-83.

Yun, K., Watanabe, K., and Shimojo, S. (2012). Interpersonal body and neural synchronization as a marker of implicit social interaction. *Scientific Reports, 2*(959). doi: 10.1038/srep00959

6 APPENDIX 1

6.1 Pre-experiment demographic questions

Gender?

- Female
- Male
- Prefer not to say
- Other

Birth Date?

Age?

Have you had formal music lessons? If so, for how long have you played an instrument or sang?

- I have not
- 0-1 years
- 1-5 years
- 5-10 years
- 10 years or more

If you have, which instrument?

Have you taken any formal dance lessons? If so, for how long?

- I have not
- 0-1 years
- 1-5 years
- 5-10 years
- more than 10 years

If yes, what type of dance did you do?

I would consider myself . . .

- A non-musician
- Amateur musician
- Semi-professional musician
- Professional musician

7 APPENDIX 2

7.1 Consent Form

Informed consent for a motion capture study in the motion capture late at the University of Jyväskylä

I have read and understood the information sheet and have received sufficient information about the course of the study. I understand that my participation is voluntary and that I can stop my participation at any time without any consequences to me. I have been told who is the researcher I can ask for more information about the study, or my performance in the study.

My data and results are only used by researchers in the *Behavioural Synchrony* research group. The researcher in charge can let other collaborators to analyse my data for scientific purposes without further consent. In this case, s/he must ensure that the data is anonymized. Any commercial use of the results or data is forbidden. I understand that the data is collected for scientific research and it will not be released to the participant, even in part.

With my signature, I confirm my participation in this study and consent to be a voluntary participant.

__________________________ ______________________________

Signature of the participant Date

__________________________ ______________________________

Name of the participant Social security number

____

Address of the participant

Master's Student Megan Buchkowski

Department of Music, University of Jyväskylä

046 942 2723

megan.e.buchkowski@student.jyu.fi

Post-doctoral researcher Tommi Himberg

Department of Neuroscience and Biomedical Engineering

Aalto University

050 313 9439

tommi.himberg@aalto.fi

CONSENT FOR FILMING / RECORDING

Name: ____

Date of birth: ____

Phone number: ____

Email:____

Address: ____

I consent that the photographs/video/audio recording of me will be used in the analysis, presentation of the results, and in later teaching and research in the University of Jyväskylä and Aalto University. I understand that the photographs/video/audio recordings can be published as part of the results of this research project and that they can be modified before publication.

I also consent that my personal information (name, gender, date of birth, contact details), information about the study where the recordings were made (name of the study, name of the researcher in charge, date and time), will be saved into a separate register of personal information.

Regarding the register of personal information, I have been given an information protection form with the details of how the personal information will be processed, and my rights, e.g. the right to check my information and to ask for correcting mistakes in the information. I have been told the register is managed by the named researchers in University of Jyväskylä and Aalto University and that my personal information will never be connected with the information published about the study. The information in the register will only be accessible by the researcher in charge and researchers in their research group.

Signature: ____

Time and place: ___________________

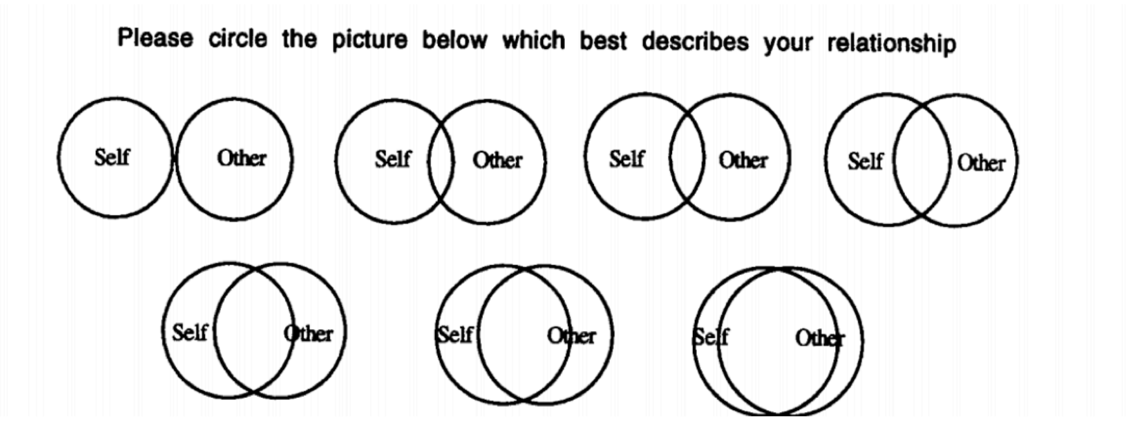
8 APPENDIX 3

8.1 Debrief Questionnaire

PARTICIPANT NUMBER:

MIRROR GAMES AND MUSIC - DEBRIEFING

1. On the scale below, circle the choice that best describes how you feel about your relationship with your partner right now.



2. Please rate which task was the most difficult

Mirroring in pairs: leading ☐ following ☐ sharing leadership ☐

3. How well did you know the other participant? (1 = not at all; 5 = we're best friends)

1	2	3	4	5

4. Comments about the mirror games. What was difficult or easy in the game? How did you feel working with your partner in this situation?

5. Comments on the musical game. What was difficult or easy in the game? How did you feel working with your partner in this situation?

6. General comments