6-2020

Singing in Synchrony: A Feasibility Study of Interpersonal Familiarity and Movement Synchrony in Group Singing

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SINGING IN SYNCHRONY: A FEASIBILITY STUDY OF INTERPERSONAL FAMILIARITY AND MOVEMENT SYNCHRONY IN GROUP SINGING

by

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A thesis submitted to the Graduate College
in partial fulfillment of the requirements
for the degree of Master of Music
School of Music
Western Michigan University
June 2020

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Western Michigan University, 2020

In a time when social isolation and decreased in-person interactions pose increasing risks for physical, emotional, and mental well-being, it is more important than ever to find ways to combat the negative consequences of social isolation. Moving in synchrony with others and singing with others have both been identified as social activities through which social bonding may occur, yet little is known about the role of natural movement synchrony in group singing. This study sought to explore the feasibility of using motion capture technology to examine the natural head movements of groups of four participants singing together. The study consisted of two experimental groups: one group of previously-acquainted individuals, and one group of "strangers" with an unknown relationship prior to participation. Results of this study outline the feasibility of the methodology and outcome variables and provide a comparison of estimated levels of group synchrony between the two experimental groups. Findings suggest that the methodology was feasible overall, and motion capture analysis revealed that while the participants' overall amount of head movement was minimal in both groups, the unfamiliar group (strangers) may have experienced greater levels of movement synchrony between participants. These findings may inform future research on the relationship between interpersonal familiarity and movement synchrony in small-group singing.

ACKNOWLEDGEMENTS

I first must extend my sincerest thanks to the members of my committee, Professor Ed Roth, Dr. Sangwoo Lee, and Dr. Jennifer Fiore, for their guidance throughout this thesis process. None of this would have been possible without the patience and consistent support of my committee as topic changes and life changes altered my original project goals and timelines. Thank you, Professor Roth, for being willing to take in my frazzled novel-length emails in my moments of panic, for always supporting me when my thoughts changed direction, and for guiding me to this finished project. Thank you, too, to Dr. Lee, for the use of your lab, equipment, and for your motion capture expertise.

I also owe a tremendous thanks to Dr. Emily Carlson of the University of Jyväskylä for her willingness to jump into helping with the analysis of the later portion of this study. Your generosity in time, patience, and encouragement gave me the confidence to tackle MATLAB, and I look forward to collaborating on ways to continue the analysis of this project in the future.

No list of acknowledgments would be complete without mention of my gratitude to my family and friends for their years of patience and (sometimes tired) support in completing this degree. I can't wait to celebrate thesis-free when we are all able to reunite!

And finally, my biggest and most heartfelt thanks goes to my research partner, fiancé, and best friend, Molly Grettenberger. Grad school, thesis-writing, and life are so much better with you by my side. Thank you for your unending love, support, and of course your editing expertise. I can't wait to see where life takes us next!

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INTRODUCTION

In a time when in-person social interactions are increasingly replaced with social media, the experience of social isolation is becoming a major health concern (Holt-Lunstad et al., 2015). This problem has become even more relevant as the current COVID-19 pandemic highlights the implications social isolation has for both physical and mental well-being in people of all ages. Social isolation is defined as "a state in which the individual lacks a sense of belonging socially, lacks engagement with others, has a minimal number of social contacts, and [is] deficient in fulfilling and quality relationships" (Nicholson, 2009, p. 1346). Numerous studies link increased social isolation to harmful outcomes, ranging from increased physical and mental health problems to higher mortality rates (Holt-Lunstad et al., 2015; Nicholson, 2012). Individuals experiencing social isolation may be at a higher risk for cognitive decline or dementia, suicide, coronary heart disease, and stroke, amongst other serious conditions (Nicholson, 2012).

According to the AARP (n.d.), more than eight million adults ages 50 and above are affected by social isolation. Loneliness, or the subjective experience of feeling socially isolated, has been reported nationally in over one-third of adults over 45, equating to over 42 million older adults (Wilson & Moulton, 2010). While research on social isolation is often associated with middle-aged and older adults, studies also identify social isolation in young adults, some pointing to a link between high levels of social media use, which is more common in younger populations, and high levels of social isolation (Primack et al., 2017). One study comparing the experience of loneliness and social isolation between age groups found that young adults (ages 21-30) reported experiencing twice as many lonely and isolating days compared to older adults (ages 50-70), indicating that the dangers of social isolation span multiple age groups (Child & Lawton, 2017).

As research on social isolation and loneliness continues to develop, and the severity of the problem becomes clear, the need for interventions to reduce these experiences grows. Social isolation is linked not only to physical and mental challenges, but to economic burdens as well. A 2017 study looking at the relationship between social isolation and Medicare spending found that social isolation costs the US government approximately $6.7 billion additional dollars annually (Flowers et al., 2017). Social isolation and loneliness have also been closely linked to depression (Cacioppo et al., 2006), which is the leading cause of disability worldwide and costs the U.S. economy hundreds of billions of dollars per year, or over $210 billion dollars in 2010 alone (Greenberg et al., 2015; Shensa et al., 2017).

It is clear that social isolation has a negative impact on numerous lives as well as on the economy, prompting the need for innovative, cost-effective approaches for decreasing social isolation. One approach to reducing social isolation involves increasing what is missing: social bonding and connection with others. Social connectedness has been found to predict lower loneliness and depressive symptoms in adolescents (Jose & Lim, 2014; Jose et al., 2012). However, more research is needed in this area to determine safe, reliable, and cost-effective methods for increasing social connectedness. In a 2018 systematic review of interventions targeting loneliness and social isolation, no consensus on the most effective interventions was found, as the nature of interventions varied and were difficult to compare (Poscia et al., 2018). While the need for more research in this area is clear, studies continue to conclude that social connection and bonding may be the key to preventing or minimizing the harmful health and economic consequences of social isolation in today's society (Martino et al., 2017).

Synchronization, or synchronous movements between individuals, is one concept at the heart of a growing body of research on increasing social bonding (Mogan et al., 2017). Moving

in synchrony has been linked to increased social bonding, cooperation, prosocial behavior, and even altruistic behavior in a wide range of settings and populations (Cohen et al., 2010; Göritz & Rennung, 2019; Valdesolo et al., 2010; Valdesolo & Desteno, 2011). While some studies on synchrony focus on prescribed movements designated by the researchers, others look to activities in which synchronous movements are a natural component, such as singing and dancing. Group singing, in particular, has historically been a way for different groups of individuals, such as religious groups or communities in different cultures, to come together and experience social connection. Research on group singing, like research on synchrony, suggests links between singing as a group and positive outcomes including increased trust, cooperation, pain tolerance, inclusion, and social closeness, amongst others (Anshel & Kipper, 1988; Weinstein et al., 2016). This study sought to explore whether synchrony may be one mechanism by which group singing influences social bonding.

The positive outcomes found in both synchronous activities and group singing experiences are similar and identify potential opportunities for targeting social isolation. However, most studies on group singing utilize groups of singers who already know one another. Individuals experiencing the impact of social isolation may not have a community of people with whom to engage in this type of experience, and therefore might more likely find themselves amongst strangers when seeking to find community. The current study aimed to explore the relationship between group singing and movement synchrony using motion capture technology. The primary research objectives of this study were to (a) determine the feasibility of using motion capture technology to estimate movement synchrony during small group singing, and (b) explore the effect of interpersonal familiarity on observed movement synchrony in small group

singing. Research questions related to feasibility were:

1. Will the recruitment strategies be effective in obtaining an adequate sample of participants for both experimental groups?
2. Will the music intervention be acceptable and achievable for the participants?
3. Will the placement of the motion sensors capture measurable head movement from all four participants?
4. Will analysis of the motion capture outcome data allow for a comparison of movement synchrony between experimental groups?

Synchrony was measured in small groups of singers in two conditions: one group in which the participants all knew one other, and a second in which the participants had an unknown relationship prior to study participation ("strangers"). Using motion capture technology to record the head movement of each participant while singing, the study looked at the feasibility of measuring the synchronicity of each individual with each other person in their group. As synchrony has been linked with social bonding, this study aimed to explore whether synchronicity might be feasibly measured in groups of singers as an objective estimation of social bonding. Qualitative data on the participants' subjective experiences of social bonding was also collected in the form of a brief group interview, to be analyzed and reported separately. This study also focused on differences in the observed synchrony between the two groups to determine whether singing with strangers might facilitate the same level of synchrony, linked to social bonding, as singing with familiar people.

The researcher hypothesized that analysis of the movement data would reveal synchronous movement between participants, and that there would be no difference in the observed synchronicity of singers who were familiar compared to those who were strangers. If

confirmed, this would suggest that the same effects of social bonding experienced by groups of friends or acquaintances singing together could be experienced by groups of strangers seeking community and connection through singing. These results could prove useful to community leaders striving to build or strengthen group connections, as well as to music therapists working with clients on social bonding goals. Additionally, feasibility outcomes from this study aim to contribute to future research involving the use of motion capture technology to capture and analyze the movements of small groups of singers.

As the problem of social isolation continues to grow in today's society, the need for creative interventions to combat the physical, mental, and economic consequences of social isolation and loneliness is clear. Movement synchrony during group singing may be one mechanism by which singing increases social bonding, potentially strengthening the idea that singing with others may be a cost-effective and safe way to increase social bonding and decrease social isolation. This study aimed to explore whether the same level of synchrony could be found in strangers as in groups who already have a social bond, to determine whether group singing may be an opportunity for social bonding in individuals suffering from social isolation. If social bonding can be experienced through synchrony in singing with a collection of random strangers, group singing could hold the key to a powerful, safe, accessible, and cost-effective intervention to target social isolation.

REVIEW OF LITERATURE

Music has been known throughout history as a social activity used to bring groups of people together (Tarr et al., 2014). Shared music-making, singing, and chanting, as well as rhythmic movement such as marching or dancing, have long been part of cultural rituals and traditions in religious, military, and community groups in all parts of the world. These types of shared experiences are often associated with increased social bonding, but the mechanisms by which social bonding occurs are complex, prompting the need for additional research on the various components at play (Tarr et al., 2014). One element common to most group music experiences is a shared sense of rhythm, leading to synchronous behavior (Bispham, 2006). This study aimed to explore the concept of synchrony as it relates to social bonding, particularly through shared music experiences. Additionally, this study sought to explore whether synchronous movement in music extends to group singing, whether spontaneous movement during singing is observable and measurable, and whether motion capture technology might be used as a way to analyze this movement.

Mechanics of Synchrony

Synchrony is defined as "happening, existing, or arising at precisely the same time," (Merriam-Webster, n.d.). Synchronous movements can occur in musical and nonmusical contexts, and may be prescribed, planned movements or natural responses to a rhythm or another person. Synchrony is most easily observed visually, through physical movements happening at the same time, but it can also involve responses that are auditory or internal. Moving in synchrony has been linked to increases in positive behaviors including social bonding, cooperation, prosocial behavior, and even altruistic behavior in a wide range of settings and populations (Cohen et al., 2010; Göritz & Rennung, 2019; Valdesolo et al., 2010; Valdesolo &

Desteno, 2011). These responses are thought, in part, to be the result of neural pathways in the brain activated when people move in time with one another (Overy & Molnar-Szakacs, 2009).

When a person performs an action and that same action is simultaneously observed or heard (in synchrony), neurons in the brain known as "mirror neurons" are activated (Overy & Molnar-Szakacs, 2009). The mirror neuron system involves an individual's "action" and "perception" networks. When activated at the same time, the combination of these networks is thought to result in a blurred sense of "self" and "other" known as self-other merging (Overy & Molnar-Szakacs, 2009). When individuals are less able to distinguish between themselves and the people around them, social bonding, or "the psychological experience of social closeness reflected in prosocial behaviors," is often the result (Tarr et al., 2014, p. 1).

The mirror neuron system is cited in many studies on synchrony to explain how feelings of social affiliation or social closeness result from synchronous movements (Tarr et al., 2014; Tarr et al., 2016; Valdesolo & Desteno, 2011). These studies emphasize the effect of self-other merging on prosocial behaviors, such as increased feelings of affiliation and increased willingness to help another person after synchronizing with them (Kirschner & Tomasello, 2009; Valdesolo & Desteno, 2011). However, most research on the mirror neuron system and synchrony is focused on pairs of participants, as the mirror neuron system is most acutely observable in dyadic interactions (Tarr et al., 2014). In order to understand group social bonding, a more complex understanding of the mechanisms that facilitate social bonding while engaging in synchronous behaviors is necessary.

In addition to the mirror neuron system, Tarr and colleagues propose a second mechanism through which synchronized movements influence social bonding: the release of endorphins through the endogenous opioid system (2014; 2016). The endogenous opioid system

involves the release of endorphins and has been linked to feelings of pleasure when listening to music (Tarr et al., 2014). Endorphins are also released most frequently during synchronized activities. When synchronized movement happens within the context of group music-making, these researchers suggest that the endogenous opioid system is a key neurohormonal factor leading to social bonding (Tarr et al., 2014).

Entrainment

While synchrony does not necessarily require a steady rhythmic beat, synchrony in musical experiences is typically rhythmic. A concept that is integral to a complete understanding of synchrony as it relates to music and rhythm is entrainment. Much research on synchrony in humans is founded on the idea that human beings are naturally rhythmic creatures, born with an innate ability to recognize and synchronize to a rhythmic pattern (Patel et al., 2005). When a person is exposed to an auditory stimulus with a steady beat, the auditory input excites neurons in the spinal cord in a process known as audio-spinal facilitation (Thaut et al., 2014). These neurons prime muscles for movement, which can lead to physical responses such as tapping a foot or nodding along in synchrony with the beat. This process is known as entrainment, or "spatiotemporal coordination resulting from rhythmic responsiveness to a perceived rhythmic signal" (Phillips-Silver et al., 2010, p. 3).

In simpler terms, entrainment is the process through which a person naturally and automatically responds to a perceived rhythm, or any consistent external stimulus, resulting in movements or other observable behaviors happening in synchrony with that rhythm. Anytime entrainment occurs and movement results from it, those movements will be in synchrony with the original rhythmic stimulus (Phillips-Silver et al., 2010). This means that in a group music

experience, the music or rhythm is what facilitates the synchrony between group members as each person entrains to the shared rhythm.

Foundational Synchrony Research

Research suggesting that the ability to synchronize or entrain to rhythm is innate and shared between most humans prompted the need for deeper research on the ways in which individuals synchronize together. Early research exploring synchrony between individuals focuses on one of the most simple but measurable human movements: finger tapping. In a full review of literature on this topic completed in 2013, the researchers highlight the role of finger tapping studies in providing a foundation for studying synchronization in more complex movements (Repp & Su, 2013). Finger tapping studies typically involve measuring participants' abilities to tap a single finger along to an auditory metronome or rhythmic stimulus. An overview of finger tapping literature suggests that individuals are able to synchronize finger taps with a beat consistently starting between ages 5-6 and continuing through elderly years, with no differences in ability generally found between musicians and non-musicians, suggesting most people possess this ability innately (Repp & Su, 2013).

Building from initial finger-tapping studies, research has explored synchrony in more complex movements as technology advances. The same review of literature examined more recent research on interpersonal synchronization in rhythmic activities including walking, dancing, speaking, and performing music. It concluded that the tendency to entrain with others is based on information people perceive about others. The likelihood of that entrainment is also dependent on multiple factors including social factors. Entrainment consequently affects social responses and attitudes which contribute to feelings of group cohesion as a result of synchronous activities (Repp & Su, 2013).

Synchrony and Prosocial Behaviors in Children

Positive, prosocial responses resulting from synchronous behaviors have been found in people of all ages, including children younger than two years old (Carpenter et al., 2013; Cirelli., Einarson, & Trainor, 2014; Cirelli, Wan, & Trainor, 2014; Cirelli et al., 2016). In a series of studies, Cirelli and colleagues investigated 14-month-old babies' altruistic responses after bouncing in or out of synchrony with another person (Cirelli, Einarson, & Trainor, 2014; Cirelli, Wan, & Trainor, 2014; Cirelli et al., 2016). In these studies, babies were held and bounced in time with music by one researcher while facing a second researcher who either bounced in synchrony with them in the same direction, synchronously in the opposite direction (anti-phase), or completely out of synchrony.

Results found that the 14-month-olds were more likely to engage in helping behaviors when the second researcher bounced in synchrony with them, either in phase or anti-phase (Cirelli, Einarson, & Trainor, 2014). Helping behaviors were measured by testing whether the baby helped the second researcher in a simple task such as picking up a dropped object. Subsequent studies revealed that the helping behaviors prompted by bouncing in synchrony could also be transferred to a third researcher when that researcher demonstrated affiliation with the second researcher, further strengthening the social effect that bouncing in synchrony had on the 14-month-old participants (Cirelli, Wan, & Trainor, 2014; Cirelli et al., 2016).

A 2009 study that focused on 4-year-old children from German urban daycares also supports the idea that synchronized musical experiences may promote helping behaviors in young children (Kirschner & Tomasello, 2009). In this study, children were assigned a partner and had to work together to complete a "game" by either singing and marching together or just marching together. The partners then had to complete a task designed to test their willingness to

help one another. Results found that the children were significantly more likely to help out their partner if they were in the singing condition than the non-singing condition (Kirschner & Tomasello, 2009). Similarly, a 2016 study of campers at a YMCA summer camp found that children who participated in a singing group were more cooperative and reported a greater sense of "we"-ness than children in groups focused on art or competitive non-musical games (Good & Russo, 2016). Consistently, in research that compares synchronized activities for children to non-synchronized activities, synchronous movement and singing lead to the greatest positive and prosocial gains.

Synchrony in Non-Musical Activities

While much of the current research on the positive effects of synchrony is focused on synchrony through shared musical experiences, similar positive results have been found in synchronous experiences that do not involve music, such as physical exercise or sports (Cohen et al., 2010; Göritz & Rennung, 2019; Sullivan & Rickers, 2012). In one study, employees of a publishing company were assigned to a physical exercise group involving synchronous movement or a no-movement group for nine weeks. Results found that synchronous movement increased social closeness, reduced stress related to work, and even decreased employees' number of sick days taken following the nine-week treatment (Göritz & Rennung, 2019).

Group synchronous activity also often leads to stronger results than individual rhythmic activity. This was demonstrated by a study comparing competitive rowing on a team to rowing individually. Results found that participants who rowed in a synchronous group demonstrated higher pain thresholds, a proxy measure of endorphin release, than individual rowers (Cohen et al., 2010). A separate study compared rowing individually to rowing on a team of either known teammates or unknown strangers. This study again found that rowing in a synchronous group,

whether or not the group members knew one another, yielded higher pain thresholds than rowing alone (Sullivan & Rickers, 2012).

A 2017 meta-analysis on synchrony reviewed studies in which healthy, undiagnosed participants completed either experimentally-manipulated synchronous actions or control conditions (Mogan et al., 2017). Results of this meta-analysis found that synchronous actions affected all four dimensions of response analyzed: prosocial behavior, perceived social bonding, social cognition, and positive affect. This study also compared results based on group sizes and found that synchrony in large groups resulted in a greater increase in prosocial behavior and positive affect compared to small groups, but no difference was found in measured social cognition or perceived social bonding based on group size (Mogan et al., 2017). Overall, research on synchrony, both in musical and non-musical contexts and particularly in group contexts, consistently reveals links between synchronous movement and increased feelings of social bonding and positive, prosocial behaviors.

Social Bonding in Group Singing

In addition to the constantly expanding body of research on the links between movement synchrony and social bonding, a related area of research focuses on the relationship between group singing and social bonding. Studies link group singing to increases in oxytocin, which may cause increased feelings of closeness and connection with others, and decreases in cortisol, or stress (Keeler et al., 2015; Kreutz, 2014; Pearce et al., 2015; Schladt et al., 2017). A 2014 study comparing singing with others to chatting with others found higher reports of positive feelings, higher measures of oxytocin, and higher overall social bonding in the singing condition (Kreutz, 2014). Singing may also provide a quicker way for social bonding to occur, such as in a 2015 study comparing adult education classes focused on singing to "non-singing" classes. Both

groups in this study led to overall feelings of closeness over time, but the singing group brought participants together at a significantly faster rate than the non-singing group (Pearce et al., 2015).

Studies on group singing often involve participants in choirs, the most common structured form of people singing together. One study compared individuals singing as soloists to the same participants singing in a choir and found that while happiness increased and worry, sadness, and cortisol (stress) decreased in both conditions, positive mood effects were greater after singing in a chorus than singing alone (Schladt et al., 2017). Weinstein et al. compared sizes of choirs and found increased feelings of inclusion, connectivity, positive affect, and endorphin release, as well as comparable pain thresholds, in both the large choir and smaller subgroup choirs (2016). This study also found that smaller subgroups of singers showed greater levels of social closeness both before and after singing together, but that the larger choir had a greater net change in social closeness. Weinstein et al.'s study on a large-scale choir (n = 232) also explored the effect of group singing with people who may or may not know one another, given the large nature of such a choir. Because this study demonstrated that social bonding can occur in both familiar and unfamiliar groups, it has particular relevance to the current study.

Another 2016 study compared individuals from pre-existing subgroups or "Cliques" in a college fraternity in a variety of singing tasks (Pearce et al., 2016). This study specifically measured feelings of "closeness" to participants' own Clique and a competing Clique before and after participating in a singing exercise in one of four conditions: singing competitively or cooperatively with members of their own group and singing competitively or cooperatively with members of a different subgroup. Results from this study found that participants felt significantly closer to their fellow singers after singing with teams from Cliques other than their own in both the competitive and cooperative conditions. However, while cooperative singing with members

of their own Clique also led to increased feelings of closeness, singing competitively with members of their own Clique reduced feelings of closeness. These results support the idea that singing in a group can facilitate increased feelings of closeness regardless of level of familiarity, although singing competitively may have the opposite effect in groups that are extremely close (Pearce et al. 2016).

Synchrony and Social Bonding through Dance

Building from the evidence suggesting links between group singing and social bonding and synchrony and social bonding, the current study aimed to explore whether synchronous movements naturally occur in group singing, with a hope of further strengthening the evidence and possibilities for group singing's potential effects on increasing social bonding. However, very little research specifically explores the natural movements occurring in group singing. Instead, a bulk of the closest research to this topic focuses on synchrony experienced in another musical and rhythmic activity: dance.

In one study measuring the effects of movement synchrony in dance, groups of four strangers were randomly assigned to a synchronous movement condition, a partial synchrony condition, or an asynchronous condition (Tarr et al., 2016). Participants in each group learned a set of four dance moves: either the same moves (synchronous condition), the same moves in a different order (partial synchrony), or moves at a different tempo (asynchronous). Results of this study found that members of the synchronous condition reported the greatest increase in feelings of social closeness and demonstrated elevated pain thresholds compared to the other groups, strengthening evidence connecting synchronous dancing and perceived social bonding (Tarr et al., 2016).

A second study involved dancers performing sets of choreography specifically created to manipulate group synchrony throughout the pieces for four different audiences (Vicary et al., 2017). Levels of synchrony were measured during the performance via wristbands worn by each dancer, and audience members rated their responses to the performances throughout the pieces on tablets. This study found predictive relationships between synchrony, enjoyment ratings, and spectator arousal, suggesting that synchrony in group dancing not only impacts the social connectedness of the dancers to each other, but potentially influences observers' experiences of those movements positively as well (Vicary et al., 2017).

Other studies specifically explore the movements of dancers in dyads (Carlson et al., 2018; Carlson et al., 2019). Carlson, Burger, and Toiviainen explored the natural movements of participants in dyads dancing to different music using motion capture technology (2018). Each participant danced to a variety of music excerpts alone and in dyads with three different partners. Results came from analysis of a variety of factors including participants' amount of movement, self-reported personality and empathy measures, and where on their bodies participants moved most with each of their partners. Results overall showed links between empathy and differences in amounts of movement when dancing with different partners. One finding particularly relevant to the current study showed a significant relationship between female participants' levels of "agreeableness" and their partners' head movements, leading to a suggestion that "head movement may function socially to indicate affiliation in a dance context" (Carlson et al., 2018, p. 1). The current study aimed to build from this finding by exploring the relationships of head movements between participants when singing together using motion capture technology.

Synchrony and Motion Capture

While prior research on movement synchrony has consistently linked synchrony to positive, prosocial outcomes, the methods by which synchrony is measured in these studies often vary. Advances in motion capture technology have opened up new possibilities for recording and analyzing complex physical movements, replacing and/or strengthening previous time-consuming and labor-intensive analysis methods such as hand-coding video recordings frame-by-frame or basic frame-differencing methods (Condon & Sander, 1974; Paxton & Dale, 2013). Despite the availability of more advanced technology, the body of research utilizing motion capture technology to measure synchrony between individuals remains small.

Synchrony has been studied in individuals completing a variety of tasks, including exercising, rowing, dancing, or simply conversing with another person (Carlson et al., 2018; Cohen et al., 2010; Göritz & Rennung, 2019; Paxton & Dale, 2013; Tarr et al., 2016). A 2016 study by Preissmann and colleagues used motion capture technology similar to that of the current study to measure synchrony between two types of dyads: romantic male-female couples, and professional musicians paired with an unknown partner to form a male-female dyad (Preissmann et al., 2016). Data from these sets of couples were compared to a control group taken from a previous study that measured movement synchrony in randomly selected individuals paired with unknown partners to form male-female dyads (Llobera et al., 2016).

In each of these studies, participants wore motion capture suits, and movement synchrony was measured in an implicit task and an explicit task. In the implicit task, participants were asked to walk together in a circle, and the time it took for them to walk in synchrony was recorded. In the explicit task, participants took part in a mirror game, executing a set of movements with a goal of "mirroring" their partner. Motion capture data from each task was then analyzed in a

variety of ways to estimate the levels of synchrony demonstrated by each dyad. Results found that while no difference was observed in the implicit and explicit synchrony tasks for the romantic couples compared to the control group, significant differences were found between the musicians and the control group in both tasks. While Preissmann et al. did not use music in their study of movement synchrony, their findings that musicians more easily synchronize with an unknown partner than romantic partners or the control group led them to an interest in music's role in the social bonding that occurs through synchrony (2016).

Current Study

The current study sought to further previous explorations of synchrony measured by motion capture technology to investigate whether movement synchrony naturally occurs in group singing, and whether that synchrony may feasibly be observed and measured via motion capture technology. Due to the limitations of the motion capture technology proposed for this study, the experimental groups consisted of four participants each, and only the head movement of participants was captured, building from previous research on synchrony using head movements (Boker et al., 2009; Carlson et al., 2018; Himberg & Thompson, 2011;Kwon et al., 2015; Paxton & Dale, 2013). While a major focus of the current study was an analysis of the feasibility of the methodology, preliminary analysis of the motion capture data sought to provide an estimate of movement synchrony in order to compare synchronous movements between groups, further contributing to the current research on this topic. If movement synchrony naturally exists between participants while singing, the results of this study may have important implications for future research on interventions that increase social bonding and decrease social isolation.

METHODS

Study Design

The current study was part a larger, mixed-methods study that used a between groups design with one intervention and two outcome variables, as demonstrated in Figure 1. The

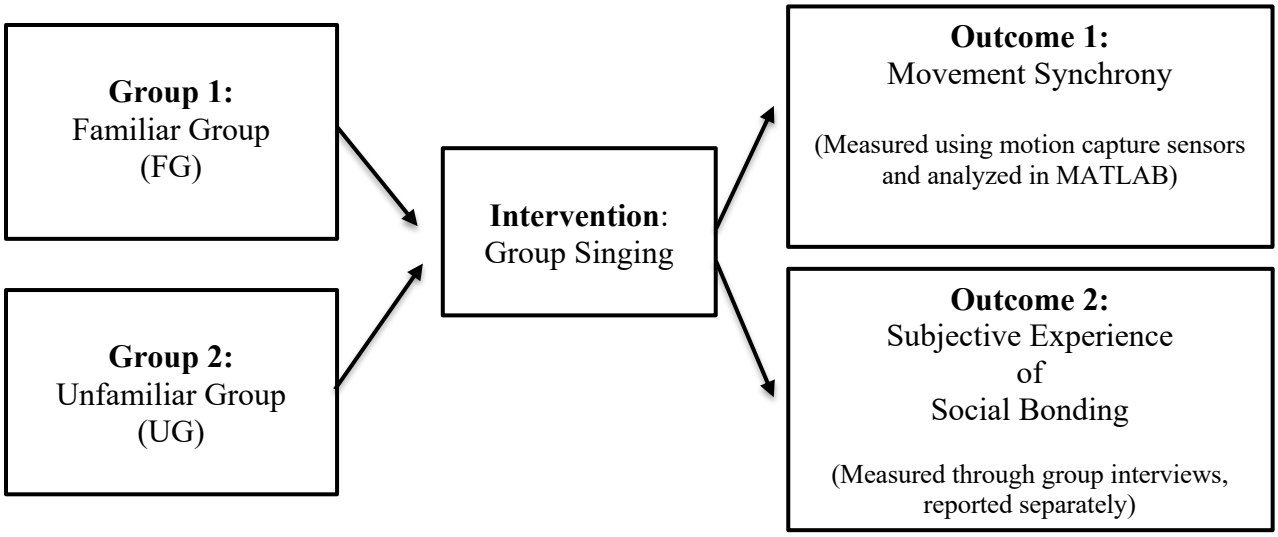

Figure 1. Study Design

participants in this study were assigned to one of two experimental groups: the Familiar Group (FG), in which the participants had a known social connection prior to study participation, and the Unfamiliar Group (UG), in which the participants had no known relationship prior to the study. Both groups completed an identical group singing intervention measured via motion capture technology. The two primary outcome measures for this study included observed movement synchrony, analyzed via motion capture data, and the participants' subjective experience of social bonding, analyzed via a group interview following the singing intervention and reported separately. In addition to analysis of the outcome variables, the feasibility of the study design and procedures was analyzed using study outcomes and researcher reflections based

on recommendations for feasibility trial analysis outlined by LaGasse (2013) and Shanyinde et al. (2011).

Participants

A total of eight participants were recruited and enrolled for this study to form two experimental groups of four. All participants met the inclusion criteria, as they were (1) current Western Michigan University (WMU) students, (2) over the age of 18, and (3) capable of using their voice to sing. Exclusionary criteria included (1) any physical limitations that would prevent movement of the head, and (2) membership in a WMU voice studio, as students in voice studios regularly sing with others multiple times per week. Participants were recruited via flyers posted in campus buildings and emails distributed to students via professors in those buildings. The recruitment information specified that interested individuals could sign up either as an individual or as part of a group of four (see Appendix A for recruitment flyer). Participants communicated interest in the study by emailing the researchers, and information and informed consent documentation were provided to those who expressed interest on a first-come, first-served basis until enough participants were enrolled.

After eligibility was determined and consent obtained, participants were enrolled in one of two experimental groups: the UG, in which the participants had an unknown relationship to the other group members prior to the study, or the FG, in which each participant had a previous social connection with each other member of the group. The FG was recruited as a group of four who confirmed their connection with each other group member as “acquaintance-level or higher” prior to study enrollment.

Instrumentation

Motion capture data was recorded and measured using the Vicon Real-Time Motion Capture System (VICON, Centennial, CO, USA). This three-dimensional motion capture system included six infrared cameras surrounding the experiment space that collected data at a sampling rate of 250 Hz. Small, sphere-shaped reflective plastic markers were attached to the crown of participants' heads via a wide fabric headband to capture head movement of all four participants while singing**.** The head movement motion capture data was processed using the Vicon Nexus software to generate data files in the C3D format, which was then imported into and analyzed in both the Kwon3D Motion Analysis Suite (Visol Inc., Seoul, Korea) and in MATLAB using the MoCap Toolbox (Toiviainen & Burger, 2010) and other functions. While motion capture data was collected, video cameras simultaneously recorded singing from two angles in order to match the timing of the singing tasks with the motion capture data.

Procedure

Data collection for this study took place in a biomechanics lab equipped with Vicon Real-Time Motion Capture technology located on the WMU campus. Both experimental groups were assigned separate times to complete the study, and the procedure for each group was identical.

Upon arrival for their group's session, participants reviewed the informed consent documentation with the researchers to confirm their consent for participation and were given the opportunity to ask questions. The four participants then entered the motion capture recording area and were provided with headbands to capture the movement of their heads while singing. Once all participants were equipped with motion sensors, they were asked to stand in a circle on marked locations approximately three feet apart, facing one another. See Figure 2 for a visual of the lab space and experimental setup.

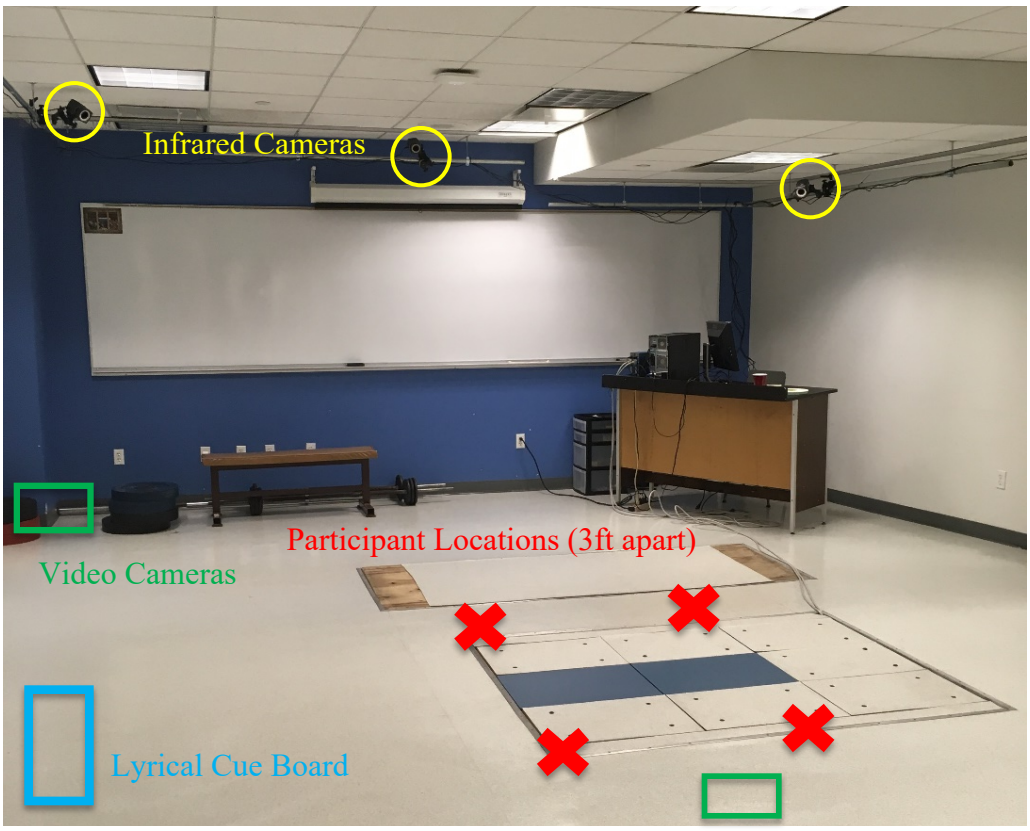

Figure 2. Motion Capture Lab Configuration

Once all participants were in position, a researcher joined the circle and instructed the participants to introduce themselves to the group by saying their first name. The participants then engaged in singing "Happy Birthday" as a warm-up, led by a researcher's starting pitch but with no provided accompaniment. "Happy Birthday" was selected as the warm-up song as it is short, well-known, and often sung among groups with little regard for musical quality. The participants were informed that quality of singing was not a focus of the study but that it was important for study outcomes that everyone sang. After this, the group was presented with the three study songs: "Jingle Bells," "You Are My Sunshine," and "Lean On Me." These songs were selected based on their simple, repetitive forms, ubiquity across age groups, range of genres, and common use in music therapy sessions, based on the researchers' own clinical experience and an analysis of clinical songs by Silverman (2009). The researcher provided lyric sheets for each song and

sang through each song with the group for a "rehearsal period," pausing to answer questions from the group about the form or the lyrics. See Appendix B for copies of the lyric sheets used.

When the group felt comfortable with all three songs, the rehearsal period concluded, the lyric sheets were removed, and the researcher left the circle. Participants were then provided with a poster board positioned outside of the circle, but in view of each participant, listing short lyrical cues for each song and outlining the song format (see Appendix B: lyrical cues from the poster boards are included in italics, titled "Form," beneath each song's lyrics). Participants were encouraged to look at one another during the songs as often as possible and to only look at the poster when necessary. They were asked to sing each song one time as a group following the prescribed form and were instructed to sing and move as they would naturally, making sure to stay on their marked spot. Participants were cued by the researchers as to when to start each song in order to align with the start of the motion capture recording but were not given tempos or starting pitches.

The participants sang through each song as a group, in their own time, for the "recording period" of the study. Motion capture data was recorded for each song separately for purposes of feasibility and analysis. When finished, the participants removed their motion sensors and returned them to the researchers. They were then taken to a separate space to participate in a brief, 10-20-minute group interview about the experience, analyzed separately. Following the interview, participants were given time to debrief with the researchers, concluding their participation in this experiment.

Data Analysis

The head movement data captured by the Vicon system was first processed on Vicon Nexus software to generate the data into a C3D format, or time series data for the three-

dimensional location of the reflective marker of each participant. The C3D file was then imported into the Kwon3D Motion Analysis Suite (Visol Inc., Seoul, Korea) in order to extract the resultant acceleration of the marker. The raw three-dimensional coordinate of the marker was filtered using a Butterworth zero phase-lag 4th-order low-pass filter with a cut-off frequency of 6Hz, determined using the residual method to eliminate experimental errors, in order to analyze the acceleration of each participant, as acceleration has been identified in previous studies to provide general information about overall amount of movement during dance performances (Carlson et al., 2016; Carlson et al., 2018).

The C3D data generated by the Vicon Nexus software was also imported into MATLAB for further analysis using the MoCap Toolbox developed by Toiviainen & Burger (2010). The C3D data was manipulated by the MoCap Toolbox to create time-series data sets representing the velocity and acceleration of the markers in three dimensions. While these data sets could be analyzed in a myriad of ways, the researcher chose to focus on analyzing the cross-correlation of the time-series acceleration data of the vertical dimension for purposes of this study. Vertical acceleration of head movement has been identified in previous studies to capture the periodicity of overall movement, and thus was selected as this study's estimate of movement synchrony between participants (Himberg & Thompson, 2011; Toiviainen et al., 2010).

RESULTS

The objectives of this research study were to (1) explore the feasibility of using motion capture technology to estimate movement synchrony during small group singing, and (2) to explore the effect of interpersonal familiarity on observed movement synchrony. Results of this study include analysis of the feasibility of the methodology as well as preliminary descriptive and statistical analyses of the recorded motion capture data.

Feasibility Results

Feasibility outcomes from this study were examined using guidelines for the assessment and reporting of pilot and feasibility studies outlined by LaGasse (2013) and Shanyinde et al. (2011). These included assessments of sample size, eligibility, recruitment, enrollment, randomization, blinding procedures, adherence to and acceptability of the intervention, and appropriateness of the study protocols, logistics, and outcome assessments (Donald, 2018; LaGasse, 2013; Shanyinde et al., 2011).

Recruitment, Enrollment, and Group Assignment

Eight participants were successfully recruited and enrolled for this study, creating two experimental groups of four participants each. A total of 24 people expressed interest in the study across a three-week recruitment period, 12 of whom expressed interest in participating as individuals or in groups smaller than four people, and 12 who expressed interest in participating as part of a pre-existing group of four. Every person who expressed interest in the study met the inclusion criteria and was eligible to participate with the exception of two individuals who expressed interest in participating together. Both of these individuals would have been eligible to participate in separate UGs had there been multiple UGs in the study design, but they were ineligible to participate together without two other acquaintances to form a FG group of four.

Of the 24 people who expressed interest, nine participants were recruited on a first-come, first-served basis. One individual did not respond to the researchers after their initial email, so recruitment continued until there were a total of eight enrolled participants: four individuals who formed the UG, and a pre-existing group of four individuals who formed the FG. All eight enrolled participants completed the entirety of the study for a 100% retention rate. For purposes of this feasibility study, sample size was kept small, but follow-up trials could scale up the sample size in order to obtain results with more statistical power.

Based on the structure of the study and transparency of the enrollment process, participants were not blinded to their group assignment or to the basic premise of the study as they intentionally enrolled either as an individual or as a group of four and were aware of the composition of the other type of group. The enrollment of participants was also not randomized beyond enrolling participants in the order in which they communicated interest in the study.

Participants in the FG signed up together and each confirmed identifying their relationship with each of the other group members as "acquaintance level or higher" prior to taking part in the study. Participants in the UG signed up individually and had an unknown relationship with the other participants prior to the study. Due to chance, two of the four participants in the UG had met prior to the study, so the four UG participants were not complete strangers prior to the start of the study, but still formed an unfamiliar group of people as a whole. Also of note, although this factor was not assessed prior to the study itself nor controlled for during recruitment, it was revealed through the group interviews following the singing task that all four participants in the UG were music majors, while no members of the FG were music majors. As this study involved making music, this difference between group participants could have impacted the study results.

Music Intervention Acceptability and Participant Adherence

All participants in both groups adhered to the intervention to the best of their abilities. The study design included a rehearsal period for the participants to learn and rehearse the three songs prior to the official recording of the motion capture data. This time was not structured to mandate a specific number of rehearsals per song and was also not timed, and as such, the FG requested more practice than the UG prior to recording. The FG also requested an additional rehearsal of the final song, "Lean On Me," mid-recording period—between songs two and three—prior to its recording. These additional rehearsals were requested due to the group's voiced uncertainty regarding their ability to accurately sing the songs without lyric sheets or a researcher leading them.

The UG had a shorter overall rehearsal period but had to record the first song, "Jingle Bells," twice due to an unexpected problem with the motion capture technology. Both groups also exhibited some difficulty in following the prescribed song forms using the lyrical cue boards, as the UG spontaneously added an additional verse and chorus to "Lean On Me," while the FG left out the second half of the final chorus of "Jingle Bells." Overall, both groups sang together, either in rehearsal or while being recorded, for more time than planned, and followed the song forms to the best of their abilities. A breakdown of each song's prescribed form and each group's actual performance is outlined in Table 1.

The music intervention appeared to be acceptable to participants, as at no point during the intervention did participants report that the task was more uncomfortable or difficult than expected based on the informed consent and information provided about the study. The exception to this was the FG's voiced concern for their ability to remember "Lean On Me" and subsequent request for an additional rehearsal between recordings. The length of the rehearsal

Table 1
Prescribed Song Forms and Duration of Actual Recording Periods

Song	Prescribed Form	FG Actual	UG Actual
Jingle Bells	Jingle... Dashing... Jingle... Dashing... Jingle...	Jingle... Dashing... Jingle... Dashing... *Jingle... (ended halfway through this chorus)*	Jingle... Dashing... Jingle... Dashing... Jingle… *(Sang entire song twice due to motion capture technical difficulties)*
Duration of Singing		1m 14s	1st time: 1m 28s 2nd time: 1m 22s
You Are My Sunshine	Sing 3 times total	Sung 3 times total	Sung 3 times total
Duration of Singing		54s	1m 11s
Lean On Me	Sometimes in our lives... Lean on me... So just call... Lean on me... Lean on me…	Sometimes in our lives... Lean on me... So just call... Lean on me... Lean on me…	Sometimes in our lives... Lean on me… *Sometimes in our lives…* *Lean on me…* So just call... Lean on me... Lean on me…
Duration of Singing		1m 47s	2m 43s
Total Duration of Singing		3m 56s	6m 44s

period for each group was not recorded. The FG sang for a total recorded time of 3 minutes and 56 seconds, excluding the additional rehearsal mid-recording period, across all three songs. The UG sang for a total recorded time of 6 minutes and 44 seconds, due to the repetition of the first song, and because of a spontaneously added repetition of a portion of the third song that occurred naturally as the participants sang, as noted in Table 1. Each group also completed a group interview immediately following the recorded singing, lasting no longer than 20 minutes, and analyzed in a separate paper, for a total study time of less than one hour. The intervention was of

no cost to the participants aside from time and potential shifts in mood. Participants were reimbursed with one $40 gift card each for their participation in the study.

Outcome Measures and Analysis

Motion capture data of each participant's head movement was recorded for the duration of each song. The use of wide fabric headbands was successful for placement of the reflective markers, and the motion capture system was able to capture the head movements of all four participants via the Vicon Real-Time Motion Capture system. No recording problems occurred during the FG trial, but during the UG session, due to unexpected problems with the system, participants recorded the first song, "Jingle Bells," twice as the first data was unable to be used. Video data was successfully recorded from two angles for preliminary observational analysis, and the motion capture data was successfully processed and exported as three-dimensional C3D data for analysis, described below.

Motion Capture Results

After initial real-time and video observations of the singing task, the researcher determined that it was important to begin analysis with an investigation of overall movement, as visible head movement appeared minimal to the eye. Acceleration was selected for this preliminary analysis as it has been used in previous motion capture studies as an estimate of a participant's overall amount of movement (Carlson et al., 2018).

In order to visualize the acceleration of each participant, the acceleration data extracted from the Kwon3D Motion Analysis Suite representing the acceleration of the overall three-dimensional position of each participant was analyzed. Due to an unexpected and unsolvable problem in the system, acceleration data from the UG's third song ("Lean On Me") was unable to be exported and analyzed during this portion of the analysis. The average acceleration per

second was calculated for each participant and each song, with the exception of the UG's "Lean On Me," in order to graph acceleration per second to visualize overall movement for each participant in each song and group. Figure 3 below depicts the overall acceleration data for the FG participants singing "Jingle Bells."

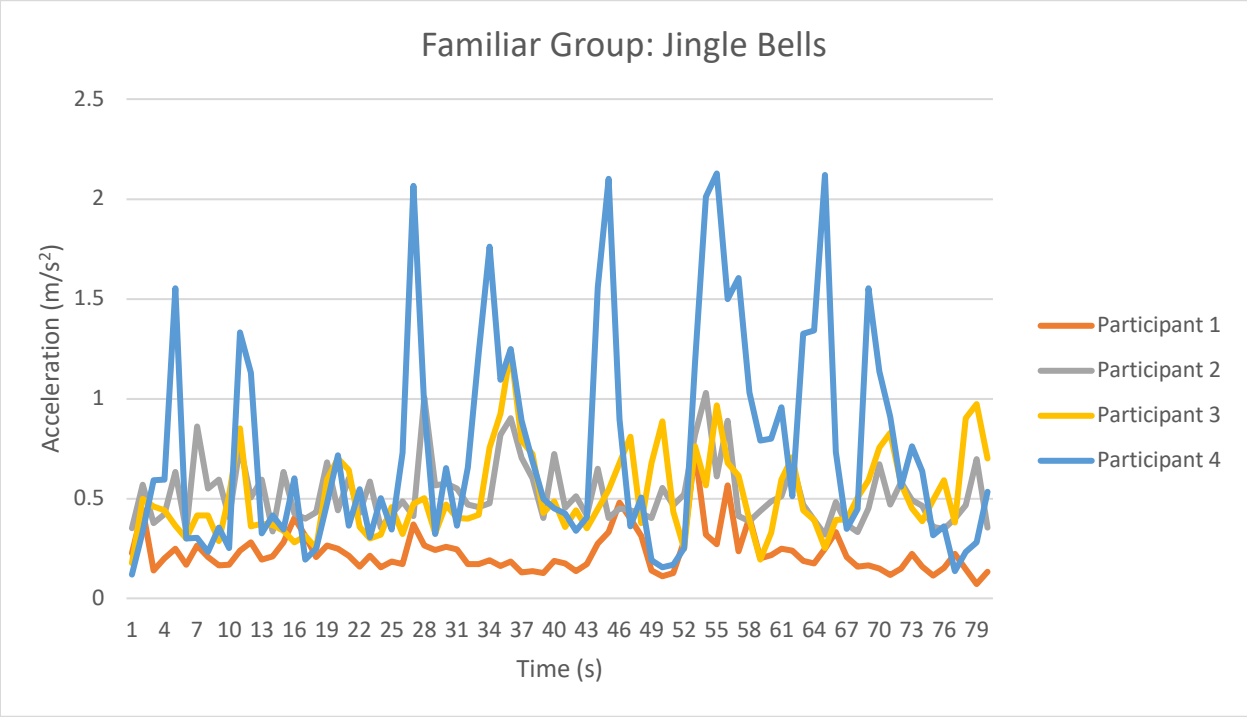

Figure 3. FG "Jingle Bells" Participant Acceleration

As seen in Figure 3, the overall acceleration for most participants was fairly minimal, or less than 1 m/s^2. The exception to this was Participant 4, who demonstrated significant spikes in acceleration throughout the song, supported by video data showing that Participant 4 often demonstrated more noticeable head movement than the other participants. Despite the relatively small amount of movement demonstrated by most participants, graphing acceleration in this manner highlighted the potential for synchronous movement to be identified between participants, particularly in moments when acceleration spiked for multiple participants simultaneously (such as around the 11-second, 35-second, and 55-second marks in Figure 3).

Graphs of overall acceleration data for the other songs and other group can be found in Appendix C, and reveal similar acceleration spikes in each condition. Based on these findings, the researcher chose to further the analysis of the motion capture data using MATLAB to explore for levels of movement synchrony between participants.

The C3D data generated by the Vicon Nexus software was imported into MATLAB for further analysis using the MoCap Toolbox developed by Toiviainen & Burger (2010). The C3D data was manipulated by the MoCap Toolbox to create time-series data sets representing the acceleration of the markers in three dimensions. While much could be analyzed from this data set, for purposes of this study, analysis focused on the cross-correlation of the time-series data representing the vertical dimension of acceleration as our estimate of movement synchrony between participants, based on previous studies conducting similar analyses (Himberg & Thompson, 2011; Toiviainen et al., 2010).

In order to calculate cross-correlation data, a function in MATLAB written by Olivier Lartillot was used (2009, University of Jyväskylä). This cross-correlation function compared the time-series vertical acceleration data of dyads to determine correlation coefficients, or levels of how closely two participants' accelerations aligned in time. These were calculated with lags of up to 25 frames, or roughly 0.2 seconds, in both directions to account for leader/follower effects if one person's movements were in time but slightly ahead or behind. The cross-correlation data generated correlation coefficients across time for each participant with absolute values ranging between 0 and 1, where 0 indicates no synchrony and 1 indicates perfect synchrony. This data was computed for each possible dyad of participants for a total of six sets of data per song, and analyzed to determine the mean, maximum, and standard deviation (SD) of correlation coefficients for each dyad in each song. These results are reported in Table 2.

Table 2
Cross-Correlation Coefficient Data

Participant Pairings	Familiar Group			Unfamiliar Group		
	Mean	*Maximum*	*SD*	*Mean*	*Maximum*	*SD*
Song 1: Jingle Bells						
1&2	0.6767	0.9168	0.1148	0.5907	0.8840	0.1321
1&3	0.4798	0.8318	0.1395	0.6630	0.8699	0.0929
1&4	0.4728	0.7875	0.127	0.5038	0.8111	0.1197
2&3	0.4733	0.8036	0.1387	0.6334	0.8264	0.0973
2&4	0.4006	0.7205	0.1333	0.4796	0.8678	0.1557
3&4	0.3850	0.8198	0.1706	0.5441	0.8533	0.1600
Averages	**0.4814**	**0.8133**	**0.1373**	**0.5691**	**0.8521**	**0.1263**
Song 2: You Are My Sunshine						
1&2	0.6451	0.8656	0.1020	0.5973	0.8694	0.1430
1&3	0.4966	0.8043	0.1487	0.6965	0.9165	0.1195
1&4	0.4715	0.7884	0.1239	0.5094	0.8293	0.1235
2&3	0.4942	0.7527	0.124	0.6207	0.8476	0.1020
2&4	0.4158	0.6548	0.0995	0.4746	0.8101	0.1756
3&4	0.4419	0.7706	0.1328	0.5738	0.9194	0.1700
Averages	**0.4942**	**0.7727**	**0.1218**	**0.5787**	**0.8654**	**0.1299**
Song 3: Lean On Me						
1&2	0.6302	0.8478	0.1130	0.5186	0.8694	0.1430
1&3	0.4620	0.8312	0.1336	0.6314	0.9165	0.1195
1&4	0.4944	0.7968	0.1171	0.4973	0.8293	0.1235
2&3	0.4581	0.8068	0.1116	0.6499	0.8476	0.1020
2&4	0.4353	0.7141	0.1129	0.5110	0.8101	0.1756
3&4	0.4171	0.7808	0.1506	0.6115	0.9194	0.1700
Averages	**0.4829**	**0.7963**	**0.1231**	**0.5700**	**0.8813**	**0.1389**

As Table 2 shows, while there is variation in the mean and maximum correlation coefficients within each song, the SD for each song remains fairly consistent across songs and groups. In general, the mean and maximum correlation coefficients appear to be higher in the UG compared to the FG, although specific participant pairings in the FG consistently stand out as higher than others, such as the pairing of Participant 1 with Participant 2. In the UG, pairings that include Participant 3 appear to be higher than pairings that do not include Participant 3.

Although this study's small sample size deems any statistical analysis of this data insufficiently powered, an independent samples t-test was conducted in SPSS to represent how a sufficiently-powered study of the same design might compare the mean cross-correlation coefficients between the FG and UG. Results of this independent samples t-test found that there was a significant difference in the mean cross-correlation coefficients for the FG (M = 0.4861, SD = 0.08273) and the UG (M = 0.5726, SD = 0.06928), assuming equal variance based on Levene's Test for Equality of Variances, t(34) = -3.399, p = 0.002. The statistical test results are reported in Tables 3-4.

Table 3
Group Statistics

Group	*N*	*Mean*	*Std. Deviation*	*Std. Error Mean*
FG	18	0.4861	0.08273	0.01950
UG	18	0.5726	0.06928	0.01633

Table 4
Independent Samples T-Test

	F	*Sig.*	*t*	*df*	*p*
Equal Variances Assumed	0.025	0.875	-3.399	34	0.002
Equal Variances Not Assumed			-3.399	32.983	0.002

These results suggest that interpersonal familiarity may have had an impact on observed levels of group synchrony. Specifically, the p-value of 0.002 suggests that participants in the UG, who had no previous known relationship prior to singing together, moved together with demonstrated levels of synchrony greater than those of the participants in the FG who knew one another prior to the study.

DISCUSSION

As the negative impact of social isolation continues to grow in today's society, the need for safe and cost-effective therapeutic interventions to address these problems increases. Movement synchrony and group singing have both been identified as potential mechanisms through which social bonding can occur, effectively decreasing the harmful effects of social isolation (Anshel & Kipper, 1988; Cohen et al., 2010; Göritz & Rennung, 2019; Valdesolo et al., 2010; Valdesolo & Desteno, 2011; Weinstein et al., 2016). This study sought to explore how movement synchrony may play a role in group singing, measured via motion capture technology, with the idea that the natural occurrence of synchrony in group singing may further strengthen the social bonding effect of singing with others. Specifically, this study explored the feasibility of using motion capture technology to estimate natural movement synchrony during small group singing, and the effect of interpersonal familiarity on that observed movement synchrony, in an effort to further previous research connecting group singing and social bonding and synchrony and social bonding.

Results of this study revealed that the methodology was feasible overall. However, there were elements of the study protocol, technical difficulties, and limitations to the study that could be improved in future research. The study's preliminary findings also reveal that while overall movement during group singing was minimal, recording head movement while singing yielded data that could be analyzed in dyads to create estimates of movement synchrony between group members. Statistical analysis suggested potential differences in movement synchrony between the experimental groups, contradicting the original hypothesis of the study, although the small sample size and unexpected additional differences between the experimental groups may limit

what can be drawn from these findings. The feasibility and motion capture data results are discussed below.

Feasibility Discussion

Recruitment, Enrollment, and Group Assignment

As outlined in the results, the overall methodology of the study proved feasible. The recruitment methods were successful in recruiting ample participants who met the eligibility criteria for both experimental groups, and all enrolled participants successfully completed the entire study. One unexpected factor in the makeup of the experimental groups was the fact that two participants in the UG had met prior to the study, which was not discovered until the group interview following the singing task. This meant that the UG did not consist entirely of individuals who had never met, although the group as a whole was still unfamiliar with one another. This occurred due to chance, likely because all participants were recruited from the same campus buildings in a single university. Using a larger sample size with multiple FGs and UGs would likely mitigate the impact of these chance occurrences. Additionally, future researchers could include a question for each participant in the UG rating their familiarity with each other group member before beginning the study. If future studies aim to translate this work towards a clinical application, however, the need to control for a completely unfamiliar UG may decrease, as therapy groups and community groups often include a mix of familiar and unfamiliar group members.

Another potentially confounding factor was the difference in musical background between groups. While this was not assessed as part of this study's protocol, it was revealed in the group interviews that all four UG members were music majors, while no FG members were music majors. As this study directly involved making music, this could have impacted the study

outcomes, particularly as this study utilized a between-groups design. The intention behind not controlling for musical background was to allow for participants with a random mix of musical backgrounds to participate together. However, given the clear difference in musical backgrounds separating these two groups and the study's small sample size, there is no way to determine the level of impact this difference may have had on the outcome measures. It could also be possible that people with more musical experience, such as music majors, were more likely to enroll as individuals in a study requiring music-making, which would increase the likelihood of those participants having met prior to the study when recruiting from a limited sample population. Overall, it may be useful in future studies to collect more preliminary information from each participant, including previous music experience, academic area, and familiarity with each other group member, prior to the study or to include additional eligibility criteria to control for these factors.

Participants were also not blinded to their group assignment or to the independent variable of interpersonal familiarity due to transparency on the recruitment flyer and the informed consent documents outlining the two options for enrollment. The knowledge that their group, either consisting of people they knew or did not know, was being compared to a group of the opposite constitution, may have impacted their participation in some way. Having to wear a motion capture sensor at the crown of the head and stand in view of the motion capture cameras may have also influenced the ways participants may have otherwise naturally moved. While knowledge of the motion capture data collection could not necessarily be controlled in future motion capture-specific studies, it may be possible to recruit participants in different ways, perhaps recruiting for each experimental group separately, in order to control for awareness of the interpersonal familiarity factor.

Music Intervention Acceptability and Participant Adherence

Participants in both groups completed the full duration of the singing and interview portions of this study. While no participants voiced concerns or complaints over the study procedures, both groups spontaneously strayed from the prescribed song forms in small ways, including the technical problem in the UG's "Jingle Bells," as well as the spontaneous deletion of the last part of the FG's "Jingle Bells," and both groups' confusion during "Lean On Me." Both groups later identified "Lean On Me" as the song they were least familiar with in the group interviews. While the technical problem in "Jingle Bells" could be addressed by advance testing and more extensive rehearsal with the motion capture equipment, concerns over participants' abilities to accurately follow the prescribed song forms could be addressed through assessing what songs are used in this type of study and how those songs are presented.

The three songs used in this study were selected based on their simple, repetitive forms and their ubiquity across age groups informed by the researchers' clinical experience and an analysis of clinical songs (Silverman, 2009). However, while "Jingle Bells" and "You Are My Sunshine" appeared to be acceptable to the participants, "Lean On Me" presented more of a challenge with this population. Future studies could explore the use of other songs or take participants' preferences into consideration, either by asking for song requests from participants or providing song options prior to the study time in order for participants to prepare and learn the songs in advance, to control for confusion about the songs' lyrics or forms. Lyric sheets were only used in the rehearsal period of this study in an effort to encourage participants to look at one another instead of looking at the lyrics. However, the use of one poster board of lyrical cues may not have been the most effective way to mitigate this challenge while still supporting participants in singing these songs with such short rehearsal time. Future studies may try placing multiple

posters of lyrical cues in different areas for easier viewing by all participants, or experiment with different methods of providing visual cues to guide participants through the songs. Additionally, future studies could explore the option of including fewer than three songs, as movement synchrony and differences between groups may be captured in a single song.

This study design did not include an external rhythmic stimulus such as a metronome click or accompaniment pattern for the participants to sing along to, nor were participants provided with a starting tempo or pitch. This was an intentional choice as the goal of this study was to explore how the participants moved and worked together to sing these songs, with the hope that having no external stimulus to entrain to would require the participants to work together to entrain to and synchronize with one another. However, this lack of provided musical or rhythmic structure could have further contributed to some participants' feelings of uncertainty and hesitation when singing, and therefore moving, in this unfamiliar setting and while attempting newly assigned songs of varying familiarity. It may be interesting for future researchers to explore how the presence of an external rhythmic stimulus may affect the findings. While participants with musical backgrounds may find an additional stimulus structure grounding or comforting, it is also possible that those with less musical experience might find it creates additional pressure or a need to sing "correctly" in order to align with the external source. Obtaining subjective interview data on the experience of singing in an unfamiliar group to this type of external stimulus would likely be useful in exploring this type of study design.

Outcome Measures and Analysis

Aside from the technical problem during the first recording of the UG's "Jingle Bells," head movement data was successfully captured for all four participants in each condition using the Vicon Real-Time Motion Capture System. This data was analyzed in the Kwon3D Motion

Capture Suite with the exception of the UG's "Lean On Me," but C3D data for all six song conditions was successfully analyzed in MATLAB for cross-correlation calculations.

Motion Capture Discussion

As described in the results, the motion capture analysis began with an analysis of participants' acceleration as an estimate of their overall amount of movement. Graphing this data revealed simultaneous peaks in acceleration, seen in Figure 3 and in Appendix C, warranting further investigation by calculating cross-correlations of the data sets. The cross-correlations of the vertical acceleration was calculated for each possible pair of participant dyads in each condition. Results of these calculations, detailed in Table 2, demonstrated fairly consistent mean, maximum, and standard deviation values for the cross-correlation coefficients for each pair of participants across all three songs, suggesting some consistency in how each participant moved in relation to the others in their group for the duration of all three songs. Certain dyads in each experimental group demonstrated consistently higher correlation coefficients than others, including the pairing of Participants 1 and 2 in the FG, and any participant paired with Participant 3 in the UG, suggesting that these pairings may have been more "in synch" than others. Further analysis of the differences in results between pairings may also lead to interesting findings related to the presence of leader or follower roles within the group.

These results also reveal higher mean and maximum cross-correlation coefficients in the UG than the FG overall, further supported by the independent samples t-test. However, it is important to acknowledge that little can be concluded from this comparison given the insufficient power of a sample size of only four participants per group. As previously discussed, it is also important to acknowledge that interpersonal familiarity was not the only factor that differentiated these groups of participants, as they also differed in level of previous musical

experience. It is possible that the fact that the participants in the UG were all music majors, and therefore are used to making music with groups of people, could have contributed to their higher synchrony scores, regardless of their level of familiarity. Interestingly, this finding aligns with previous research suggesting that pairs of unfamiliar musicians may more easily synchronize with one another compared to pairs of familiar non-musicians (Preissmann et al., 2016). Because of the small sample size of this study, none of these claims can be made with sufficient evidence, but they do provide interesting insight for future research in this area.

Future researchers may also want to take into account that while head movement data was able to be analyzed because of the sensitivity of the motion capture system, the participants in both groups did not naturally display much head movement that was visible to the eye. While the motion capture data picked up similarities in participants' movements, it may be interesting to explore whether the participants themselves were aware of how they were or were not naturally moving with the others in their group, or the effect that prescribing specific choreographed movements may have on this type of study. Song choice may again play an interesting role here, as exploring different genres of music that naturally promote more movement, adding an accompaniment for the participants to sing along with, or even just a metronome click as discussed above, could add further motivation or freedom for natural movement compared to the a cappella singing of the songs used in this study.

It may also be interesting for future researchers to alter the experimental setup or the language used around how the participants were asked to move, as this may have impacted the little visible movement demonstrated by these groups. Participants were asked to move as they would naturally but were also asked to make sure to stand on their marked location in order to ensure their motion capture sensor could be detected. Being asked to stand in one place could

have limited how participants might otherwise have naturally moved together; future research might explore allowing more freedom of where or how participants are asked to stand. While doing so might limit the number of participants the motion capture sensors could feasibly record at once, decreasing the number of participants (for example, exploring singing in dyads), could provide interesting insight on a fuller range of the natural movement a person might demonstrate when singing with someone else.

Replicating this study with only dyads could also include measuring data from more than just the head movement, as it is possible that while head movement is the strongest indicator of synchrony in dancers, there may be other body parts that result in more useful data in singers. Future researchers could consider measuring other movements such as trunk sway or hand and arm movement, as each of these were visible in the video data from this study. Additionally, while this study explored head movements of people singing together in a one-time singing task, it may be interesting to see how levels of movement and synchrony differ over time in people singing together across more than one session. Each of these ideas for future research could expand on the feasibility results of this study and further strengthen what is currently known about the use of motion capture technology to measure movement in people singing together.

Overall, findings from the motion capture data suggest that while natural head movement during group singing may not be conspicuous, differences in movement can be detected via motion capture and analyzed to provide an estimate of synchrony between participants using cross-correlation comparisons. This study focused specifically on the cross-correlation of vertical acceleration data, but much more could be analyzed from what was collected, including acceleration of the other dimensions or of the overall position of the participants. The knowledge

that detecting measurable differences during group singing is possible opens the door to much potential future research in this area.

Implications and Conclusion

The goal of this study was to explore the feasibility of measuring synchronous movements in small groups of singers, building from previous research suggesting links between group singing and increased social bonding, and movement synchrony and social bonding. The study also sought to explore whether interpersonal familiarity within members of the singing groups had an effect on the measures of observed synchrony. Results of this study found that the methodology was feasible overall, although adaptations to the study protocol may be beneficial in future studies in this area. Analysis of the motion capture data collected revealed a measurable estimate of synchrony between group participants, and this level of synchrony was higher in the UG, or "strangers," than in the FG for this set of participants. Further research with larger sample sizes could strengthen these findings and provide additional insight into the role that interpersonal familiarity may play in observed synchrony while singing.

Overall, this study adds to previous research in the areas of both group singing and movement synchrony as they relate to social bonding. Each of these activities have been found to play a role in increasing social bonding, an important goal as the world grapples with increasing cases of social isolation and its negative effects. If movement synchrony is a naturally occurring part of group singing, as this study suggests it may be, this could further strengthen the role that singing with others—acquaintances or strangers—may have on bringing socially isolated people closer together.

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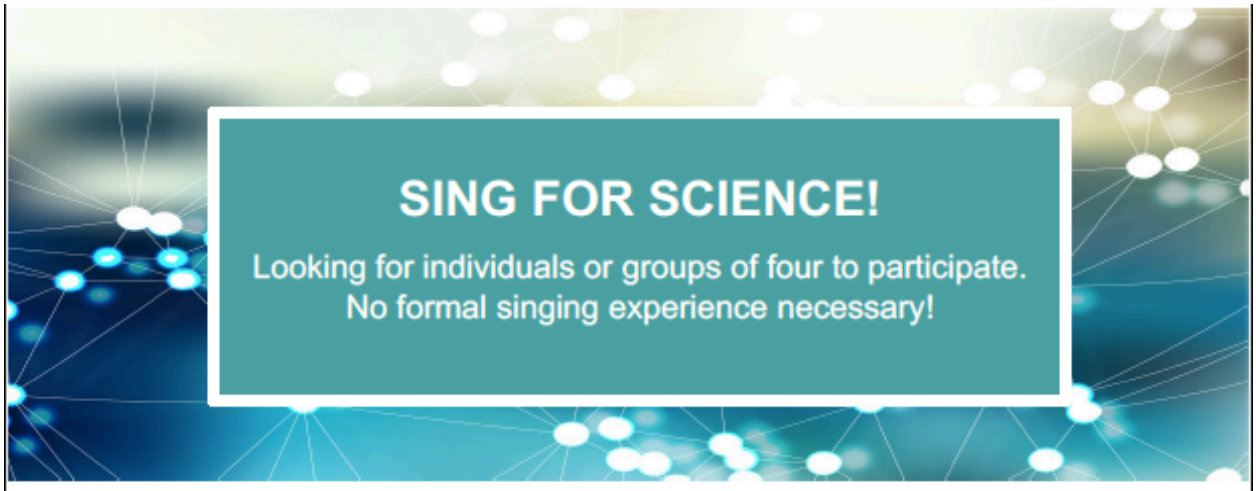
APPENDIX A

Recruitment Flyer



SING FOR SCIENCE!

Looking for individuals or groups of four to participate.
No formal singing experience necessary!

Interested in a research study involving singing familiar songs in a small group while wearing motion capture sensors?

This study will explore how people move while singing together. Participants will be asked to sing three short songs as a group while wearing motion capture sensors, followed by a brief interview about their experience. No formal singing experience or musical background is necessary to participate!

Interested participants may sign up as individuals or in groups of four. Please let our researchers know if you have a group of four people interested in completing the study together.

Each participant will receive:

- A $40 gift card as compensation for their time
- Information on results of the study at its completion

Location

- Study participation involves one 60-minute session located in the WMU Student Recreation Center

Are you eligible?

- 18 years of age or older
- Currently a WMU student
- Capable of using your voice to sing
- Not a member of a WMU School of Music Voice Studio

If you're interested in participating or unsure if you meet the requirements, email a member of the study team:

- Student Investigators:
  - Sheridan Brown, MT-BC: sheridan.r.brown@wmich.edu
  - Molly Grettenberger, MT-BC: molly.a.grettenberger@wmich.edu
- Principal Investigator:
  - Edward Roth, MM, MT-BC: edward.roth@wmich.edu

Contact us for more information!

Sing for Science Study
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APPENDIX B

Lyric Sheets

Jingle Bells

Jingle bells, jingle bells
Jingle all the way
Oh what fun it is to ride
In a one-horse open sleigh
Jingle bells, jingle bells
Jingle all the way
Oh what fun it is to ride
In a one-horse open sleigh

Dashing through the snow
In a one-horse open sleigh
O'er the fields we go
Laughing all the way
Bells on bobtails ring
Making spirits bright
What fun it is to ride and sing
A sleighing song tonight

Form: Jingle, Dashing, Jingle, Dashing, Jingle

You Are My Sunshine

You are my sunshine, my only sunshine
You make me happy when skies are gray
You'll never know dear, how much I love you
Please don't take my sunshine away

Form: Repeat 2 times (sing 3 times total)

Lean On Me

Sometimes in our lives
We all have pain
We all have sorrow
But, if we are wise
We know that there's
Always tomorrow

Lean on me, when you're not strong
And I'll be your friend
I'll help you carry on
For, it won't be long
'Til I'm gonna need
Somebody to lean on

So just call on me brother, when you need a hand
We all need somebody to lean on
I just might have a problem that you'll understand
We all need somebody to lean on

Form: Sometimes in our lives, Lean on me, So just call,
Lean on me, Lean on me

APPENDIX C

Acceleration Graphs

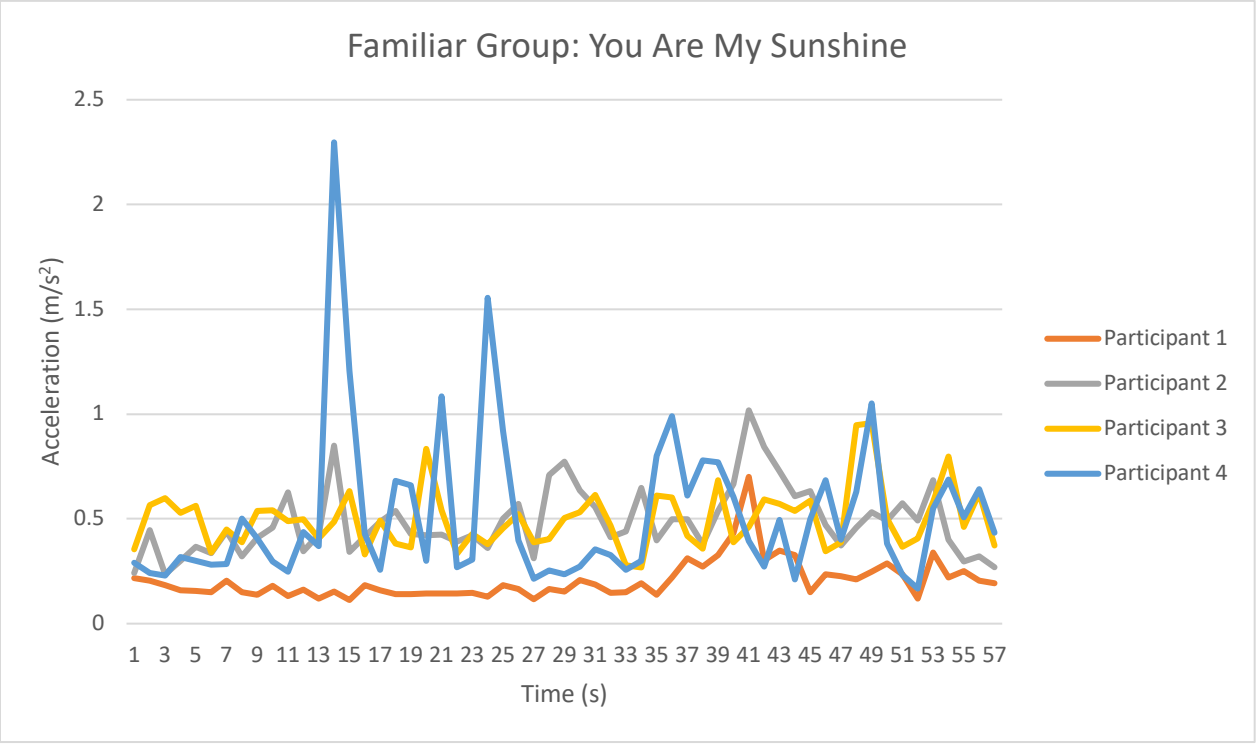


Figure 4. FG "You Are My Sunshine" Participant Acceleration

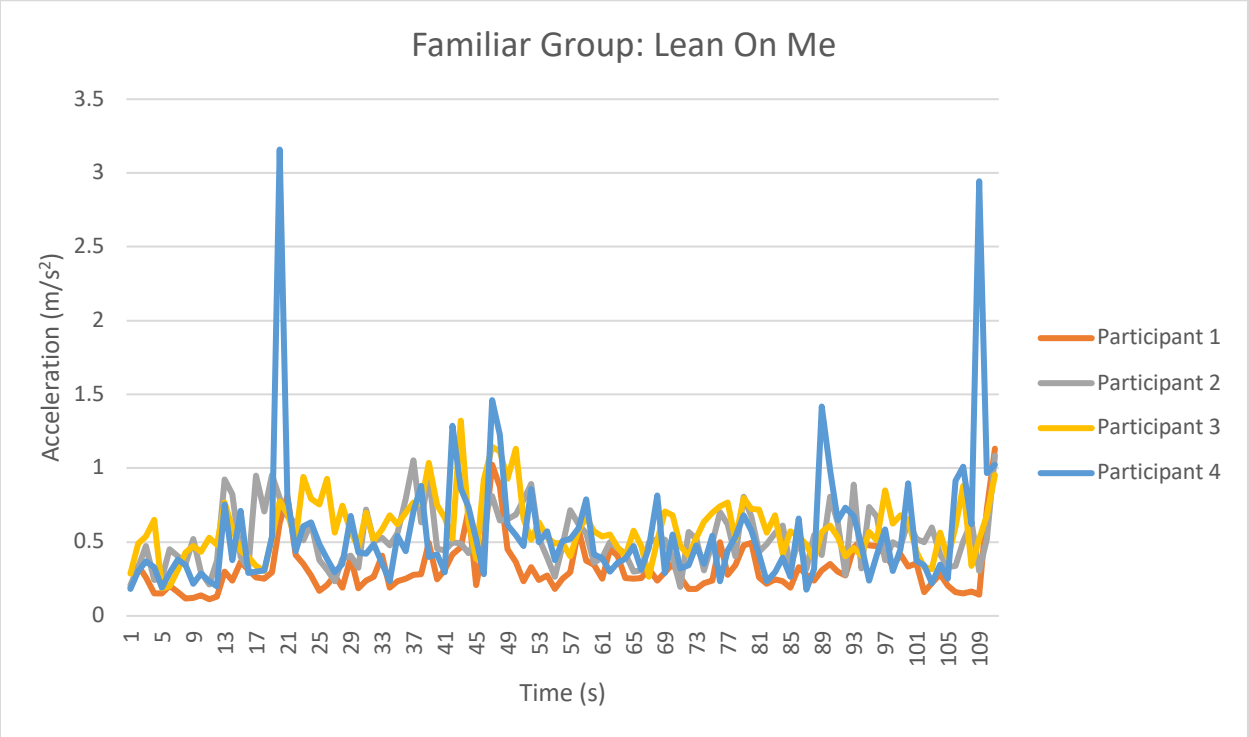


Figure 5. FG "Lean On Me" Participant Acceleration

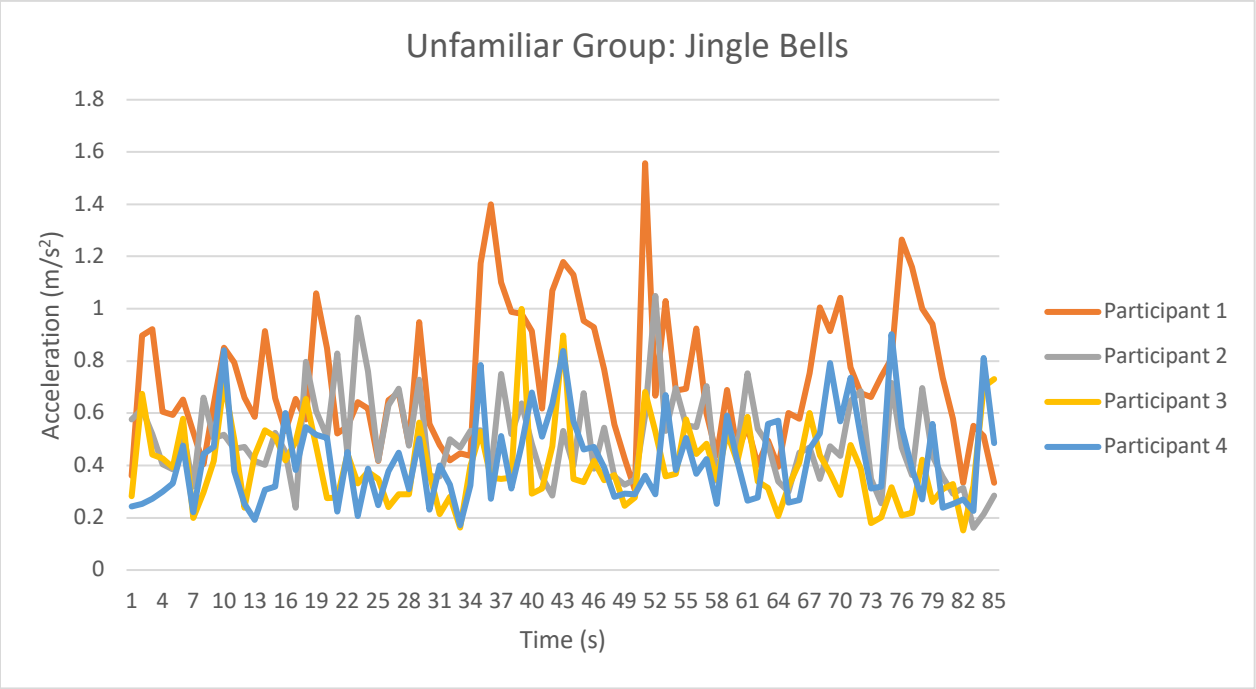


Figure 6. UG "Jingle Bells" Participant Acceleration

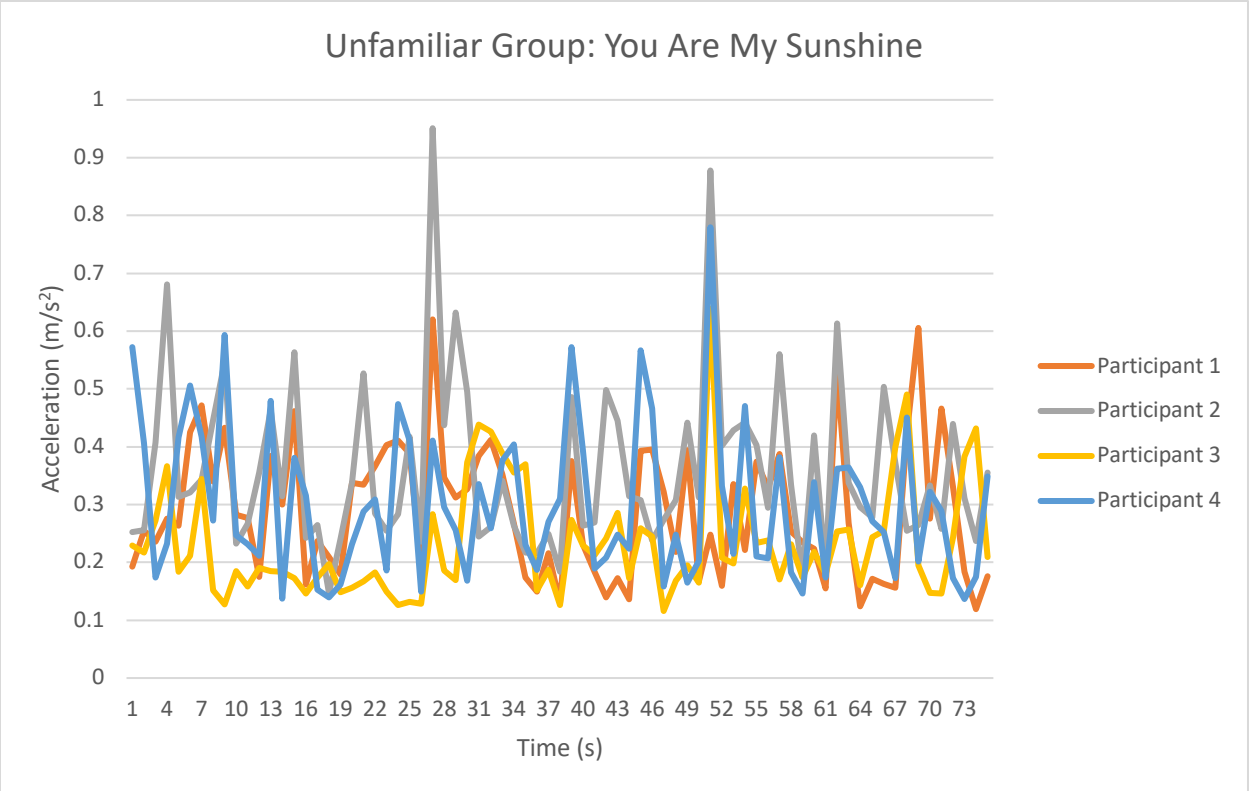


Figure 7. UG "You Are My Sunshine" Participant Acceleration

APPENDIX D

HSIRB Approval Letter

WESTERN MICHIGAN UNIVERSITY

Institutional Review Board
FWA00007042
IRB00000254

Date: October 21, 2019

To: Ed Roth, Principal Investigator
Sangwoo Lee, Co-Principal Investigator
Sheridan Brown, Molly Grettenberger, Student Investigators for thesis

From: Amy Naugle, Ph.D., Chair

Re: IRB Project Number 19-10-32

This letter will serve as confirmation that your research project titled "Singing with Strangers: The effect of Interpersonal Familiarity on Synchrony and Social Bonding in Group Singing" has been **approved** under the **expedited** category of review by the Western Michigan University Institutional Review Board (IRB). The conditions and duration of this approval are specified in the policies of Western Michigan University. You may now begin to implement the research as described in the application.

Please note: This research may **only** be conducted exactly in the form it was approved. You must seek specific board approval for any changes to this project (e.g., ***add an investigator, increase number of subjects beyond the number stated in your application, etc.***). Failure to obtain approval for changes will result in a protocol deviation.

In addition, if there are any unanticipated adverse reactions or unanticipated events associated with the conduct of this research, you should immediately suspend the project and contact the Chair of the IRB for consultation.

The Board wishes you success in the pursuit of your research goals.

A status report is required on or prior to (no more than 30 days) October 20, 2020 and each year thereafter until closing of the study.

When this study closes, submit the required Final Report found at https://wmich.edu/research/forms.

Note: All research data must be kept in a secure location on the WMU campus for at least three (3) years after the study closes.

Office of the Vice President for Research
Western Michigan University
1903 W. Michigan Ave., Kalamazoo, MI 49008-5456
PHONE: (269) 387-8293 FAX: (269) 387-8276
WEBSITE: wmich.edu/research/compliance/hsirb

CAMPUS SITE: Room 251 W. Walwood Hall

APPENDIX E

Informed Consent Documents

Western Michigan University
Music Therapy Department

Principal Investigator: Ed Roth, MM, MT-BC, Professor and Director of Music Therapy
Student Investigators: Sheridan Brown, MT-BC, Molly Grettenberger, MT-BC
Title of Study: Singing with Strangers: The Effect of Interpersonal Familiarity on Synchrony and Social Bonding in Group Singing

STUDY SUMMARY: This consent form is part of an informed consent process for a research study, and it will provide information that will help you decide whether you want to take part in this study. Participation in this study is completely voluntary. The purpose of the research is to examine the relationships between singing and synchrony and singing and social bonding. This research will serve as both Sheridan Brown and Molly Grettenberger's theses for the requirements of the Master of Music degree in Music Therapy. If you take part in the research, you will be asked to wear a motion sensor while singing a brief vocal warm-up and three familiar songs in a small group of four participants. After singing, you will participate in a brief 10-20 minute group interview with a student investigator in order to share your experience of singing with the group. Your time in the study will take approximately 60 minutes. Possible risk and costs to you for taking part in the study may be discomfort experienced while singing in a small group and time necessary to complete the study. There are no anticipated benefits of taking part in this study other than a potential positive shift in mood as a result of singing. Your alternative to taking part in the research study is not to take part in it.

You are invited to participate in this research project titled "Singing with Strangers: The Effect of Interpersonal Familiarity on Synchrony and Social Bonding in Group Singing," and the following information in this consent form will provide more detail about the research study. Please ask any questions if you need more clarification to assist you in deciding if you wish to participate in the research study. You are not giving up any of your legal rights by agreeing to take part in this research or by signing this consent form. After all of your questions have been answered and the consent document reviewed, if you decide to participate in this study, you will be asked to sign this consent form.

What are we trying to find out in this study?
The purposes of this study are: (1) to determine the relationship between singing in a small group and movement and (2) to explore the personal experience of singing in a small group.

Who can participate in this study?
Anyone can participate in this study who is a WMU student, over the age of 18, and capable of using their voice to sing.

Exclusionary criteria are any physical limitations that would prevent movement of the head and membership in a WMU voice studio.

Where will this study take place?
This study will take place on Western Michigan University's campus in Room 1061 in the Student Recreation Center at 2000 W. Michigan Ave, Kalamazoo, MI, 49008.

What is the time commitment for participating in this study?
You will be asked to come to Room 1061 of the Student Recreation Center for a single visit. The duration of your time commitment once you arrive will be approximately 60 minutes.

What will you be asked to do if you choose to participate in this study?
After this informed consent has been signed, a student investigator may ask one follow-up question via email to confirm eligibility for participation in this study. After this, a student investigator will contact you via email to schedule a session time for your participation. During your participation in this study, you will be equipped with motion sensors to record the movement of your head. You will then engage in a short vocal warm-up with a student investigator and three other participants. After this, you will sing three familiar songs as a group. At the conclusion of the singing, you will participate in a short group interview with a student investigator regarding the singing experience. You will then have an opportunity to debrief with a student investigator.

What information is being measured during the study?
During this study, your natural head movements will be measured using a motion sensor placed on the top of your head. The singing portion of the study will also be video-recorded, in order to match the timing of the singing tasks with the motion capture data. Interview responses will be audio-recorded and transcribed to be analyzed for themes amongst participants.

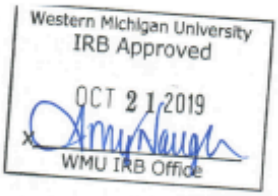
What are the risks of participating in this study and how will these risks be minimized?
There are no known risks to participating in this study other than any discomfort experienced while singing in a small group and time necessary to complete the study.

What are the benefits of participating in this study?
There are no anticipated benefits of taking part in this study other than a potential positive shift in mood as a result of singing.

Are there any costs associated with participating in this study?
There are no costs associated with participating in this study.

Is there any compensation for participating in this study?
Compensation for this study will be a $40.00 gift card for completing the study.

Who will have access to the information collected during this study?
Only the principal investigator, student investigators, and research assistants will have access to the information collected in this study. Results of this study may potentially be shared at professional music therapy conferences and in peer-reviewed journals, but all information will be



de-identified when shared. This means that no names or individually identifiable data will be shared during or after your participation in this study.

What will happen to my information or biospecimens collected for this research after the study is over?
After information that could identify you has been removed, de-identified information collected for this research may be used by or distributed to investigators for other research without obtaining additional informed consent from you.

What if you want to stop participating in this study?
You can choose to stop participating in the study at anytime for any reason. You will not suffer any prejudice or penalty by your decision to stop your participation. You will experience NO consequences either academically or personally if you choose to withdraw from this study.

The investigators can also decide to stop your participation in the study without your consent.

Should you have any questions prior to or during the study, you can contact the following researchers:

- Principal Investigator: Ed Roth, (269) 387-5415, edward.roth@wmich.edu
- Student Investigator: Sheridan Brown, (586) 744-9013, sheridan.r.brown@wmich.edu
- Student Investigator: Molly Grettenberger, (231) 944-4105, molly.a.grettenberger@wmich.edu

You may also contact the Chair, Institutional Review Board at 269-387-8293 or the Vice President for Research at 269-387-8298 if questions arise during the course of the study.

This consent document has been approved for use for one year by the Western Michigan University Institutional Review Board (WMU IRB) as indicated by the stamped date and signature of the board chair in the upper right corner. Do not participate in this study if the stamped date is older than one year.

I have read this informed consent document. The risks and benefits have been explained to me. I agree to take part in this study.

_____
Please Print Your Name

_____ _____
Participant's signature Date