Sensorimotor Synchronization:

The Effect of Musical Training and Musicality of Stimulus

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Abstract

Synchronization to an external rhythm is a cognitive process that is fundamental for music performance. Individual differences in musical experience affect synchronization accuracy, as does the stimulus present. To investigate the effects of musical training and musicality of stimulus on synchronization, 25 participants (Musician = 10) were involved in a finger tapping experiment using two different stimuli. Synchronization was performed with a musical excerpt, and a nonmusical rhythmic stimulus. Analyses showed nonmusicians displayed higher negative mean asynchrony than musicians ($p = .047$), and tapped with greater variability ($p = .005$). The presence of a musical stimulus had a significant positive impact on mean asynchrony ($p = .025$) yet had a nonsignificant effect on variability compared to a nonmusical rhythmic stimulus ($p = .253$). Musical training and stimulus displayed a nonsignificant interaction effect on both variability ($p = .918$) and asynchrony ($p = .401$). These findings further add to the evidence of an effect of musical training on synchronization. The impact of stimulus on entrainment, and lack of interaction effect, is relevant to rhythmic interventions utilizing music.

Introduction

Sensorimotor synchronization (SMS) is the coordination of movement with a predictable sensory stimulus (Repp, 2005). SMS can occur with visual and physical stimuli, such as a flashing light or repetitive tap on the shoulder, however the effect is most pronounced with auditory stimuli (Repp, 2013). Because of SMS's close relationship with auditory stimuli, study of SMS is particularly relevant to music and entrainment to musical rhythm. Music with a defined rhythm is present cross culturally, and the ability to synchronize with this rhythm is important for musicians, dancers and listeners (Clayton, 2005; Merker, 1999/2000, 2000; Repp, 2006). Rhythm entrainment is a cognitive process that has traditionally been seen as a uniquely human phenomenon (Merker, 1999/2000; Patel, 2009). The process of synchronizing movements to a beat is natural and often unconscious (Repp, 2004, 2013). Even if told to sit still, listeners may still attend closely to the beat and hold back the urge to move (Large, 1999). Synchronization can therefore be seen as a natural and spontaneous reaction to a rhythm. However, some people synchronize to a rhythm more accurately than others. Namely, musicians have consistently demonstrated a greater synchronization accuracy compared to non-musicians across myriad different measures and conditions (Chen, 2008b; Ehrlé, 2005; Franěk, 1991; Krause, 2010a; Repp, 2010, 2013; Stoklasa, 2012). It is important to understand this difference because of its implications both within and outside the realm of music.

Music and musical ability are traditionally associated with the language areas of the brain (Fitch, 2006). However, SMS and beat synchronization is integrated with a wide variety of cognitive and neural systems like auditory perception, prediction, attention, working memory and motor coordination (Bidelman, 2011; Pallesen, 2010; Patel, 2005; Rammsayer, 2006; Slater, 2015; Strait, 2010; Zuk, 2013). Tapping a finger in synchrony with a beat, for example, requires the coordination of a consistent internal timekeeper with precise motor movements, and persistent attention to the stimulus to allow for error correction (Aschersleben, 2002; Repp, 2005; Vorberg, 1996). Imaging studies have shown that tapping to an auditory beat relies on the continued and consistent interaction of a network between the thalamus and subcortical areas like the cerebellum and basal ganglia, and the pre-supplementary motor cortex and medial prefrontal cortex (Bengsston, 2009; Chen, 2006, 2008a; Pehnhune, 1998, 2005; Nombela, 2013; Tierny, 2013; Ullén, 2008). Because of this widespread integration, studies of SMS have applications outside music, such as in interventions for dyslexia and Parkinson's (Bhide, 2013; Huss, 2011; Nombela, 2013). Research into interventions for Parkinson's, as well as other motor conditions like Huntington's disease and stroke, have shown that entrainment to an external rhythm can improve difficulties of gait by improving stride length and reliability, and walking speed (Nombela, 2013).

Experimentally, SMS is often studied through the use of tapping tasks. Participants are asked to listen to a rhythm, usually a metronome of some sort, and tap in synchronization with the beats (see Repp, 2013 for review). The reasoning behind tapping tasks is that the accuracy (e.g., mean distance of taps from the beat) and reliability (e.g., variability of tap position relative to the beat) of finger movements are theorized to be behavioural correlates of difficulty in the processing of rhythmic and metrical structures (Snyder, 2006). In relation to music, SMS responses of higher accuracy are more valuable, as playing in close synchrony to an outside beat is vital for playing in an ensemble (Clayton, 2005). However, completely accurate synchronization is nearly impossible for humans, even at frequencies used in music (Repp, 2005, 2006a, 2006b). Participants have been found to consistently 'fail' in three areas of synchronization; inter-tap variability, negative asynchrony, and speed of error correction

(Aschersleben, 2002; Mates, 1994; Mates & Müller, 1994; Repp, 2005, 2010; Thompson, 2015).

Inter-tap variability, in a finger tapping task, is the consistency of the temporal distance between a participant's taps. An isochronal stimulus (i.e. a metronome), by definition, consists of taps that are temporally consistent. When synchronizing with such a stimulus, participants must tap with the same consistency, or become desynchronized. Inter-tap variability has been hypothesised to be a product of an inconsistent 'internal timekeeper' as well as difficulties translating the internal timekeeper into motor movements (see, e.g., Large, 2002; Vorberg & Wing, 1996; Wing, 1971). However, perception also plays a role (Repp, 2013). Specifically, the rhythmic information of the stimulus (i.e. the amount of beat events present and the variety of subdivision). A study by Snyder et al., (2001), studied the difference in synchronization accuracy between a piano music excerpt featuring both the left and right hand parts, and an excerpt featuring just the right hand's part. Variability was greater for participants who tapped to the right hand played alone than when they tapped to both parts played together. This demonstrates the importance of rhythmic information, as the left hand part of piano music is typically responsible for the bassline and keeping time. Inter-tap variability has been found to be lower in musicians, and specifically percussionists, than nonmusicians (Repp, 2007, 2010, 2013; Krause, 2010b).

SMS research has found that participants taps reliably precede each beat event, in what has been named the 'anticipation tendency' (Aschersleben, 2002, 2003; Repp, 2013). The degree of anticipation can be used as a metric of synchronization accuracy, as a smaller negative mean asynchrony (NMA) would mean a closer synchronization. Anticipation, or tapping too early to the beat, isn't generally noticed by the participants, with participants even believing they are tapping too late when they display no NMA (Aschersleben, 2003). Musicians and non-musicians have been shown differ greatly on NMA, with nonmusicians making both larger errors of anticipation as well as making them more often (Aschersleben, 1994, 2002; Repp, 2005). NMA is seen as a process of prediction, and is affected by the amount of sensory information available (Aschersleben, 2002; Wohlschläger, 2000; Repp, 2006a). NMA can be reduced by giving participants more feedback for their taps, such as an auditory tone (see Aschersleben, 2002 for review). The pitch of the stimulus can also affect NMA, with a rising pitch causing greater asynchrony (Boasson, 2012). NMA has also been hypothesized to be caused by an underestimation of the empty distance between tones, and can be reduced by introducing more information (i.e. beat events) between taps (Wohlschläger, 2000; Repp, 2013).

The amount of sensory information inherent to the stimulus being synchronized to has been shown to affect participant's errors of asynchrony and variability, as well as their correction (see, e.g., Aschersleben, 2002). Typically, tapping studies involve a stimulus consisting of a series of tones at a computer controlled Inter-Onset Interval (IOI; i.e., the temporal distance between each beat of the stimulus), with other stimuli that may aid synchronization controlled for (Repp, 2013). Music, by contrast, contains a wide breadth of perceptual cues that have been demonstrated to affect the beat perception and prediction required for SMS (Repp, 2006). Pitch can alter perception of the beat (Ammirante, 2011; Boasson, 2012; Boltz, 1998). Boltz, et al., (1998), found that participants perceived melodies that shifted across a wide range of pitch to unfold more slowly than melodies with less pitch movement. The direction of pitch can also effect tapping accuracy, with rising pitch being demonstrated to cause participants to begin tapping faster (Boasson, 2012). Studies on individuals with "pitch deafness" have found that an inability to determine pitch are also related to difficulties in perceiving rhythm, suggesting the two systems are related (e.g., Lagrois, 2019; see also, Phillips-Silver, 2013).

Music contains rhythms at additional IOIs, either subdividing the beat or complimenting in a polyrhythm (cf., Pressing, 1996). The addition of subdividing IOIs to an isochronal stimulus can aid in SMS by reducing variability and NMA (Zendel, 2011). NMA has been hypothesized to be caused by an underestimation of the empty distance between tones, subdivisions therefore act to fill this negative space with relevant information (Wohlschläger, 2000).

Presence of meter (i.e. rhythmic accents that denote 'strong' and 'weak' beats) also influences SMS. Meter may serve to guide the performers attention to particularly salient beats when synchronizing with music (Keller, 2005). As part of a study by Patel, et al., (2005) participants were asked to tap along to rhythms with metrical structure. They found that participants' taps were better synchronized to beats with strong meter than weak meter. However, the accuracy of their synchronization for excerpts with strong meter and to simple excerpts with no meter showed a nonsignificant difference (Patel, 2005). Participants taps have been shown to distort around metrical structure, with participants shortening their Inter-tap intervals (ITIs; i.e., the temporal distance between participant's responses) before a strong beat, which are then lengthened for the subsequent weak beat (Billon, 1995). In a study of uneven rhythms (i.e., rhythms composed of nonischochronous beat periods), Repp, London, and Keller (2005), found results that suggest errors of synchronization are corrected using information from the entirety of a metrical phrase, rather than beat to beat. However, whether this finding is applicable to isochronous rhythms is unclear. Common to all these findings is the result that accented rhythms effect the relationship of individual taps to one another. What these studies demonstrate is a nuanced impact of meter on SMS, rather than a straightforward positive or negative impact.

Individual differences may affect the impact that the perceptual cues of music have on synchronization, namely differences in perception (Repp, 2005). Musicians differ from nonmusicians on their ability to perceive a beat, and have demonstrated a more accurate mental image of timing changes and pitch (Aleman, 2000; Pecenka, 2009, 2011). Musicians have been shown to be quicker to identify and adapt changes in a beat (Repp, 2013; Scheurich, 2020). Musicians react to changes in pitch and rhythm faster than nonmusicians, and imaging studies have shown changes in pitch to elicit a greater ERP response in musicians (Boasson, 2012; Habibi, 2013, 2014; Jongsma, 2005).

These various perceptual cues present in music are often omitted in SMS research, which instead minimize the effects of cues not the direct focus of research (Repp, 2013). Due to this paradigm, extant SMS literature may be lacking in generalizability and applicability to the understanding of music and performance. This is particularly alarming considering interventions based on beat synchronization research often utilizing music instead of these experimental style nonmusical stimuli. The aim of the present study was, therefore, to investigate the effects of the musical elements of a stimulus on accuracy of SMS.

The secondary aim of this study was to investigate the effect of musical training on SMS response. A difference between musicians and nonmusicians has been repeatedly demonstrated (see, e.g, Repp, 2006, 2010), however the sample sizes of these studies are often small, and as evident in the study Repp, et al. (2010), the same sample is often used to replicate this difference. Further replication using new participants would serve to strengthen the literature surrounding this difference.

As mentioned, the majority of SMS research utilises a nonmusical stimulus. However, due to musicians' enhanced perception of musical elements like pitch and rhythm (cf. Habibi, 2013, 2014), the difference demonstrated between musicians and nonmusicians may be exacerbated by the presence of these elements. The final aim of this study was to investigate the interaction between the difference in SMS response base on musical training and the level of musical elements present in the stimulus, to understand the ecological validity of the synchronization benefit experienced by musicians.

It was hypothesized that:

(1) There would be a difference between Musicians and Nonmusicians in (a) mean asynchrony, and (b) tap variability. Musicians would show less negative mean asynchrony, and a lower variability of taps.

(2) The presence of a musical stimulus would increase tapping synchrony compared to a nonmusical stimulus.

(3) Musicians and Nonmusicians would differ on the extent to which musical elements affected their response. Due to perceptual benefits, Musicians would feel a greater benefit from the presence of musical cues than Nonmusicians.

Methods

Participants

25 individuals took part in the study, consisting of 17 females. Data of 23 participants was suitable for analysis, due to procedural problems with two participants. The majority of the participants were between the ages of 18 – 30, with only five participants aged 31 to 50. Participants were recruited through convenience sampling methods such as the researcher's personal social media networking and word of mouth. In order to gain access to a higher density of musicians, elements of snowball sampling were involved as those who were initially recruited were asked to contact other musicians who may be eligible for the study. Music schools were contacted and those that consented were visited by the researcher where participants could be recruited, and the experiment was run. Schools were chosen to be contacted because of convenience sampling reasons like distance, access, availability and language spoken.

Every participant was required to fill out an ethical consent form prior to being accepted for the study where full information of their rights was given, such as the anonymity of their data and their ability to opt out at any time.

Exclusion criteria for the present study were based on the operational definitions of the Musician and Nonmusician groups. Musician was defined as a Participant displaying two out of the three following responses to the Application Form (See Appendix B); (a) least one full year of musical training, (b) self identifying as working in a profession relation to music, and (c) recent regular practice of one hour or more a week.

Participants who were musicians of middling ability (i.e., did not meet the requirements for musician, but possessed some amount of training in the past) were excluded from the present study.

No coercion was used in the recruitment process, and all participants gave fully informed consent before committing to the study. Participants' data was deidentified and involvement in the study was anonymous.

Materials

The tapping data of participants was recorded using the program Ableton Live 9, running on a 2012 i5 MacBook Pro, in MIDI format. The MIDI format is reliable for recording timing data at a resolution of 1ms, and, according to the manual, Ableton Live's processing of timing data on MacOS is reliable within 1ms with little to no jitter (DeSantis, 2014).

Participants tapped on the keyboard of the laptop. This method of recording taps gave participants a tactile recognition of their taps, while minimizing accentuation force required and auditory feedback. Similar tapping studies often employ MIDI instruments such as percussive pads and 'piano like' MIDI keyboards (cf. Repp & Dogget, 2007; Patel, 2005). A laptop keyboard was used in the case of this study because of the use of Nonmusician participants, who may be less familiar with such instruments. As such, a laptop keyboard was chosen by the researcher because of its assumed familiarity to all participants. The timing data was manually retrieved from Ableton Live 9.

Design

The current study employed a cross-sectional, quasi-experimental design. The two nonequivalent groups were the Musicians and Nonmusician participants. The experiment consisted of two different conditions based on the excerpt played, Musical or Metronome stimulus. Within both conditions two variables were used to describe aspects of a given participant's synchronization accuracy; Mean Asynchrony and Variability of Taps.

Mean Asynchrony (MA) was measured in milliseconds, with an asynchrony of zero being in exact synchrony with the beat event of the stimulus, a negative asynchrony meaning the participant's tap was recorded before the beat and a positive asynchrony indicating a late response. Mean asynchrony has been described as the precision of a participants' taps, with lower asynchrony being closer to the target set by the stimulus (see, e.g., Snyder, 2006).

Variability of taps was operationalized in this study as the standard deviation of mean asynchronies (SDA). SMS tasks often differ on their operationalization of variability (Repp, 2005), SDA was identified for use in the present study because of the tapping paradigm used. The present study utilizes 1:1 tapping paradigm with a single IOI, 500 milliseconds, between both conditions with no perturbation. As a result of this, no additional calculations need to be made to adjust for variable IOIs, and SDA is an effective measure of variability (Repp, 2013).

Procedure

Participants consented to take part in the research by reading the information sheet, and filling out the consent form and demographic form (see Appendix A, B, and C, respectively). During this process, the researcher was available to answer questions about the process of the experiment and reasoning behind it as well as to ensure the participant had a full understanding of their ethical rights regarding the anonymity of their data and their right to terminate involvement in the study at any time.

After this process the experiment may begin. The experiment takes place in a small room devoid of outside stimuli that may impose on the attention required for the task such as loud noises or moving images. As the researcher brings the participant into this room, other participants waiting to begin the experiment may also be present, however the participant engaged in the task has no view of these people. Group entrainment to a rhythm or the sight of other people has been found to effect synchronization (Clayton, 2005), so the participants would complete the task without outside influence such as the sight or sound of another participant’s taps.

The task involved using headphones to listen to an excerpt of music and an isochronal metronome stimulus, devoid of musicality. The order of the conditions was randomized by flipping a coin. Participants sat in front of a 2012 i5 MacBook Pro running Ableton Live 9 and were asked to tap the E key of the laptop keyboard in synchrony with the music. This tapping was 1:1 in phase tapping with the beat of the stimulus (i.e. for the metronome, taps were made at the same time as each beat was heard). If the participant was unsure as to when to tap, the researcher would give a brief demonstration of what was required. While tapping, participants could see the laptop screen. However, they had no visual feedback of their taps or any other visual information that could inform their synchronization. Other visual stimuli, such as the researcher and possible other participants in the room were not in view of the participant. Auditory feedback of their taps (i.e. the sound of pressing the keyboard), as well as outside noise, was mitigated through the use of headphones. Participants would continue tapping until informed to stop by the researcher, who would tap the participant’s shoulder and come into view.

The excerpt of music was retrieved from YouTube (Karel De Matteis - Music., 2015), and involves a drumkit, electric guitar, bass guitar, synthesizer melody, and rising pad. The excerpt was chosen based on the presence of a computer controlled IOI and a ‘kick’ of the bass drum every tactus (i.e., every 500ms).

The metronome condition involved a 1.5 kHz tone. Both stimuli were played with an inter-onset interval of 500ms, with the timing of the musical excerpt being computer controlled to remove human error. Both excerpts involved two sections, the pre-recording ‘practice’ phase, and the ‘synchronization’ phase where taps were recorded for analysis. During each phase, participants were told to feel free to perform any other behaviours that may help their synchronization, such as foot tapping, head nodding, and counting or singing out loud. Participants could tap on the keyboard before the synchronization phase, however those taps would not be recorded as part of the analysis. The pre-recording phase was 16 beats long, four of which consisted of a brief change in stimulus marking the beginning of the synchronization phase. In the musical condition, the synchronization phase began at the end of a four beat long drum fill, and the beginning of the fifth bar of music. The metronome condition marked the end of pre-recording using a brief pitch change, a rise to 2 kHz in the tones produced. While the synchronization phase for both conditions lasted an indiscriminate amount of time and may have lasted many more beats than was required for collection, only the first 16 taps were used for analysis in order to maintain consistency across participants.

After one condition ends, there is a brief intermission before the next condition begins. Participants can remove the headphones and move for up to one minute. At this point, the participant is also reminded of their right to terminate involvement in the study at no cost. When ready, the participant begins the next condition, beginning with the pre-recording phase. Once both conditions are completed, the participant is thanked, asked if they have any questions and handed a debriefing sheet with the researcher’s email should they want any further information. Then the experiment continued with the next participant, if present.

Results

Descriptive statistics for MA and SDA are displayed in Table 1. Variability, when viewed as SDA as a percentage of the IOI, shows Musicians with a variability of 3.12%, and Nonmusicians with 5.75%. Mean asynchrony for the sample as a whole, was more negative during the metronome condition (Mean = -14.06) than the musical condition (Mean = 5.46).

Table 1.

Group descriptive statistics categorized by Musical Training and Stimulus Condition.

Variable	*Group*	*N*	*Mean*	*STD*	*Min*	*Max*
MA - Music	Musician	9	22.27	9.03	9.6	35.67
	Nonmusician	13	-1.84	34.87	-73.13	41.06
	Total	22	8.026	29.55	-73.13	41.06
MA - Metronome	Musician	9	8.74	31.11	-41.44	58.8
	Nonmusician	13	-30.15	57.64	-125.5	67.38
	Total	22	-14.24	51.48	-125.5	67.38
SDA - Music	Musician	10	13.8	4.45	7.44	21.84
	Nonmusician	13	26.59	11.54	12.15	47.85
	Total	23	21.03	11.08	7.44	47.85
SDA - Metronome	Musician	10	17.42	6.35	8.58	27.61
	Nonmusician	13	30.92	20.09	8.58	27.61
	Total	23	25.05	16.84	8.58	92.07

Note. MA = Mean Asynchrony; SDA = Standard Deviation of Asynchronies.

Mean Asynchrony during the metronome task can be viewed as a boxplot in Figure 1. Note the distance of each group to zero, as zero asynchrony represents perfectly accurate taps. Nonmusicians tend to tap after the beat, and have a wider range of asynchronies overall.

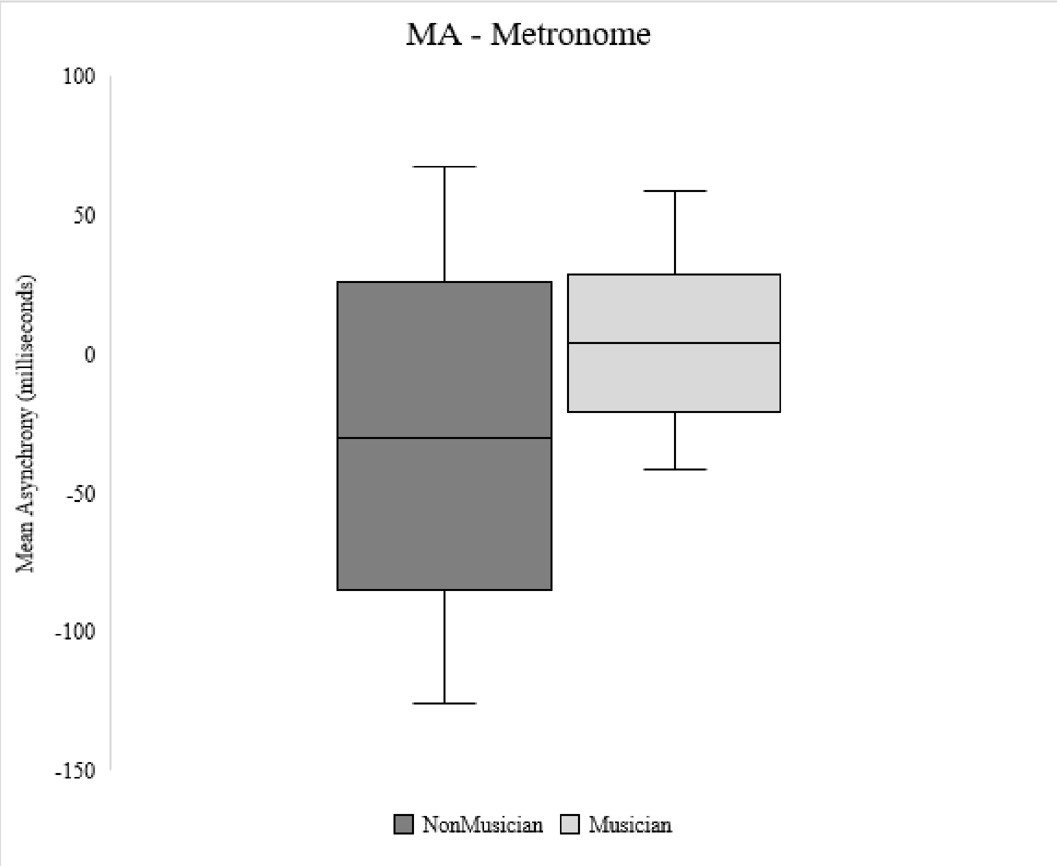

Figure 1. Boxplot comparison of Mean Asynchronies during Metronome Condition.

Hypothesis 1 – Musical Training

Preliminary analysis for 2-way mixed ANOVA found an outlier for Musician group which was removed as well as a violation of normality for Mean Asynchrony. However, the test chosen is robust (Howell, 2012), especially when only a single variable violates normality, so no additional changes were made.

The results of a 2-Way Mixed ANOVA showed that there was a significant main effect of Musical Training on MA ($F(1, 20) = 4.483$, $p = .047$, $\eta_p^2 = .183$), with nonmusicians (Mean = -15.993) showing a tendency towards negative MA compared to musicians, who instead responded positively (Mean = 15.504). A separate 2-Way Mixed ANOVA analysing variability of taps showed a significant main effect of Musical Training on SDA ($F(1, 21) = 9.599$, $p = .005$, $\eta_p^2 = .314$). Musicians showed a more stable tapping response during the experiment, smaller average SDA (Mean = 15.61) than nonmusicians (Mean = 28.753). Important to note is the magnitude of this difference, which was quite large ($\eta_p^2 = .314$, Mean Difference = 13.144).

Hypothesis 2 - Stimulus Condition

A significant impact of condition was also found on MA ($F(1, 20) = 5.901$, $p = .025$, $\eta_p^2 = .228$), with participants as a whole responding with positive asynchrony for the musical stimulus, (Mean = 10.217), and negatively to the non-musical stimulus (Mean = -10.706). In practice, this meant on average taps to music were made after the beat, and taps to the non-musical stimulus were made before the beat. In contrast to MA, a nonsignificant effect of condition on SDA was found ($F(1, 21) = 1.382$, $p = .253$, $\eta_p^2 = .062$), with participants maintaining similar SDA results when listening to either the musical (M = 20.2) or non-musical stimulus (Mean = 24.17).

Hypothesis 3 – Interaction Effect

There was also no significant interaction between Musical Training and condition ($F(1, 20) = .735$, $p = .401$, $\eta_p^2 = .035$). Descriptive statistics showed that while musicians performed more reliably than nonmusicians, outperforming them in both the musical condition (Musician Mean = 13.8, Nonmusician Mean = 26.6) and the non-musical condition (Musician Mean = 17.42, Nonmusician Mean = 30.91), this difference between groups could not be explained by the type of stimulus present. Similarly, there was a nonsignificant interaction between Musical Training and condition ($F(1, 20) = .735$, $p = .401$, $\eta_p^2 = .035$). Musicians, while showing a lower overall SDA, showed a similar mean difference across conditions as nonmusicians (Mean Difference Musicians = 3.62, Mean Difference Nonmusicians = 4.32). Participant's MAs were affected to the same degree between stimuli, regardless of musicianship. The results of the 2-Way ANOVAS has be represented graphically in estimated marginal means plots on Figure 2 and Figure 3.

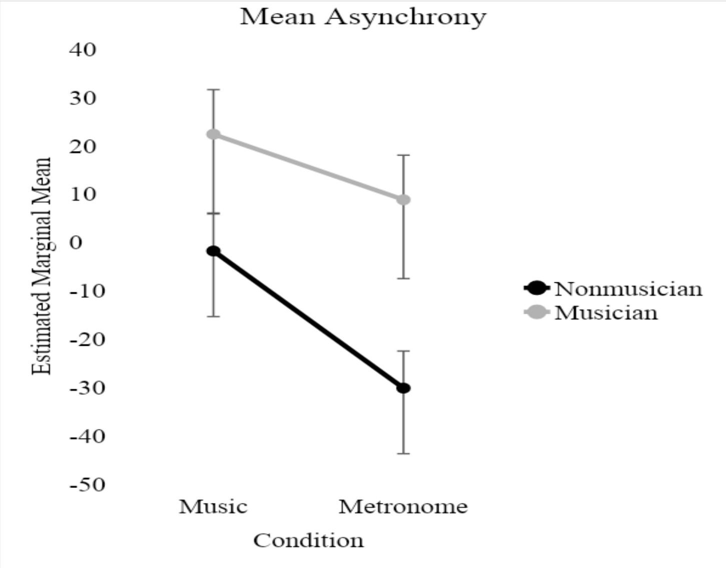

Figure 2. Results of 2-Way Mixed ANOVA for MA between Condition and Training groups.

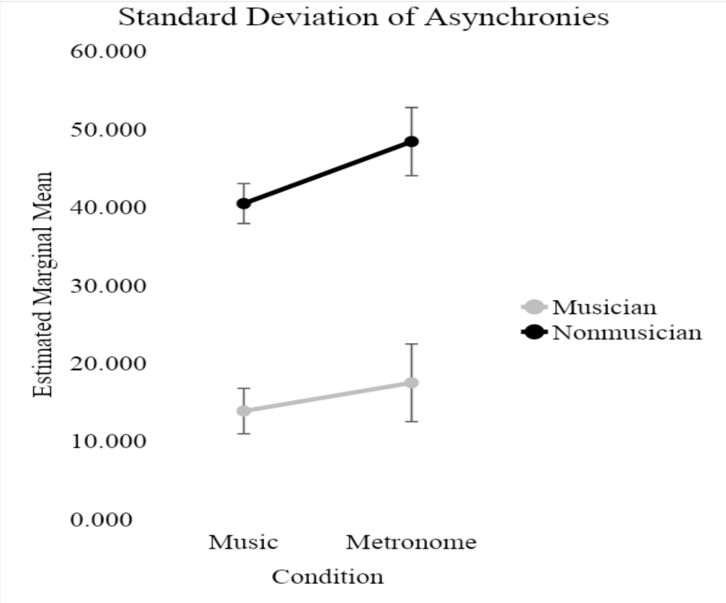

Figure 3. Results of 2-Way Mixed ANOVA for SDA between Condition and Training groups.

Discussion

The purpose of this study was to investigate the effect of a musical stimulus, musical training, and the interaction between stimulus and training on SMS accuracy. It was hypothesized that there would be a significant difference between musicians and nonmusicians on two observable aspects of their SMS response, Mean Asynchrony (MA) and the standard deviation of those asynchronies (SDA). There was indeed a large significant difference between Musicians and Nonmusicians on both MA and SDA, which coincides with previous literature (see, e.g., Repp, 2006). This difference was found in both the musical and the metronome conditions.

In the case of MA, Nonmusicians' taps were significantly more negative than Musicians, meaning they on average tapped earlier before the beat than Musicians. With regard to previous literature, a tendency towards negative asynchrony is common, especially when taps offer little to no auditory feedback such as in this study (Aschersleben & Prinz, 1995; Stoklasa, 2012). Similarly, a difference between Musicians and Nonmusicians in MA has been repeatedly found in tapping tasks with and without a pacing signal (Aschersleben, 2002; Krausse, 2010a; Repp, 2005, 2010, 2013). What was unexpected in the present study, however, was the tendency for musicians towards positive MA, with the means for the Musician group being positive in both conditions. While reducing negative MA means more accurate tapping, the goal is to be close to zero (i.e. taps coinciding with the beat), therefore high positive asynchrony still reflects poor tapping precision. Positive MA means there is a delay between the beat and the participants taps, participants are "dragging" the beat. Positive MA is rarely found in tapping literature, especially at the IOI used in this study, however its not unprecedented (see, e.g., Toiviainen & Snyder, 2003). Positive asynchronies are found at extreme IOIs (Repp, 2013). When tapping along to long IOIs (>2000ms) participants have been shown to display positive asynchronies, with the researchers attributing this to participants reacting to the beat rather than anticipating it (Repp, 2007). It has also been demonstrated at extremely high IOIs, as participants struggle to keep up with the pacing signal, reaching their physical limits for tapping speed (Fuji, 2011; Repp, 2003, 2013). However, neither of these apply to the present study, which used an IOI of 500ms, well within the limits needed for accurate SMS. Positive asynchronies could, theoretically, reflect a group tendency for musicians to either over-correct their own negative MA during the music condition, or an error in accurately perceiving the beat of the music. However, this positive MA displayed by musicians may be simply the result of computational delays inherent to the data collection process, as will be explained in further detail in the Limitations section.

Analysis revealed a significant difference in SDA. Musician's SDA was significantly lower than Nonmusicians, with the scale of this difference being the largest of the study. In practice, this meant that Musicians' tapped at a much less variable rate, with their taps being more evenly spaced and closer to an 'isochronal ideal'. For real world applications of SMS, being able to hold a steady beat is particularly important; in music, low SDA aids in stable interpersonal synchronization as well as lower tendency to accelerate in self-paced synchronization (Flach, 2005; Pecenka, 2011). For rhythmic interventions for Parkinson's, low variability in SMS response translates to improved gait, with greater reliability of stride length,increased speed and lower risk of falling (Bella, 2015; Ghai, 2018; Haussman, 2007a, 2007b). The benefit of Musical Training on SDA being replicated in this study is therefore important, because of its diverse real world benefits.

Aside from musical training, another focus of the study was the effect of the stimulus present on tapping accuracy. For the sample as a whole, regardless of training, the metronome condition was related to more negative MA compared to the music condition. This coincides with the study's hypothesis that presence of music would aid in tapping accuracy. For a theoretical explanation of this relationship, we can understand music as having additional sensory information that aids in predicting the beat (Aschersleben, 2002; Repp, 2002, 2003, 2006).

Wohlschläger & Koch (2000) theorized the reason behind a negative tendency in participant's MA as individuals underestimating the 'empty' distance between beats in an experimental isochronal stimulus. During the period of time between beat events when a metronome stimulus would be silent, music provides other information, such as the presence of other beat events that may subdivide the main beat. A benefit of additional IOIs with a relationship to the main beat (i.e., subdivisions of the beat), has been found to reduce negative MA in a variety of studies (Repp, 2013; Zendel, 2011). Zendel et al., (2011) studied this subdivision benefit in one condition of their study by reducing the stimulus IOI while keeping ITI's constant, meaning they asked the participants to tap at the same rate while the stimulus increased in rate in steps equal to half the initial IOI (i.e., 1:*n* tapping, where *n* is an integer). The result of this was reduced negative MA, an increase in tapping accuracy. An explanation for the positive effect of music on MA in this study could be attributed, at least in part, to the benefit provided by additional subdivisions of the beat.

The benefit of subdivision has also been found in participant's SDA (Repp, 2008; Zendel, 2011). However, the present study found a nonsignificant impact of stimulus present on SDA. A nonsignificant difference in the variability of taps between stimulus conditions could be interpreted as meaning additional sensory information in the auditory stimulus aside from the primary beat that is the focus of synchronization (e.g., music) has no perceivable impact on SDA. Looking back on previous literature and theories of SMS, this conclusion is not widely supported. Perception of asynchronies, ability to perceive the beat, and to compare ITIs to IOIs is essential to error correction and by extension to a stable tapping response (Mates, 1994a, 1994b; Patel, 2005; Repp, 2005; Schulze, 2005). Another interpretation is that the specific difference between perceptual cues present in the music condition were of no benefit to synchronization. However, this is unsupported by extant literature, as a presence of additional IOIs, easily perceived beat, and metrical expression, which were all common to the musical condition and not the metronome, have displayed an impact on SDA (Patel, 2005; Stupacher, 2016; Zendel, 2011).

While there was a nonsignificant difference in SDA between conditions, this does not mean there was no difference in the variability of taps. Variability of taps may still have been affected by the addition or omission of musical information, especially metrical and expressive timing elements. When a task requires participants to tap along to music with computer controlled perfect tempo, their taps can display a systematic pattern of asynchrony that has been hypothesized to reflect expectations of expressive timing and meter (Drake 2000; Patel, 2005; Repp, 2002; 2006). In a series of studies, Repp, et al., (1999a; 1999b; 1999c; 2002), investigated the characteristics of participants taps when asked to tap along to expressively timed music by Chopin, or the participants' own recordings. The researchers found that the anisochrony of participants taps, and the lengthening and shortening of ITIs, was related to the metrical structure and expression either found or expected to be found in the stimulus, with prediction increasing in subsequent trials (Repp, 2006). Participants tend to use the metrical structure of music to guide their synchronization, with variability and asynchrony increasing with the relative strength or weakness of a beat (Patel, 2005). This phenomenon can be showcased in jazz percussionists, who show a precise pattern of asynchrony based on the tradition of 'swing' in the jazz genre, whereby their taps have a high variability but this pattern is predictable and expected by other performers in an ensemble (see, e.g., Collier, 1997; Friberg, 2002; Schögler, 1999). With this in mind, there is a possibility that, in the present study, the music may have had a more qualitative impact on the characteristics and pattern of participants taps. This would explain why participants displayed a benefit of music on their tapping accuracy through a reduction in negative MA, but did not benefit from a significant reduction in SDA. This effect of musical stimuli on response stability may be troubling for rhythmic interventions, particularly those that are concerned with reducing SDA such as a variability of gait in motor disorders (see, e.g., Nombela, 2013). The effect of a musical stimulus on variability was not negative compared to the metronome, however, so the benefits to MA might outweigh the risk of impairing or altering inter response reliability. However, the results and data of the current study cannot make any substantial inferences based on the information available. In order to investigate a characteristic change to participant's tapping patterns, data from participants undergoing multiple trials using the same condition should be analysed.

There was a nonsignificant interaction between musical training and musicality of stimulus. It was hypothesized that musical training would lead to a disproportional ability of musicians to synchronize to musical stimuli compared to a metronome, due to training's benefits to perception and understanding of musical information. The positive effects of musical elements on MA, for instance, were experienced universally by the sample. The lack of interaction effect suggests this benefit of perception and mental imagery experienced by musicians may have no impact on their ability to synchronize with a stimulus. This result has positive implications for the ecological validity of non-musical stimuli in SMS research, as tapping accuracy appears to be generalisable across stimuli. The present study however omitted the use of a phase perturbation paradigm to investigate differences in error correction. Perception is important for all aspects of SMS, but the process can be simplified to two points of attention; (a) perception of the rhythm of the stimulus, and (b) perception of one's own response. Error correction occurs as these two are compared. The IOI in the present study was computer controlled at 500ms for the entire duration across both stimuli, with no perturbation. While the musical stimulus would affect perception of elements such as pitch and meter, aspects of music that musicians have demonstrated an increased perception of (df. Habibi, 2013, 2014), the lack of rhythm changes may have reduced the need for attention to the stimulus. This would make the experiment a test of perception of one's own response, which would not be affected by condition. Changes to the IOI in the musical stimulus may have resulted in a difference between groups that was more pronounced, as has been demonstrated in previous research (Repp, 2013). A difference in response to phase perturbations between musicians and nonmusicians has been demonstrated repeatedly in previous research (cf. Repp, 2010), so perhaps musician's perception of rhythm can affect accuracy of synchronization. However, the focus of this study was specifically on the effect of musical elements, like pitch and meter, on response, to this end, a nonsignificant difference was found.

In conclusion, Musicians and Nonmusicians showed a difference in their tapping ability, with Musicians exhibiting significantly less negative MA and lower SDA than Nonmusicians regardless of Stimuli. The effect of stimulus on participant's taps was a significant negative displacement of MA, and a nonsignificant change in SDA. The effect on MA interpreted as evidence for Wohlschläger & Koch's (2000) theory of MA based on an underestimation of empty IOIs. The effect on SDA was understood not as a lack of effect of stimulus, but that a distortion to the characteristic pattern of response based on expected meter and expressive rhythm had resulted in a lack of quantitative improvement for the variability of taps. A nonsignificant interaction effect of Stimulus and Musical Training was viewed as having positive implications for the ecological validity of musical tapping task stimuli.

Limitations

A limitation of this study, and as highlighted by Thompson et al., (2015) of studies focusing on differences between Musician and Nonmusician in general, is a lack of generalisable definition of Musician. The current study's definition excluded potential participants of middling musical ability; those who had studied in the past but have not recently been 'in practice', or those who had only begun learning an instrument. The musician participants of tapping tasks are often highly trained full-time professional musicians (see, e.g., Repp, 2010), which may not be representative of the global population of amateur musicians.

The definition of musician used in the current study also did not discriminate between the musician's preferred instrument. In previous research, a difference between percussionists and non-percussionists in their tapping accuracy has been repeatedly displayed (Krause, 2010a; Repp, 2013). Failing to discriminate between types of musician may have resulted in a nonrepresentative sample of musicians as a population.

The present study aimed to investigate the effect of musicality of stimulus on SMS response. However, the experiment only contained a single musical excerpt with which to synchronize. While this excerpt contained many features of music that are of common to music in general, like presence of meter, tone, and harmony, the ability for a single excerpt to represent all forms of music is limited. For example, the excerpt used contained many features of modern western music, like the use of a drum kit and syncopation, that may not be applicable to all forms of music (see, e.g., Clayton, 2005). Previous studies of SMS and music in particular utilize musical excerpts from more historic pieces, like Bach and Chopin, that do not contain these modern elements (see, e.g., Rankin, 2009; Repp, 1999a). Any attempt to consolidate 'all of music' into a short enough excerpt to be used in a study is inevitably going to be reductionist, however there are key aspects of certain genres of music, such as high prevalence of polyrhythm or 'groove', that may have significant effects on SMS response (Stupacher, 2016; Snyder, 2006).

The present study consisted of two auditory stimuli of the same fixed computer-controlled IOI. This restricted the researcher's ability to investigate group difference in error correction response through the use of a phase perturbation paradigm (see Repp, 2013 for review). In SMS research, it is common for researchers to focus on the ability of participants to perceive and react to subtle changes in IOI, and investigate individual differences in their responses (Large et al. 2002; Palmer et al. 2014; Repp 2002, 2013; Scheurich, 2020; Thaut et al. 1998). There is precedent in extant literature for musicians and nonmusicians to differ in this ability to perceive and correct erroneous responses (Praamstra, 2003; Turgeon, 2011; Repp, 2010; Spiro, 2012), therefore implementing a phase perturbation stage to the current study may have assisted in the study's aim of investigating a difference between these groups.

The program used for recording data was Ableton Live 9. SMS research is typically done using different software or materials, such as bespoke experiments written in MAX or other coding environments (see, e.g., Elliot, 2009; Finney, 2001). Ableton Live 9 is not intended for use in an experimental setting, being designed for music production and editing. While sources of variability and delay were minimized by the researcher by using the recommended configuration for highest accuracy (DeSantis, 2014), the untested and unprecedented nature of the program in SMS research may have led to unforeseen outcomes. Of particular note is the positive trend in MA for all participants when compared to previous research. When studying professional percussionists, negative MA for comparable IOIs to the present study with non-musical stimuli has been demonstrated from ranges of 0ms to -50ms (Krause, 2010a; Fuji, 2011), whereas nonmusicians have been observed to tap with an MA of -20ms to -70ms (Thompson, 2015). The novel presence of positive MA for Musicians, as well as the unusually low negative MA for Nonmusicians may suggest a delay in the tapping recording inherent to the program used, possibly in the range of +10ms to +30ms. A systematic delay to common to all participant's taps would not have an impact on comparing a mean difference between groups, so the analysis used in the present study would still be appropriate, however any inferences or conclusions made regarding the positivity or negativity of asynchronies would be based on flawed data.

Future Research

The results of this study can be seen as a demonstration of a difference between Musicians and Nonmusicians in their ability to synchronize with a beat. However, little inference can be made as to the cognitive and neural mechanisms that underlie this difference nor the causal relationship between musicianship and accuracy. Future study should endeavour to investigate why musical training has been shown to influence SMS accuracy.

A significant effect of musicality of stimulus on MA was observed in the present study, with a nonsignificant effect on SDA. This was hypothesized to be indicative of a characteristic difference in the pattern of participants taps. Future research should further investigate this characteristic difference in taps, with particular focus on the effect of metrical structure, and how this relates to accurate and reliable synchronization to an isochronal beat.

The nonsignificant interaction between musical training and musicality of stimulus suggests the benefits of musical perception experienced by musicians may have limited impact on SMS response, as these perceptual cues equally benefitted musicians and nonmusicians. This interpretation fails to consider the relationship between phase changes and musical elements, however. It is not unreasonable to imagine a piece of music that, as pitch lowers and deepens, the rhythm becomes slower and vice versa. Future research should investigate the ability of musicians to use nonrhythmic musical cues to predict changes in IOI, such as a task that involves random perturbations and perturbations based on musical expression.

It was recommended by the researcher that study of the effects of musical training should move towards a clear and universal definition of a musician. Further research should focus on different aspects of musicianship, such as instrument played, level of practice, and years of study, to develop a functional taxonomy of the Musician population for use in research.

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Appendix A.

Psychology Study about Rhythm Differences Between Musicians and Non-Musicians.

Official Title:

Sensorimotor Synchronization: The Effect of Musical Training and Musicality of Stimulus.

Hello! I would like to invite you to take part in a research study.

Before you decide you need to understand why the research is being done and what it would involve for you. Please take time to read the following information carefully.

Ask questions if anything you read is not clear or if you would like more information. Take time to decide whether or not to take part.

Who am I?

My name is Daegan Finlay, I am studying a BA in psychology at the National College of Ireland (NCI).

What is this study about?

The study is about the differences between musicians and non-musicians in their ability to tap along to a beat. Specifically, this study aims to investigate the relationship between how musical a beat is and how accurately people can tap along to it.

The study is also investigating the differences between musicians and non-musicians in their ability to keep time with a beat.

What will taking part involve?

Taking part in the study means being part of a psychology experiment. In the experiment your ability to tap along to a beat will be measured.

Taking part will involve being available to participate in an experiment in NCI, with the expected duration being anywhere between 5 - 10 minutes.

Do you have to take part?

Absolutely not! Participation in this study is purely voluntary and you have the right to refuse participation. You also have the right to terminate involvement in the study at any time, including in the middle of the experiment and afterwards. You also have the right to see your data after it has been collected and revoke anyone's access to it at any time.

Refusal of participation at any stage of the study will have no consequences to you whatsoever.

What are the possible risks and benefits of taking part?

A benefit of taking part in this study is to learn more about your own rhythmic abilities and to help advance research (if only by a little) into the understanding of how people think about music.

While there is no risk of physical harm, there is a small risk that the experiment may prove to be stressful. If this is the case, the experiment can be stopped and access to helplines will be there for you.

Aware (a mental health helpline). Phone - 1800 80 48 48

Participation in this study is purely voluntary, and no monetarial reward will be given. If you are not interested in being part of the study, there is a risk that you may feel as though you have wasted your time should you participate.

Will taking part be confidential and will my information be private?

Yes and Yes. Your data will be collected and protected according to the law and the ethical guidelines of NCI. Your identity will remain totally anonymous, we don't even have to know your name!

If at any time you wish to review revoke your data from the study, you have the right to do so and will be accommodated.

How do I take Part?

Simply fill out the application form and the ethical consent form provided. If you are eligible to take part, you will be contacted with details about the date and time of the experiment.

Thank you for taking the time to read

Appendix B.

Application Form to participate in the study titled -

Sensorimotor Synchronization: The Effect of Musical Training and Musicality of Stimulus

Please circle the most appropriate answer.

I identify as -

Male Female Prefer not to say

I am aged -

0 - 17 years old 18 - 35 years old 36-50 years old Over 51 years old

I have been studying music / learning an instrument for -

<1 year 1-4 years 5+ years

I am currently working in a profession related to music (e.g., Music student, music performer, music teacher, etc.)

Yes No

I regularly practice and instrument for this many hours a week, on average

0-1 hours 1-6 hours 7+ hours

Appendix C.

Sensorimotor Synchronization: The Effect of Musical Training and Musicality of Stimulus.

Consent to take part in research

1. I voluntarily agree to participate in this research study.
2. I understand that even if I agree to participate now, I can withdraw at any time or refuse to answer any question without any consequences of any kind.
3. I have had the purpose and nature of the study explained to me in writing and I have had the opportunity to ask questions about the study.
4. I understand that participation involves an experiment consisting of tapping to the beat of a metronome and music and having those taps recorded.
5. I understand that I will not benefit directly from participating in this research.
6. I understand that all information I provide for this study will be treated confidentially.
7. I understand that in any report on the results of this research my identity will remain anonymous.
8. I understand that if I inform the researcher that myself or someone else is at risk of harm they may have to report this to the relevant authorities - they will discuss this with me first but may be required to report with or without my permission.
9. I understand that under freedom of information legalisation I am entitled to access the information I have provided at any time while it is in storage as specified above.
10. I understand that I am free to contact any of the people involved in the research to seek further clarification and information. Names, degrees, affiliations and contact details of researchers and academic supervisors.

I agree that I understand and consent to participation in this study.

________________________ ____________________

Participant Number Date (*mm/dd/yy)*

I believe the participant is giving informed consent to participate in this study.

________________________ ____________________

Signature of Researcher Date (*mm/dd/yy)*

Appendix D.

Thank You!

Thank you for participating in the study. This study was designed to examine the differences between musicians and non-musicians in their ability to tap to different beats. This study in particular was focused on the difference in tapping ability between a neutral sounding metronome and an extract of music both for musicians and non-musicians.

Thanks to the data from your participation in this experiment, we will be able to analyze how these different stimuli affected your tapping accuracy.

If you have any more questions about the study or would like to see the paper when it is complete, feel free to contact the researcher at the details below.

Email - x17449774@student.ncirl.com

Appendix E.

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
1	p number	M/N	studytime	working	practice	gender	age	ASYNCH-r	VARI-mus	ASYNCH-i:	VARI-mus	ASYCNH-n	VARI-mus	ASYNCH-i:	VARI-iso-s
2	0	M	2	2	2	m	2	35.66666	502.1333	58.8	499.2	7.435649	9.597684	8.580598	14.84228
3	1	M	3	1	3	f	2	9.6	500.8	14.57142	500.7142	21.83819	33.08010	24.94491	22.89240
4	2	N	1	2	1	m	3	30.35714	500	67.38461	494.6923	14.23580	19.23538	23.46871	17.58594
5	3	N	1	2	1	m	3	16	499.0625	16	498.4375	33.63353	156.8623	42.69660	29.31183
6	4	N	1	2	1	f	2	21.6875	564.0625	-59	499.0625	12.15460	19.92476	13.01921	18.71162
7	5	M	3	2	2	f	2	28.125	502.5625	26	503	12.15460	19.92476	13.01921	18.71162
8	6	M	3	2	2	f	2	15.75	503	-7.3125	496.5625	13.33932	17.79000	27.61311	15.39670
9	7	M	3	1	2	f	2	16.75	499.875	-13.875	502.0625	16.42026	26.13299	16.95951	28.21783
10	9	N	1	2	1	F	2	-4	497.8125	-61.5	497.1875	18.43908	21.49772	15.43129	17.76308
11	10	N	1	2	1	M	2	-15.75	496.2188	29.1875	501.4375	47.85459	34.01101	30.99842	37.47660
12	12	N	1	2	1	F	2	33.4375	500.4375	36.625	501.0625	28.92440	22.21336	92.05600	61.94743
13	13	M	3	1	2	F	3	-51	499	-9.0625	500.6875	11.83215	11.95826	11.81349	8.708607
14	14	M	3	1	2	M	3	33.4375	500.4375	36.625	501.0625	8.411069	9.797759	14.34780	12.52731
15	15	M	3	1	3	M	3	23.625	500.4375	-16.9375	499	12.02536	14.99570	16.27294	11.62432
16	16	N	3	2	1	M	2	-8.5625	499.8125	-33.75	496.4375	24.04934	25.50788	27.81074	12.87909
17	17	N	1	2	1	F	2	-8.375	502.4375	-8.8125	501.0625	21.17449	26.51643	23.28148	21.20279
18	18	M	3	2	1	F	2	23.9375	501.5	22.1875	499.5625	16.00573	25.57586	15.52505	21.69092
19	19	N	1	2	1	M	2	41.0625	500.5625	-38.5	503.25	41.71400	32.60745	17.48570	17.90076
20	20	N	1	2	1	F	2	-73.125	497.5	-99.5	496.5	42.42769	52.02763	29.55926	38.93263
21	21	N	1	2	1	F	2	15.5	500.25	-21.75	502	21.15419	26.22379	35.50968	15.09966
22	22	M	2	2	2	F	2	13.5625	501	-41.4375	502.5	18.53701	19.92799	25.12212	22.84458
23	23	N	2	2	1	P	2	-7.875	500	-125.5	496.5	15.96823	20.70024	22.48888	25.68559
24	24	N	2	2	1	f	2	-64.25	502	-92.8125	497.8125	23.94133	29.32788	28.11409	27.32036

Note: Further data, such as Ableton or SPSS project files, available on request.