PHYSIOLOGICAL AROUSAL AND SENSORIMOTOR SYNCHRONISATION: AN INVESTIGATION EMPLOYING RESONANCE FREQUENCY BREATHING

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Tiivistelmä – Abstract

It is common for individuals to move their bodies in time with external cues such as sound or music, a phenomenon known as sensorimotor synchronisation. However, not all time intervals are optimal for synchronisation, with some being too short and some being too long to effectively track and time one's actions to. Moreover, cues often have varying periods meaning individuals must correct their movements to re-synchronise with the new rhythm. The ability to synchronise and re-synchronise thus requires correct time interval tracking. Changes in physiological arousal level have been linked to time perception and a number of investigations into the effect of meditation on time perception have been undertaken. Yet, little is known empirically as to how alterations to systems involved in time tracking affect sensorimotor synchronisation. The primary aim of this study is therefore to investigate how a shift in physiological arousal impacts sensorimotor synchronisation with rhythmically-stable and rhythmically-shifting sounds. To this end, participants performed a finger-tapping synchronisation task after either a breathing intervention or sitting quietly. The breathing intervention used was resonance frequency breathing, which increases heart rate variability and creates a parasympathetic-dominant, relaxed state of being. Circular statistics were used to generate mean phase angles and variability of finger taps relative to the sound onsets while a circular analogue of Hotelling's T2 sample test was used to detect differences in synchronisation between conditions. No differences in synchronisation or re-synchronisation were found between conditions; additionally, physiological arousal and heart rate variability showed no significant correlation with synchronisation and re-synchronisation performance. The findings are discussed in the context of other research into time perception and altered states of consciousness. Recommendations for using resonance frequency breathing as a manipulation in future sensorimotor synchronisation research are given.

Asiasanat – Keywords

Sensorimotor synchronisation, time perception, resonant frequency breathing, heart rate variability, error correction, mean asynchrony.

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"The wind outside is blowing, but it don't dance." - Leif Vollebekk, *In the Morning*

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1 INTRODUCTION

The passage of time is a subjective phenomenon. Time slowing down during non-preferred activities and speeding up during enjoyable ones is undoubtedly an experience familiar to most readers upon reflection. In 1890, William James pointed out the peculiarity of time perception by noting how novel experiences tend to give rise to the sense that time is passing more quickly while a lack of novelty or change produces the perception that very little time is passing (Glickson, 2001). This early observation likely informed, and is indeed largely congruent with, later empirical studies into time perception. Changes in the speed at which time seems to be passing can be somewhat beyond an individuals control, such as it trickling by during a particularly uninteresting yet mandatory meeting, but it can also be intentionally manipulated though substance ingestion like stimulants (Wittman and Palaus, 2008) or psychedelic drugs (Kenna and Sedman, 1964), or through meditation (Travis & Shear, 2010).

While noticing and tracking the passage of time is certainly of importance to any organism, coordinating movements in time is a required ability if an organism is to interact with and move about its environment with any efficiency (Goldman, 2018). Going one step further, humans are particularly adept at coordinating their movements in time in ways that do not directly relate to locomotion or survival. Sensorimotor synchronisation (SMS) is an example of an individual matching the timing of their movements with an external cue, most often a rhythmic one. Two common and ubiquitous expressions of this refined capacity are music and dance which both require producing movements that match a specific temporal pattern. In other words, music and dance are examples of movements embedded in intervals of time.

It is thus that we arrive at the question informing the current research project: what happens to movements that are embedded in time when one alters physiological and cognitive parameters that are involved in time perception? Specifically, this project explores what happens to humans' ability to synchronise movement with auditory sequences when a mild shift in consciousness and physiological arousal occur. There exists an extensive body of literature examining the properties of human SMS to both isochronous auditory sequences as well as music. Moreover, previous work has examined factors affecting SMS such as environment/ context, cognitive load, or musical expertise (Aschersleben, 2002; Pöppel, 1997; Repp & Su, 2013). These, among other factors, have been observed to influence certain aspects of SMS such as the size of the interval between tone onsets that allows for synchronisation or how accurately an individual synchronises with sounds (Aschersleben; Repp & Su). By having subjects engage in cued relaxation breathing and subsequently undertake a SMS task to auditory sequences, this research intends to understand how a shift in consciousness and physiological arousal level can impact properties of audio-motor synchronisation (AMS).

In particular, this research will examine the properties of error correction (EC) and prediction to make determinations about synchronisation capacity. EC can be divided into two types: phase correction and period correction. Phase correction refers to correcting the phase of one's movements relative to the phase of the stimulus, while period correction refers to corrections of one's movements relative to the period of the stimulus. In each type of correction, an auditory stimulus such as a tone deviates from it's predicted position in a sequence requiring the individual to correct their newly-unsynchronised movement in order to resynchronise with the sequence. Given the establishment of some typical EC patterns in previous literature (for example, see Thaut, Miler, & Schauer, 1998), there exists a reference to which EC patterns that might emerge in a meditative state can be compared. Equally well-established in the literature is the negative mean asynchrony (NMA), the average amount of time an individual taps their finger ahead of a tone in a sequence of tones (Repp, 2005**)**. This response is taken as evidence for prediction in SMS with isochronous tone sequences (Repp, 2005).

What makes EC and the NMA interesting parameters to study are their necessary roles in SMS: if one cannot error correct, then a compounding of inherent variability in one's movements would prevent synchronisation with an external signal (Repp, 2005; Thaut et al., 1998). Similarly, prediction of a stimulus is required for SMS, otherwise an organism will be responding to rather than synchronising to a stimulus. Many species are unable to synchronise their movements to an external stimulus in the robust and spontaneous way that humans are

(Merker, Madison, & Eckerdal, 2009). Moreover, the ability to synchronise with an external stimulus is linked to human social bonding (Kirschner & Tomasello, 2010) and audio-motor synchronisation is a key capacity underlying the human ability to produce, enjoy, and move to music (Janata, Tomic, & Haberman, 2012). Ultimately, an examination of the psychological and physiological factors that affect or underlie one's predictive capacity and EC processes could shed some light on the mechanisms that make SMS possible. Investigating these key parameters of SMS allows us to probe more basic time-keeping and stimulus-tracking capacities that play a role in the perception and production of a complex auditory phenomenon like music.

The aim of this study is to extend investigations as to how changes in state of consciousness and physiological arousal impact the basic processes that directly facilitate SMS (prediction and EC). Before reviewing the literature in this area, I would like to make a note on the use of a meditative state, or a meditative-like state, to conduct this research. A meditative state can be grouped into the category of "altered state of consciousness" (ASC). Krippner (2000) defines a state of consciousness as having stable patterns along cognitive, perceptual, and affective dimensions. It can therefore be useful to think of consciousness as being constructed of a number of parameters (for example, attention, memory, language, and mood, non-exhaustively) that, in different combinations, give rise to particular experiences and conceptualisations of reality. The dimensions of cognition, perception, and affect are themselves composed of more basic processes which are malleable to external and internal environmental conditions. There is ample evidence of this from drug research (for examples see Nichols, 2016) and more general psychological research examining states of consciousness (for example, Hove et al., 2015). To be in an ASC is thus merely to have manipulated certain parameters which contribute to our construction of reality and ourselves. When it comes to studying music psychology, there are two main reasons why one might use an ASC paradigm. The first is to identify therapeutic potentials of combined ASC-music therapies. Internally-directed attentional states that prompt a focus on mental imagery are used successfully in conjunction with music to alleviate anxiety in some populations (Burns, 2001) while psychopharmacological work has probed the therapeutic usefulness of music listening during guided LSD-induced states (Kaelen et al., 2015; Kaelen et al. 2016).

A second reason to study music during an ASC is to look at more basic changes in music cognition related to the manipulated parameters of consciousness. This area is driven by an interest in trying to understand how musical experiences would be different if one's state of consciousness was different. The present study, however, focuses only on audio-motor synchronisation during an ASC rather than music listening - so why describe the value of ASC paradigms to music cognition here? The answer is again twofold. SMS frequently occurs during music listening both spontaneously and intentionally in the form of dance and it is, as mentioned, a key capacity for the perception and playing of music. Second, and following from the first, the perceptual and cognitive processes that underlie SMS, some of which are the focus of this project, are key components in music perception and cognition (a stronger case will be made for this in the Literature Review, p. 11). The present research will employ a pseudo-meditative state to manipulate, primarily, the parameters of physiological arousal and heart rate variability in order to investigate their effect on the processes underlying SMS. So, by studying SMS under different states of consciousness, we can study variability in the component processes involved in musical abilities. This type of research can highlight ways in which rhythmic behaviour is sensitive to different psychological and physiological conditions as well as identify conditions under which a robust behaviour like SMS is affected. Understanding these conditions may help researchers to understand human cases in which SMS is unattainable or to identify potential species-specific differences in mechanisms promoting SMS. While the present study does not attempt to assess musical experiences during an ASC per se, its purpose is to explore how the more fundamental capacity of SMS and some of its component processes are affected by a meditation-mediated shift in consciousness. Out of this type of research, the aim is to slowly build an understanding of how certain psychological and physiological states contribute to the complex phenomenon of music and what the possibility space for music perception and production is when psychological and physiological conditions are altered.

2 LITERATURE REVIEW

This section will be composed of two distinct parts: research into time perception and SMS, and ASC-focused research. The first section on time perception is the logical beginning as it sets the stage for understanding audio-motor synchronisation. This section will also provide a more extensive background about the NMA/stimulus prediction and EC. The second section on ASC's will present examples of how time perception is flexible under varying psychological, physiological, and environmental conditions. Resonant frequency breathing and heart rate variability will then be outlined and tied into the main aims of the current study.

2.1 Time perception

The psychology of time and time perception is a broad field and encompasses research areas that extend from understanding time perception at the millisecond (ms) level to the more abstract level of projecting into the future or the past. Only a subset of this body of research is primarily of relevance to SMS, namely research that focuses on the perception of relatively short-term time intervals in the range of milliseconds to a few seconds. Thus, the perception of intervals with short temporal durations will be of focus in this literature review.

2.1.1 Temporal windows and SMS

All motor behaviour is embedded in time. Sensorimotor synchronisation is an example of motor behaviour that requires, by definition, the ability to track intervals, integrate sensory and motor information, and engage the motor system in a periodic fashion. A key aspect to temporally-sensitive behaviour is a perceptual window of temporal integration. Pöppel (1997) proposed a hierarchical model of temporal perception that involves two main processing systems: a high-frequency sampling system and a low-frequency sampling system. A combination of these systems is argued to underlie the perception of intervals of time. The high-frequency sampling system takes samples approximately every 30 ms. Evidence for the high-frequency system in the auditory domain comes from research suggesting that if events are to be considered as both separate and successive, they must be presented about 20 ms apart in order to achieve 75% accuracy in temporal judgements while 40 ms separation is needed to achieve 98% accuracy in temporal judgements (Hirsh & Sherrick, 1961). This can therefore be considered a lower bound for tracking and perceiving the temporal position of events, meaning stimuli must be separated by about 30 ms to make SMS theoretically possible. At the other end, the low-frequency system is presented as defining the perceptual "now", a 3-second sampling interval that is composed of integrated, discrete perceptual units from the high-frequency system (Pöppel). Importantly, Pöppel notes this 3-second interval is perceptually-mediated, meaning cognitive processes such as memory do not need to be invoked to track or construct this interval. Effectively, this 3-second interval can be seen as an upper-bound for the perceptual tracking of time and events in time. What evidence exists for this window and how is it relevant to SMS?

Neurophysiological studies have converged on the approximately 3-second window during interval duration reproduction tasks as well as change detection tasks. Elbert, Ulrich, Rockstroh, and Lutzenbeger (1991) found that subjects could accurately reproduce the length of intervals up to 3 seconds. This accuracy is reduced between 3 and 4 second interval lengths, and reproductions become significantly shorter for intervals longer than 4 seconds. Furthermore, Elbert et al. (1991) report that reproduction of longer intervals is associated with different event-related potential (ERP) activity than the reproduction of intervals in the 1- to 3-second range, suggesting divergent neural mechanisms in the perception of short and long temporal intervals. Pöppel (1997) reports that the mismatch negativity (MMN), a pre-attentive electrophysiological marker of deviance detection in a stimulus, peaks when deviant auditory stimuli are presented in 3-second intervals. This is taken as evidence that there is maximal sensitivity to information arriving in 3-second intervals, supporting the existence of a 3-second temporal integration window.

The importance of accurate short-term time perception has been noted by Meck (2005) who points out the adaptiveness of such an ability for reacting to a changing environment. In fact, there is evidence across mammals for a 3-second perceptual window that largely controls motor behaviour (Gerstner & Fazio, 1995). A similar temporal integration window has unsurprisingly been observed for SMS abilities. Mates, Müller, Radil, and Pöppel (1994) used an audio-motor finger-tapping paradigm to investigate if and how temporally-varied auditory sequences impact SMS. Their results showed increased variance between the time of a finger tap and a tone onset outside 450 ms and 2400 ms. They also saw increased variance in the intervals between consecutive finger taps as the inter-onset interval (IOI), the time between tones, increased. This means that for intervals outside of the 450-2400 ms range, synchronising finger taps to regular tones was destabilised. Their results support the idea of an approximately 3 second window that serves as a perceptual timing mechanism constraining human SMS.

Out of the above-discussed research (which, clearly, is a non-exhaustive review of the field, but rather covers main points) has come an approximated range in which humans can optimally or most effectively synchronise their movements to an auditory stimulus. Repp (2005) reports this range to be from 150-200 ms up to 1800 ms for 1:1 tapping-to-tone situations, though this can be extended by a few hundred milliseconds through musical training or by requiring tapping that is not 1:1 (1:n tapping). Through the establishment of a window of temporal perception and optimal synchronisation, research concerning prediction and error correction can now more meaningfully be discussed.

2.1.2 Prediction in SMS

As mentioned, the ability to predict what is coming next in a stimulus or a set of stimuli is necessary for SMS. Schütz-Bosbach and Prinz (2007) refer to the ability to represent future actions or events as prospective coding wherein current and past information is incorporated into an anticipatory representation for the near future. These authors note that this type of anticipatory response is highly effective in adapting to an ever-changing internal and external environment as organisms can predict what might come next. Forming these predictive representations is highly applicable to studying SMS. In finger tapping paradigms, the presence or absence of the NMA is typically considered a marker of synchronisation. In the study from Mates et al. (1994), the NMA was used to determine the point at which subjects were no longer synchronising their movements to sounds but rather responding to sounds[1]. Mates et al. (1994) and Repp and Su (2013) have proposed that the NMA is due to a combination of an anticipatory response to what is coming next in a sequence as well as compensation for the relative delay in tactile information from the finger tap arriving to the brain compared to the auditory information of the tone. By tapping slightly ahead of a tone, the perception of synchrony arises as it takes longer for the tactile information to be processed than the auditory information. If humans were unable to anticipate and predict an upcoming tone in a sequence, finger tapping would occur on or slightly after a tone onset and create an even stronger perception of response to as opposed to synchrony with an auditory stimulus. The necessity of tracking the duration of intervals is here made clear: without the ability to perceive a short interval of time, prediction as to when the next tone in a sequence will occur would not be possible and synchronisation would be replaced with response.

A number of factors seem to affect the NMA. Musically-trained individuals show a smaller NMA compared to non-musically trained individuals, and the NMA seems to decrease within musically-trained populations as a function of degree of training (Aschersleben, 2002). Nonetheless, even highly trained musicians consistently show an NMA of a few tens of milliseconds, with a possible exception of highly rhythmically-trained musicians like drummers (Repp & Su, 2013). Changes in the size of the NMA have been elicited through the use of discrete versus continuous auditory stimuli, with discrete stimuli typically producing a smaller NMA (Rodger & Craig, 2011). Developmental factors influence one's ability to synchronise rather than react, and it is thought that synchronisation abilities come online slowly from age 3-4 onward (as cited in Repp, 2005). And of course, the IOI of tones affects the stability and size of the NMA. Typically, as the IOI decreases the NMA also decreases in size (Repp & Su) until the the IOI passes the point of human synchronisation ability. Beyond a 2-3 second IOI, asynchrony in finger taps to tones also becomes more variable indicating decreased stability in synchronisation (Repp & Su). Together, these findings suggest that

[1] Notably, a positive asynchrony value that is shorter than 150 ms is still considered evidence of prediction. This is due to the time it takes to execute a motor command, making actions that occur up to 150 ms after a stimulus onset anticipatory ones (Repp & Su, 2013). It follows that positive asynchrony values exceeding 150 ms are evidence of response rather than synchronisation. Given this, it should be understood going forward that the NMA includes positive asynchronies up to 150 ms.

predictive and synchronisation capacities are impacted by contextual and person factors as well as ultimately limited by a temporal perception window in which humans can synchronise their movements to an external stimulus.

2.1.3 Error correction in SMS

Profiles of error correction have been established under the dual-process model of correction (Mates et al., 1994; Repp, 2005; Repp & Su, 2013) which distinguishes between phase and period correction. EC in finger-tapping paradigms is typically tested by shifting either single tones or a longer sequence of tones to induce EC processes. Local phase-shifts involve the temporal displacement of a single tone in a sequence that returns to its original phase immediately while global phase shifts involve the temporal shifting of a single tone that keeps the rest of the sequence out of phase with the initial sequence (Repp, 2003, Figure 1A). Similarly, period shifts involve the temporal shifting of a single tone with the remainder of the sequence taking on the new period of the shifted tone (Repp, 2003, Figure 1B). Through these methods of perturbation, researchers have been able to derive a number of insights about phase and period correction.

In particular, differences about the level at which phase and period correction processes are engaged have emerged. Phase correction is thought to be a more automatic, less-suppressible response than period correction. This observation comes from studies that have looked at increasing cognitive load during error correction processes (Repp & Keller, 2004) as well as manipulating the direction of one's attention to specific sequences over others (Repp, 2002; Repp, 2003). These studies show an automatic component to phase correction: it is largely invariant under increased cognitive load and is engaged by task-irrelevant rhythmic sequences. Repp (2005) also reports that the return to synchronisation after a phase shift follows a non-linear pattern and that the direction of the phase shift (shorter versus longer phase) impacts the compensation employed immediately after the phase shift. While period correction shares the non-linear return to synchronisation, period correction mechanisms are

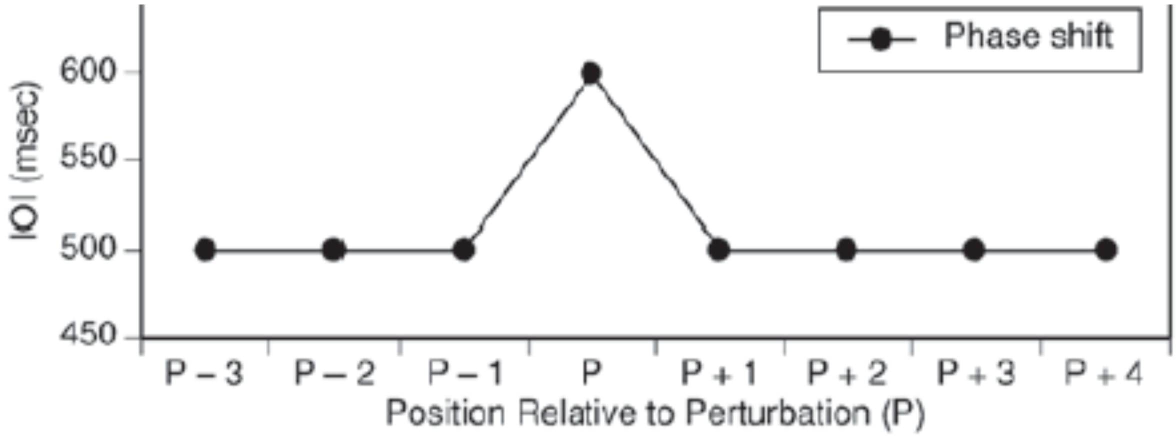


FIGURE 1A. The graph represents a global phase shift in the sequence as the IOI between the third and fourth and the fourth and fifth tones has been extended by 100 ms. This functions to push the rest of the sequence out of phase with the initial sequence (from Repp, 2005).

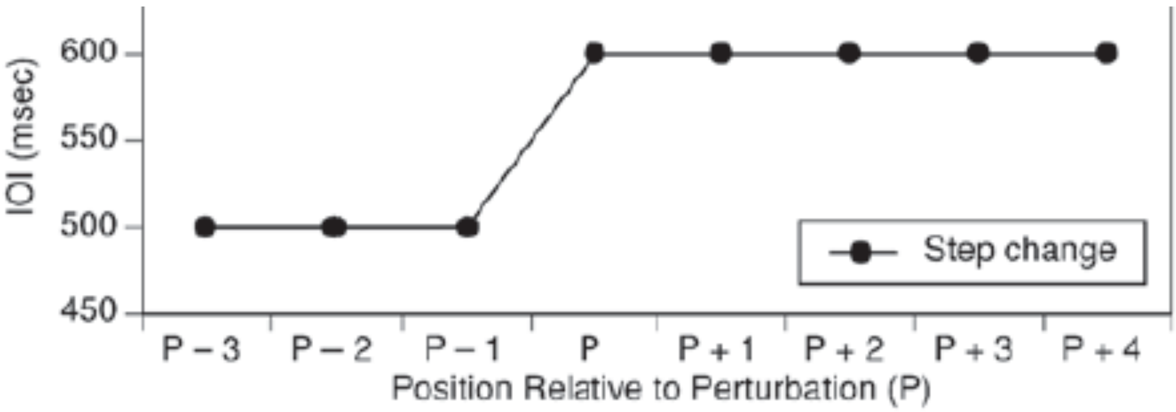


FIGURE 1B. The graph represents a global period shift where the fourth tone has been shifted to have an IOI of 600 ms as do all subsequent tones (from Repp, 2005).

thought to require larger, detectable deviations in a rhythmic sequence than phase correction mechanisms if they are to be engaged (Thaut, Miller, & Schauer, 1998). This suggests period correction is less sensitive to change or deviance than phase correction processes. Yet, correcting any error relies on the detection of deviations either in one's actions relative to a stimulus or in a stimulus relative to one's action. The detection of deviations in a stimulus is known as change detection, a term often used in vision research, that may be at a pre-attentive level or in one's awareness (Rensink, 2002). As EC would not be elicited at all if some deviance in a stimulus was not detected, this suggests that phase correction processes may be engaged by pre-attentive deviance detection. Given the apparent automaticity of phase correction and the awareness component to period correction, it is reasonable that changes in state of consciousness may not exert the same effect on these types of EC processes.

Taking the sections on the NMA and EC together, it can be seen how the more basic processes of time perception and change detection are fundamental to prediction and correction of errors in the context of SMS. The length of an interval in a sequence must be aptly tracked if one is to correctly anticipate upcoming stimuli. This anticipatory representation can be seen as providing a reference point for processes of EC because it serves, in part, as a model from which deviations in a stimulus can be detected. When temporal intervals separating stimuli fall in the range of 150 ms to 1800 ms (approximately), then processes of time perception and change detection permit for maximally-effective predictive and corrective processes to occur in order to facilitate SMS.

2.2 The malleability of time perception

This section will outline studies that have examined time perception, change detection, and SMS during altered states of consciousness (ASC). A number of altered states will be considered and reported on though focus will be on studies involving meditation as this is most relevant to the manipulation used in the current study. Ultimately, this section will serve to unite the two core ideas of this thesis, processes of SMS and ASC, in order to elucidate the empirical and theoretical grounds for investigating SMS during an ASC.

2.2.1 Perception is generally flexible

The idea that perception is dynamic is likely intuitive to most readers based on personal experiences. Nonetheless, outlining some of the psychological literature that supports this idea is useful to demonstrate the empirical precedent for exploring altered time perception. The most obvious scenarios in which perception can be altered involve the ingestion of psychotropic substances. Strong alterations in visual and auditory perception, such as enhancements of visual scenes or auditory hallucinations, are known to occur with ayahuasca, psilocybin, ketamine, and lysergic acid diethylamide (LSD) ingestion, non-exhaustively (Frecska, White & Luna, 2004; Vollenweider, 2001). Research into how language shapes perception, an idea known broadly as the Sapir-Whorf hypothesis, suggests that colour and space perception are mediated by the language one speaks (Haun et al., 2011; Winawer et al., 2007). Moreover, an individual can be linguistically primed to perceive certain phenomena such as motion in static images (Francken et al., 2014) or emotional states in emotionally-ambiguous facial expressions (Gendron et al., 2012). Finally, Forgas & Bower (1987) have shown that an individual's mood can impact the valence of their perceptions and evaluations of social situations. The cases in which language and mood influence perception are perhaps less drastic than those induced by substance ingestion, but they nevertheless show that more sensory-based perceptions as well as higher-order perceptions containing social information are influenced by a variety of environmental and psychological factors. Given the general flexibility of perception, the discussion may now turn towards the flexibility of time perception in particular.

2.2.2 Altering time perception

Perceiving a duration of time can be altered in a number of ways. The length of an auditory stimulus impacts the perception of instantaneity rather than duration, with sounds less than approximately 140 ms being perceived as instant rather than enduring in time (Fraisse, 1984). When it comes to perceiving intervals of time, Fraisse also suggests that the direction of one's attention toward the passing of time can result in an overestimation of the interval while an underestimation can result from a relative deprivation of the senses or a lack of change in the environment. It has further been suggested that physiological arousal and attention are two key factors in time perception and its alteration (Burle & Casini, 2001; Mella et al., 2011). This idea has, in part, led to a host of studies examining how arousal and attention influence both short- and long-interval perception. This section will focus primarily on studies examining short-interval perception as it is of most relevance to the current project.

A number of investigations into state-dependent temporal perception during pharmacologically-altered states of consciousness have been conducted (for early examples see Kenna and Sedman, 1964). More recently, work has been done to assess duration reproduction during an ASC in an effort to understand the subjective now and the 3-second perceptual window. Wackermann et al. (2008) found that psilocybin, a psychoactive compound in magic mushrooms, led subjects to make significantly shorter reproductions of time intervals that ranged from 1.5 to 5 seconds compared to placebo controls. Other research has linked stimulant ingestion to the production of shortened time intervals relative to a target interval and has suggested that disrupting attentional processes might influence the ability to track short passages of time (Wittman and Palaus, 2008). It thus seems that short-term time perception is vulnerable to disruption with exposure to pharmacological compounds.

Studies using meditation to manipulate physiological arousal and attention have somewhat conflicting findings when it comes to the meditative state's effect on time perception. Kramer, Weger, and Sharma (2013) used a mindfulness meditation (in meditation-naïve subjects) compared to a control condition of audiobook listening to test for differences in the perceived length of intervals ranging from 400 ms to 1600 ms. The authors report that meditators perceived intervals to be significantly longer than controls did as measured by a difference score in interval duration estimation from pre- to post-test. In contrast, Droit-Volet et al. (2014) attempted to replicate these findings but found that overestimations of interval duration by meditators were present only after meditation-naïve subjects had practised a mindfulness meditation for a number of weeks. Droit-Volet et al. suggest this is preliminary evidence for meditation having a trait effect on time perception rather than a state effect, meaning meditation practice produces long-term changes to an individual rather than short-term, immediate changes (Srinivasan & Baijal, 2007). This distinction is commonly made in the meditation literature, with a number of studies reporting trait effects of meditation on short-interval time perception (Berkovich-Ohana et al., 2011; Schötz et al., 2015; Wittman & Schmidt, 2014). This distinction between state and trait effects on time perception remains unresolved in the meditation literature, but either type of effect implicates shifts in physiological arousal and attention in the perception of intervals of time. From this evidence, one can begin to speculate that a meditative-type state may influence SMS by influencing the perception of short intervals of time.

2.2.3 Altered states of consciousness and SMS

Interval tracking: Studies looking specifically at SMS during an altered state of consciousness are few and far between. Wittman et al. (2007) administered low doses of psilocybin to subjects and assessed their ability to synchronise finger taps with sequences of tones. Using IOI ranging from 700 ms to 4000 ms, it was found that psilocybin significantly decreased NMA, increased the number of missed synchronisations, and increased the number of reactions over synchronisations at intervals between 2000 ms and 4000 ms. Wittman et al.'s findings suggest that an ASC can influence SMS behaviour. Since Wackermann et al. (2008) have shown that temporal perception is influenced by psilocybin, it is plausible that perturbations to systems of time perception underlie alterations in SMS behaviour observed by Wittman et al. Specifically, if the 3-second perceptual integration window posited by Mates et al. (1994) and Pöppel (1997) is affected during different states of consciousness, then we might expect to see shifted optimal temporal windows for SMS. By extension, prediction of oncoming stimuli may be possible in a larger or a smaller interval window, depending how the altered state influences temporal perception.

Error Correction: Additionally, meditation has shown a state effect on change detection (Srinivasan & Baijal) and response inhibition (Wenk-Sormaz, 2005). In the case of change detection, Srinivasan and Baijal report that immediately following a meditation session, individuals show an enhanced mismatch negativity (MMN) response, an electrophysiological marker of detecting a deviant stimulus, indicating that at a pre-attentive level individuals may have better change detection responses after meditating. With respect to response inhibition, Wenk-Sormaz found that meditators had faster reaction times in the Stroop task during incongruent word-colour trials relative to non-meditators. This study suggests that meditation may help to suppress automatic or irrelevant responses. While change detection and response inhibition may not be directly tied to time perception alteration, these processes must be involved in error correction during SMS. Error correction requires first the detection of a deviant stimulus (either the individual relative to the tap or a change in the IOI of a stimulus sequence) and second the shift to a new response pattern in order to resynchronise with the stimulus. This fits with the ideas of Shadmehr et al. (2010) and Clark (2013) of the brain as principally carrying out predictive processes in order to construct one's reality and interact with a changing environment. So, if shifts to physiological arousal and attention can be accomplished through a meditative state, and this state influences change detection and response inhibition, then it follows that a meditative (or a meditative-like) state may impact the EC process during SMS. The following section outlines the meditative-like intervention used in the current study.

2.3 Resonance frequency breathing and heart rate variability

Resonance frequency breathing (RFB) is a breathing technique that functions to maximise heart rate variability (HRV) by having an individual breathe at slow pace (Brabant, van de Ree, & Erkkila, 2017). In order to fully understand RFB, a discussion of HRV must first be had.

2.3.1 Heart rate variability

Oscillatory biological processes are dynamic in nature, meaning their temporal oscillations naturally vary as a result of multiple inputs influencing the oscillatory cycle (Shaffer et al., 2014). The beating of the heart is no exception. Under normal conditions, heart rate increases as one breathes in and decreases as one breathes out (Lehrer, 2007). This is known as the respiratory sinus arrhythmia (RSA), as this arrhythmic oscillation reflects respiration influence on heart rate (Porges, 2007). Heart rate variability more globally refers to the temporal variation from heart beat to heart beat that is observed in a normally functioning heart (Heathers et al., 2014). It is thus, in effect, what drives amplitude variation in a graph of heart beats. Porges notes that HRV is perhaps best understood as "the superimposed sum of several rhythmic heart rate oscillations" (p. 4) while Shaffer et al. emphasise that HRV arises from the multiple "regulatory system inputs" (p. 1) to the heart. These definitions highlight the complex nature of heart oscillations in that various biological sources contribute, at varying time scales, to the overall oscillatory pattern.

Due to these varying inputs, the heart rate pattern can be decomposed into different frequencies reflecting different input sources. Some influences such as hormones, metabolism, or time-of-day are reflected in ultra-low (≤.0033 hz) and very-low frequency (. 0033-.04 hz) domains (Laborde et al., 2017). These frequency domains are of little interest to research that examines HRV during a short time period (Heathers et al., 2014) and will not be further discussed. However, low frequency (.04-.15 hz) and high frequency (.15-.4 hz) domains reflect parasympathetic and sympathetic nervous system as well as respiratory influence on heart rate (Laborde et al.). These rhythms are detectable when observing a heart rate pattern over the span of minutes (Heathers et al.) and therefore are the frequency bands of interest when examining heart rate patterns over short periods of time. It is indeed this frequency decomposition that allows for the assessment of one's resonant frequency for breathing, to be discussed below.

The parasympathetic nervous system (PNS), the branch of the autonomic nervous system that is linked to lower-arousal states, facilitates HRV while the sympathetic nervous system (SNS), commonly-called the "fight-or-flight" system, is more associated with HRV suppression (Shaffer et al.; Task Force, 1996). So, when an individual is in a stressed state, HRV decreases, and when an individual is in a relaxed or resting state, HRV increases. Bringing this back to RFB, the PNS is of central importance to RFB as the vagal nerve is the main PNS input to the heart, and its activity is influenced by respiration (Shaffer et al.; Task Force). Effectively, vagal nerve stimulation of the heart is modulated by respiration[2] which gives rise to cardio-respiratory coupling as evidenced by the RSA. What this ultimately means is that by modulating respiration, one can modulate heart activity. This is the general principle upon

[2] It must be noted that vagal nerve stimulation is influenced by more than respiration, but discussing the complex stimulation of the vagus nerve falls outside the necessary scope of this literature review.

which RFB rests and, in light of establishing what HRV is and how it occurs, a detailed description of RFB will now follow.

2.3.2 Resonance frequency breathing

The technique of RFB involves much more than simply breathing slowly, as suggested above. Principally, performing RFB means that an individual breathes at a rate that coincides with the resonant frequency (RF) of their cardiovascular system (Brabant & Erkkila, unpublished). Most mammalian cardiac systems have a RF of about .1 hz (Shaffer et al., 2014), meaning that a breathing rate of about .1 hz (approximately 6 breaths per minute) will be the breathing rate that matches the RF of the cardiovascular system. Through the vagal nerve, respiration rate influences the depolarisations of the sinoatrial node, which triggers a heart beat (Task Force, 1996). This influence is such that when breathing at or near the RF of .1 hz, the variability in heart rate is maximised due to cardio-respiratory coupling at the RF of the cardiovascular system (Brabant & Erkkila; Shaffer et al.). Ultimately, the cardio-respiratory coupling that emerges is one where respiration and heart rate are in phase with one another (Lehrer, 2007). This leads to a heart rate waveform that bears resemblance to a smooth sine way.

The reason this cardio-respiratory coupling is important concerns the maximisation of HRV. As mentioned, HRV is typically highest during states of rest or relaxation. By breathing at a frequency of approximately .1 hz and increasing the vagal input to the heart, one is able to maximise one's HRV and facilitate a relaxed physiological state (Brabant & Erkkila, unpublished). Porges (2007) contends that from this state dominated by vagal influence, individual's are able to react adaptively and calmly to social situations. In a similar manner, RFB and RSA-focused breathing interventions have been used to relieve symptoms of major depression disorder and post-traumatic stress disorder (PTSD) by increasing HRV and decreasing sympathetic dominance over one's physiological state (Karavidas et al., 2007; Zucker et al., 2009). Overall, doing RFB promotes an emotionally calm, low arousal state of being by increasing vagal influence on the heart and with it HRV. It can thus be used as an intervention to facilitate a relaxed state of being.

2.3.3 Linking RFB, meditation, and SMS

While there are a number of types of meditation that achieve similar end states through different means, meditations also commonly involve the implicit or explicit use of RFB. Bernardi et al. (2001) report that meditating individuals often breathe around six breaths per minute while Lehrer (2001) observes that practicing Zen monks invoke breathing rates similar to those used in RFB paradigms. Comparisons between spontaneous breathing and breathing during Zen and Kinhin meditations have also been undertaken, showing that cardiorespiratory coupling occurs during the meditations but not during spontaneous breathing (Cysarz & Bussing, 2005). This suggests that during these meditations, individuals breathe at a speed that increases vagal input to the heart in a similar manner to RFB. Since there seems to be overlap between meditations and RFB in terms of effect on HRV, it is reasonable to probe the effects of RFB, used by itself, in a similar way to how the effects of meditation on perception have been probed. The idea that this might be a fruitful avenue of research for SMS specifically comes from studies showing a link between high HRV and better irrelevant stimulus suppression (Thayer et al., 2009), faster reaction times on executive tasks (Hansen et al., 2004), and better response inhibition (Thayer et al.). These findings parallel some of the meditation studies discussed earlier and point to a possible mediating of HRV in these performance improvements. The observation that RFB facilitates a relaxed physiological arousal state, combined with the potential for improved response inhibition and faster reaction times with increased HRV, lays the basis for investigating how RFB might influence SMS capacity.

2.4 Summary

To summarise the above sections, research into time perception has supported the existence of a temporal integration window that defines the present moment and that is approximately 3 seconds. This window has been shown to be relevant in SMS behaviour which occurs optimally when intervals between stimuli range from a few hundred milliseconds to 2-3 seconds. Prediction and EC are two key mechanisms underlying SMS, and they are related to the temporal integration window as well as sensitive to a variety of contextual and person factors. Given the existence of a temporal integration window that operates at the perceptual level, researchers have investigated how psychoactive substances or other altered states like meditation might influence time perception. A meditation-like state characterised by high HRV can be induced by periods of RFB, making it a candidate to observe changes in time perception and SMS behaviour as well. Overall, the evidence suggests that RFB may indeed impact short-term time perception and that altered time perception at this scale could change the temporal profile of SMS abilities.

3 THE CURRENT STUDY

This study seeks to identify how resonance frequency breathing affects sensorimotor synchronisation to rhythmic sound sequences. More specifically, the use of RFB aims to facilitate a state of relaxation or low physiological arousal in an effort to manipulate an individual's prediction of upcoming stimuli in the sequence as well as their detection of deviant stimuli and the correction to new temporal relationships. To assess this relationship, a finger tapping paradigm will be used (explained in more detail in the following section) in which individuals synchronise their finger taps to sequences of piano notes during both regular breathing and RFB.

Hypotheses in this study are non-specific as RFB has not been used in this context before. Given the relaxed state that emerges from periods of RFB, it is possible that time perception will follow a similar pattern to that previously reported in the literature. This would result in perceiving intervals of time as longer immediately after performing RFB, and so more missed synchronisations in the direction of response rather than anticipation may be expected. With respect error correction, the increased response inhibition and reaction times on executive tasks with greater HRV suggest that individuals may resynchronise more quickly following a temporal perturbation in the sound sequence. It should be stressed, however, that these are tentative hypotheses as using RFB to assess SMS has not been done before.

4 METHODOLOGY

4.1 Participants

Participants were recruited through university mailing lists and public Facebook groups as well as by word-of-mouth. They were informed that through their participation in the current study they would learn a new breathing technique that helps to promote relaxation. The only constraint on participation in the study was that participants were not familiar with the details or the aims of the project. The total number of participants in the study was 15 ($n_{female}=8$, $n_{male}=7$) and the average age of participants was 26.47 years old (minimum of 24 and maximum of 34 years old). Since music and dance training are potential sources of individual variability in synchronisation capacity, information about participants' music and dance background was collected. The sample consisted of eight trained musicians, four trained dancers, one participant trained in both, and four participants neither trained in dance nor music. Of the trained musicians, the average number of years of training was 8.50 and of the trained dancers, the average number of months of training was 8.50. In addition to musicians and dancers, the sample also consisted of eight trained meditators. On average, these participants had practiced meditation for 17.60 months, ranging from three to 48 months.

4.2 Study design

Each participant participated in two conditions, an experimental and a control condition, making this a within-subjects design. The main task in each condition involved tapping one's index finger in time with a sequence of piano notes. There were a total of 12 different piano note sequences, each of which was repeated once across the session. A random ordering of the sequences was generated for each participant with the constraint that sequences of the same tempo did not immediately follow one another. The purpose of this was to prevent an immediate practice effect at any one tempo. Participants were presented with a different randomised ordering of the piano note sequences during their second session. Additionally, the order of conditions was counterbalanced across participants to control for an order effect of condition.

4.3 Stimuli

4.3.1 Breathing cue

The breathing cue used in this study came from the programme Kardia (Version 2.2, Alivecor Inc, 2017), an inexpensive guided breathing application that was run through an Apple i-pad (Version 11.2.6). The programme displays a circle in the centre of the screen that expands and contracts at a pre-set speed (Figure 2). As performing RFB was the goal of the breathing intervention, the circle was set to expand quicker than it contracted, at a ratio of 60:40 exhalation to inhalation. A longer exhalation than inhalation was used as RSA amplitude has been observed to increase during these breathing conditions, in both natural (Porges, 2007) and paced breathing (Strauss-Blache et al., 2000) settings. Since a goal of RFB is to increase heart rate amplitude, breathing with a longer exhalation than inhalation should help to facilitate this effect.

FIGURE 2. An example of the circle expanding to cue inhalation.

4.3.2 Sound sequences

In order to test audio-motor synchronisation at varying IOIs, sequences of piano notes with IOIs of four different lengths were created with the use of a MIDI keyboard and ProTools (Version 11.03). The four IOIs were 200 ms, 1000 ms, 1800 ms, and 2500 ms. Within each IOI group, three distinct sequences were created: an isochronous sequence, a phase shifted sequence, and a period shifted sequence. Phase and period shifted sequences allowed for the assessment of error correction profiles in addition to synchronisation accuracy and stability. In total, there were twelve distinct sequences of sound (4 IOIs x 3 manipulations = 12) with 25 piano notes per sequence. Each sequence was heard twice during the main SMS task, making for a total of 24 sequences heard during each of the experimental phases (RFB and control). Furthermore, the four isochronous sequences were followed by 20 seconds of silence in which subjects continued tapping the rhythm of the preceding sequence. This task was set only for the isochronous sequences as the phase and period shifted sequences did not contain a constant rhythm for subjects to continue tapping.

The period and phase shifts were global shifts, meaning the shift in phase or period affected the entire sequence rather than isolated segments of the sequence (Repp, 2005). All phase and period shifts were positive shifts by 100 ms. For example, in a sequence with an initial IOI of 200 ms, a 100 ms phase shift led to a phase delay of subsequent notes relative to the initial notes (Figure 3). Phase shifts occurred twice per sequence while period shifts occurred once. Sequences were neither phase- nor period-manipulated on the same beat across and within tempo levels in an effort to prevent pattern detection by the participant.

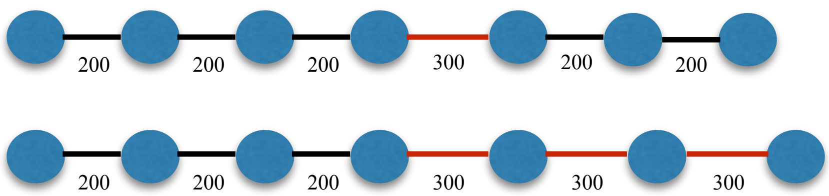


FIGURE 3. An example of phase and period shifts. The top sequence represents a 100 ms global phase shift while the bottom represents a 100 ms global period shift.

4.4 Physiological and behavioural measures

4.4.1 Collecting heart rate variability

Heart rate variability was collected through a TICKR (Wahoo Fitness, 2018) heart rate monitor that connected via blue tooth to the data-recording application EliteHRV (Version 3.16.6, Elite HRV LLC, 2014). The TICKR heart rate monitor attaches to a chest strap with two electrode pads that make contact with an individuals skin when worn. It is minimally invasive and permits natural movement of the individual wearing the chest strap and monitor. This was an important asset as the aim of the study was to have participants be relaxed during the breathing assessment and subsequent phases of the study. Heart rate data was taken during the breathing assessment (described in detail below) as well as during the entirety of the RFB and the control sessions.

4.4.2 Sensorimotor synchronisation

In order to assess SMS, a finger-tapping task was used in which the goal was to tap one's finger in time with a sequence of rhythmic sound. More specifically, temporal accuracy and stability of finger taps relative to the synchronisation cue (piano notes in the sound sequence) were measured by calculating how much finger taps deviated from the referent period for each of the twelve different sequences. Typically, the size of the asynchrony between a tap and a sound onset indicates how accurately or tightly a person is synchronised with the sound cue, while the variation in an individual's asynchrony indicates the stability of their synchronisation (Repp, 2005). A larger NMA or a positive mean asynchrony suggests less accurate synchronisation; greater variability in the NMA suggests less stable synchronisation. For the purposes of this study, the NMA was quantified using circular statistics which will be discussed in detail in the section Data Analysis (p. 37).

In line with previous investigations of EC and resynchronisation patterns (for a review see Repp, 2005), the asynchrony in finger taps during and following a temporal perturbation in the sequence was assessed. This was quantified as the value representing the average asynchrony during and after the perturbation, which provides an indication of the synchronisation accuracy during the resynchronisation process. All synchronisation data was recorded with the use of a MIDI drum pad (AKAI Professional MPX8) and Max/MSP (Version 7.3.2).

4.4.3 Questionnaires

Information on music, dance, and meditation experience was collected through a questionnaire. Extent of musical training, instrument played, and dance training have been shown to affect SMS ability in humans (Aschersleben et al., 2002; Repp, 2005; Repp & Su, 2013), therefore participants' length of music and dance training as well as type of musical training was assessed through a series of questions. Furthermore, the trait effects of meditation on time perception discussed earlier suggest that individuals with greater meditation experience or frequency of meditation practice might show different SMS responses than non-meditators. Therefore, information about one's extent of meditative practice as well as type of meditative practice was collected.

Heart-rate variability is influenced by a variety of physiological and contextual factors. Laborde et al. (2017) note that food intake, bladder fullness, stimulant ingestion, physical exercise, and sleep cycle can impact HRV. While HRV was not a primary dependent variable in the current study, information about caffeine intake, cigarette smoking, last meal time, physical exercise, and sleep/wake times was collected in anticipation of any anomalous or outlier HRV readings that might have arisen. The questions were adapted from Laborde et al..

4.4.4 Independent variable

The core manipulation in this study was using RFB versus regular breathing. During the RFB session, each participant breathed at a previously-determined rate (see Procedure) to ensure heart and respiration coupling. As RFB was used to induce a state of low physiological arousal (relaxation), physiological arousal level was an independent variable manipulated through the use of RFB. Physiological arousal was subjectively rated using an adapted version of the Self-Assessment Manikin (SAM), a three-dimensional pictorial measure of emotion developed by Lang (1980). The SAM typically assesses the dimensions of valence, (physiological) arousal, and dominance (Bradley & Lang, 1994). The arousal dimension was the only relevant dimension for the current study and was thus the only scale used. The SAM therefore captured a single nonverbal rating of participants' physiological arousal. When prompted, participants chose one of the nine images ranging from lowest arousal to highest arousal based on how they felt at the present moment (Figure 4).

The relative amplitude of the RSA and the change in HRV from control to RFB session were also treated as independent variables.

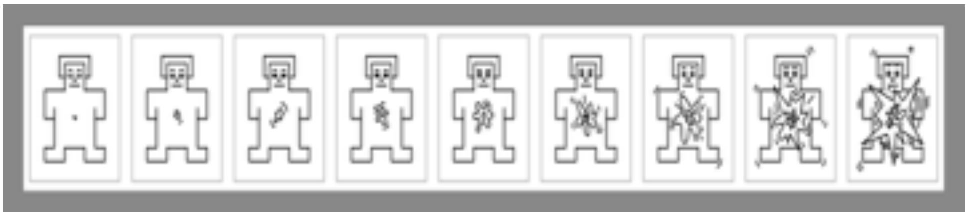


FIGURE 4. The Self-Assessment Manikin as adapted from Bradley and Lang (1994).

4.5 Procedure

Each participant took part in three sessions: one 30-minute breathing assessment to establish their resonant frequency for breathing, one experimental session involving the use of RFB and the tapping task, and one control session during which sitting quietly was substituted for RFB. A detailed description of each session follows.

4.5.1 Breathing assessment

Before beginning the breathing assessment, participants read and signed a consent form outlining the structure of the study and their rights to terminate their participation or request their data be withdrawn from analysis at any point. The structure of the breathing assessment follows a truncated procedure laid out by Lehrer, Vaschillo, and Vaschillo (2000) and in

Lehrer (2007). To begin the breathing assessment, participants were introduced to the concept of abdominal breathing. Alongside the experimenter, subjects practiced abdominal breathing by placing one hand over the abdomen and one hand over their chest with the instruction to breathe “into the abdomen”, such that the hand placed over the abdomen moved more than the hand placed over the chest. In line with Lehrer et al., (2000), participants were informed that abdominal breathing facilitates relaxation and were given time to practice it in a sitting position. Once participants felt comfortable performing abdominal breathing, they were then given further instructions as to how to best do RFB. These included breathing more slowly as opposed to more deeply, avoiding pauses after an inhalation or exhalation (continuous breathing), and using the nose to inhale and the mouth to exhale (Lehrer et al.; Lehrer). Finally, participants were told that during the breathing trials their exhale would be longer than their inhale.

After the breathing method was taught to participants, they were shown how to put on the heart rate monitor. Participants were then sent to put it on privately so that they may adjust it comfortably against their skin. Once the experimenter verified that the heart-rate monitor was transmitting data to EliteHRV, a one-minute practice trial was then undertaken at 7.5 breaths per minute (a breathing speed not included in the real assessment) to demonstrate how Kardia worked and to give the participants a chance to try breathing with the visual cue. The trial allowed participants to ask any questions about the breathing programme or their breathing technique. It also afforded the experimenter an opportunity to detect any breathing challenges for the participant (for example, failing to exhale through the mouth) and correct them before beginning the assessment trials.

The six breathing speeds used during the assessment were 7.0, 6.5, 6.0, 5.5, 5.0, and 4.5 cycles per minute. While Lehrer et al.’s (2000) manual for determining one’s RF does not include a breathing trial at 7.0 cycles per minute, the authors note that RF typically ranges from 7.0 to 4.5 cycles per minute. Therefore, this latter range was chosen for the current study. Subjects started at 7.0 cycles per minute, progressing to the slower speeds during the assessment. Consistent with Lehrer et al., subjects breathed for three minutes at each speed which gave them a chance to stabilise the synchronisation between their breathing and the breathing cue. A short break occurred between each speed during which the experimenter posed a simple question such as “how was that speed?” or “are you ready to go to the next speed?”. The act of speaking and taking a few seconds break between breathing speeds served to change the heart rate pattern and allow the subject to reset their breathing before beginning the next assessment speed.

At the end of the assessment session, participants were told they could practice RFB before their participation in the next phase of the study, although this was not required of them. A list of applications for practicing RFB was provided to participants, and their amount of practice was documented at subsequent experimental sessions. In order to determine the resonant frequency for each participant, heart rate data was analysed by the experimenter (for a description see Data Analysis) and participants were provided, via e-mail, with their resonant frequency should they wish to continue RFB practice on their own.

4.5.2 Experimental phase

As mentioned above, there were two experimental sessions in this study: an RFB session and a control session. The RFB session will be described first. Upon arrival, the participant was instructed to put the heart-rate monitor on. Once the experimenter had verified it was recording data, the participant was seated at a table in a comfortable arm chair for the duration of the session (50 minutes). Written instructions for the session were presented and the participant was given the opportunity to clarify any confusions they might have had with the experimenter. Next, the participant was familiarised with the interface used during the study. The subject then put headphones on and listened to two examples of the type of auditory stimuli that would be heard during the study. Finally, they were shown how to use the Midi drum pad and were asked to limit movement and speech unless absolutely necessary so as not to minimise these influences on heart rate. Once the participant was ready to begin the study, they provided a rating of their physiological arousal level using the SAM.

Baseline task: The baseline tapping task involved the participant tapping on the drum pad at a pace most comfortable to them before beginning the main tapping portion of the study. Two baselines were performed: one baseline before the first RFB period and one baseline after the first RFB period (see Figure 5). Participants tapped 25 times in each baseline.

Main Task: The general structure of the session was alternating periods of performing RFB and periods of doing the SMS, beginning with a period of RFB and ending with a period of SMS (Figure 5). In total, there were four periods of RFB and four periods of SMS. The initial RFB period lasted for 10 minutes while the three subsequent RFB periods each lasted for five minutes**.** During each SMS period, participants heard six sequences of piano notes that varied on the dimensions of IOI, duration, and isochronous versus perturbed. Sequences were played through Max/MSP (Version 7.3.2). Participants were to begin tapping as soon as they heard a note and to remain as synchronised as possible until the end of each sequence. In the case of the unperturbed sequences, 20 seconds of silence followed the final note. During this silence, participants kept tapping the rhythm of the sequence they had just heard. Through Max/MSP, sequence onsets were preceded by a message for participants to "get ready to tap" while a soothing bird song played to indicate the transition to a new sequence.

Once the subject had completed all periods of RFB and SMS, they rated their level of physiological arousal once again. Lastly, they removed the heart rate monitor and completed a questionnaire. As the conditions were counterbalanced across subjects, those who participated in the RFB condition after the control condition completed a longer version of the questionnaire during the RFB session, while those participating in the RFB session before the control condition completed a shorter questionnaire. The longer questionnaire recorded music, dance, and meditation experience as well as day-of eating, drinking, smoking, and sleeping habits. The shorter questionnaire gathered only the latter information. As this was a within-subjects design, information about a participant's music, dance, and meditation experience did not need to be collected at each session but rather only after one of the sessions. It was decided this information would be collected at the end of the second experimental session, regardless of condition, to prevent participants from guessing at the aims of the study.

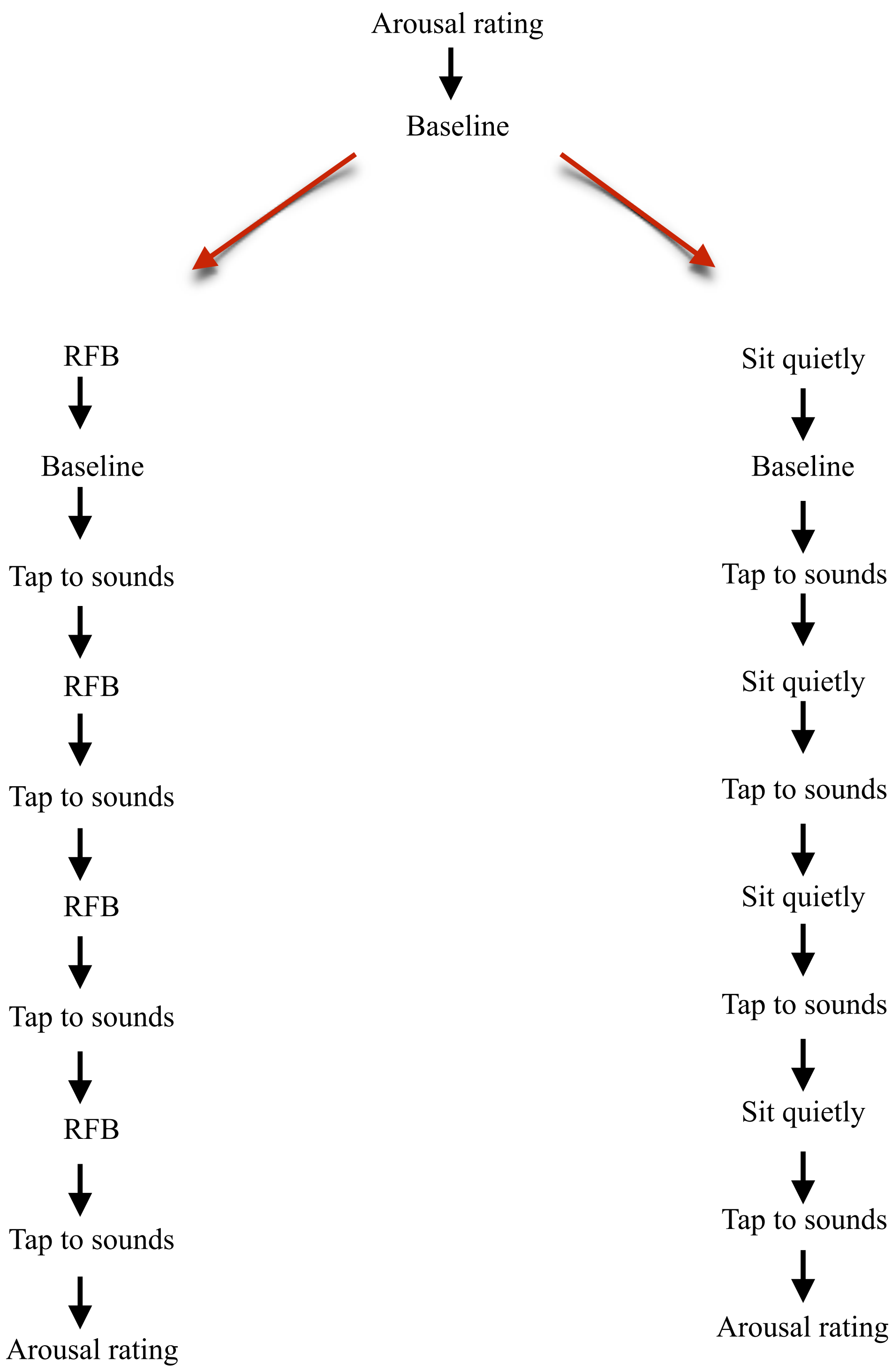


FIGURE 5. Both conditions began with participants providing a subjective rating of their physiological arousal level and a baseline tapping sequence. The left branch then shows the progression of the study in the RFB condition while the right branch shows the progression of the study in the control condition.

Conversely, information on eating, drinking, smoking, and sleeping habits was collected at both sessions as these variables have been shown to influence HR and HRV (Laborde et al., 2017).

The control session followed an identical macro-structure to the RFB session. Instead of alternating between periods of RFB and synchronised tapping, participants alternated between periods of sitting quietly and synchronised tapping (Figure 5 above). Steffan et al. (2017) previously used sitting quietly as a control task to RFB. Since it does not place any particular demands upon attention or the motor system, it was considered a good matched control task to RFB in the present study. Participants were asked to move as little as possible during these sitting periods so as to imitate the stillness of focused RFB. Since participants could not see a timer during the breathing periods in the RFB condition, only the experimenter had access to a timer during the control condition. The experimenter verbally informed the participant when they could begin the tapping task at the end of the quiet sitting period.

4.6 Data analysis

A number of inferential procedures were used to investigate the effect of RFB and HRV on SMS. Physiological arousal and HRV data were analysed using linear methods, while synchronisation accuracy and stability were assessed with circular statistics. The method used to determine resonant frequencies is first described followed by a brief description of circular statistics before an outline of the specific procedures used to analyse the data.

4.6.1 Determining resonant frequency

To determine an individual's resonant frequency, data was exported from EliteHRV into the programme Kubios (Version 1.0). Kubios displays a graph of an individual's heart rate over time in addition to quantitative information about HRV and frequency-domain information about the heart rate waveform. A low threshold for artefact correction was applied to all heart rate data. As Kubios allows for the analysis of discrete time bins of heart rate data, the data was divided into two minute bins based on notes taken during the breathing assessment that recorded the beginning of each breathing speed. Though subjects breathed at each speed for three minutes, only the final two minutes of data were analysed for each speed as it has been suggested that the first minute serve as a period of habituation to the breathing cue and pace (Lehrer, 2007). Once the six time bins were selected, the spectral analysis of each bin was compared to determine the RF for the participant. A Fast Fourier Transform (FFT) of the waveform of interest, in this case the heart rate waveform, is performed to produce the spectral analysis of contributing frequencies to the complex waveform (Stoica & Moses, 2005). Additionally, the power spectral density (PSD) is computed which shows "how the total power [of a signal] is distributed over frequency" per defined unit of time (Stoica & Moses, p.1). This means that the PSD provides information as to which frequencies are contributing most to a complex waveform. The pre-defined period of time over which the PSD analysis was performed was 300 ms.

From the spectral analysis and the PSD, an individual's resonant frequency was derived. Two primary indicators of an individual's RF for breathing are 1) the breathing speed with the highest power (derived through the spectral analysis) in the low-frequency (LF) range and 2) the speed with the largest peak in the PSD (Lehrer, 2007). These measures are rarely discrepant (Lehrer). Given this, the six breathing speeds were compared on these two dimensions to determine a participant's RF for breathing.

4.6.2 Circular statistics

The finger tapping data in this study is time series data, meaning the data points are tied to a specific time of occurrence (Brillinger, 2001). A circular statistics approach to the time series data was taken to evaluate the accuracy and stability of finger taps with respect the referent sound stimulus. Before providing the specific descriptive and inferential procedures performed on the data, a brief explanation of circular statistics and a justification for using circular statistics in this project will be given.

When dealing with periodically repeating data, the data can be transformed from the linear domain into the circular domain. In the circular domain, the circumference of the circle corresponds to the period of interest (Jammalamadaka & Sengupta 2011). This means that travelling one time around the circle (a distance of 2π) represents completing one period or cycle. Importantly, the period of interest in the data must be known in order to meaningfully map linear data on to a circle, as the transformed data values will range between 0 and 2π, or the period of repetition of interest (Himberg, 2014). The transformation of the data from linear to circular is such that the x-value and the y-value in the linear domain are mapped to the circular domain through the cosine and sine functions, respectively (Jammalamadaka & Sengupta). The outcome is that x = cos(theta) and y = sin(theta) in the circular representation. Additionally, as the primary interest with directional or time series data is typically the phase of the data relative to a periodic marker or the position of the data on the circle, the unit circle is used in these analyses (Jammalamadaka & Sengupta). More intuitively, Himberg notes that moving from the linear to the circular domain involves wrapping some linear distribution around a circle to create the circular representation. The circumference of the circle is used to represent the period of interest, and data points can be plotted along the curve of the circle; where these data points fall on the curve allows for the derivation of the angle formed between an individual data point, the origin of the circle, and the referent point 2π, giving the phase of the data point relative to the referent period (Jammalamadaka & Sengupta). Once the angles of the data points are known, then the data can be represented in radians on the circle.

Aside from producing visually salient graphs of time series data, using circular statistics offers at least three noteworthy advantages over linear statistics when dealing with time series data. First, calculating the arithmetic mean of time series data fails to yield a meaningful value, while representing time series data as circular provides the advantage of calculating means for periodic data (Berens, 2009; Himberg, 2014). Second, Himberg notes that when time series data is plotted on a circle rather than a straight line, data points with similar periods are more accurately represented in space. For example, a data point falling just before 2π and a data point falling just after 2π have in fact very similar periods. Yet, the data point falling just before 2π will have a radian value near 6.28 while the data point falling just after

2π will have a radian value just above zero. When represented on a straight line ranging from zero to 6.28, Himberg points out that these data points will fall at opposite ends of the line while in fact they represent nearly the same period. So, circular plots provide a means to more accurately representing the periodic nature of the time series data. Finally, a circular representation of time series data helps to circumvent the challenge of dealing with missing data points in a time series analysis (Himberg). In, for example, a finger tapping study, a missing data point means there is no data point (no finger tap) corresponding to the referent stimulus at a certain position in the sequence. When comparing finger tap points to the temporal position of the referent stimulus, it would appear that the finger taps drifted to a position lagging behind the referent stimulus. Similarly, if the IOI was to be taken when a data point is missing, it will inaccurately reflect a large IOI relative to the rest of the sequence and perhaps skewing an analysis of average IOI. In contrast, circular representations reset the period every 2π around the circle. This means that if a data point is missing, the next data point is simply plotted relative to the referent stimulus as if there was never any missing data.

4.6.3 Prediction

Predictive ability was measured primarily by tapping accuracy and stability at each tempo level. The finger tap times series data was first converted to circular data using the MATLAB toolbox CircStat (Berens, 2009). This conversion mapped each tap made by the participants to the circumference of the unit circle. It was performed for each subject on each of the 24 sound sequences. From this, two values emerge that indicate the mean direction of data points as well as the dispersion of the data points. The mean resultant vector provides the average direction (angle) of data points while the resultant vector length provides an indication of how scattered the data points are around the circle (this is the terminology provided in Berens). The mean resultant vector is calculated by summing the vectors from all relevant data points then multiplying by 1/n, where n is the number of vectors summed (Berens). The length of the mean resultant vector is subsequently apparent and ranges from 0-1, where 0 represents equal dispersion of all summed vectors and one represents all data points falling on the same position on the circle (Berens; Himberg, 2014). In reference to the current data set, this means that a radius length of zero suggests a participant failed to synchronise to the sound stimulus at all while a radius length of one suggests they were perfectly synchronised throughout the sequence. Similarly, a mean resultant vector having angle near zero or 2π represents a tap that is similar in phase to the referent sound (ie. synchronised) while resultant vectors having angles near between 90 and 270 degrees (between $\pi/2$ and $2\pi/3$) represent taps that are in anti-phase with the referent sound (ie. unsynchronised for the task). Descriptive statistics were computed for the mean resultant vector, the mean resultant vector length, and the circular standard deviation of the data in the sample.

The Rayleigh test was performed to determine if the data from the sample was uniformly distributed around the circle or not. This test is a first step in identifying a potential direction of the data as it tests the null hypothesis that the data is uniformly distributed against the alternative hypothesis that the data is not uniformly distributed (Berens, 2009; Jammalamadaka & Sengupta, 2001). Inferential comparisons of mean resultant vector and resultant vector length were then planned between sound sequences of the same tempo as well as between conditions in an effort to detect differences in stability and accuracy of participants' finger tapping. The comparisons were done using the circular analogue of Hotelling's T2 sample test (NCSS, 2018). Eight tests were run to determine if the mean resultant vectors and resultant vector lengths differed from the first to the second time participants heard a sequence of the same tempo, within condition. Additionally, eight tests were run to identify any potential differences between conditions at the same tempo level.

4.6.4 Error correction

Error correction was assessed in a similar way to accuracy and stability of taps during natural sequences. Finger taps occurring during and after an IOI shift were used to calculate participants' mean resultant vector for the taps that followed a change in the IOI. This gives an indication as to the accuracy of participants' tapping after a temporal perturbation. As mean resultant vector values closer to 2π indicate more accuracy in synchronisation, a participants with mean resultant vector values that are closer to 2π suggest that a participant has recovered better than a participant having a mean resultant vector further away from 2π. In this way, participants' recovery to a synchronised state after a temporal perturbation can be assessed.

4.6.5 Physiological arousal and HRV

A decrease in physiological arousal was expected to occur from the beginning of the RFB session to the end of the RFB session. It was also expected that the RFB session would result in a greater decrease in physiological arousal than the control condition. This prediction is based on the effect of RFB on vagal activity, as discussed in an earlier section (Shaffer et al., 2014). Both the within- and between-condition predictions were assessed using a paired-samples t-tests.

Additionally, a paired-samples t-test was used to ensure HRV was indeed higher during the RFB condition than the control condition. Data from each time bin was averaged per participant then entered into the paired-samples t-test. As a follow up, paired samples t-tests were again used to determine if HRV was higher not only during the periods of RFB versus the periods of sitting quietly, but also during the periods of tapping in the RFB condition versus the control condition. A repeated measures ANOVA was used to determine if there was a main effect within condition of time period on HRV.

Finally, four multiple regression analyses were planned to determine if physiological arousal and HRV predict changes in the synchronisation stability and accuracy. Change in physiological arousal and relative HRV were used as the IV's in each analysis while the mean resultant vector was the DV in one analysis and the resultant vector length was the DV in the second analysis. These two analyses were meant to elucidate the relationship between physiological arousal/relative HRV and accuracy and stability of synchronisation, respectively. From this, conclusions regarding the way in which physiological arousal and relative HRV are related to a change in prediction capacity during SMS could be drawn. Moreover, these two analyses provide information as to the specific relationship between physiological arousal/relative HRV and SMS stability and accuracy.

5 RESULTS

This section provides descriptive information about resonant frequencies followed by descriptive and inferential statistics outcomes for heart rate variability, physiological arousal, and tapping performance. Values in tables that are followed by an asterisk are statistically significant. Unless otherwise indicated, the type I error threshold (denoted by α) for all inferential tests is .01.

5.1 Resonant frequencies

The average RFB rate determined by the breathing assessment was 5.0 cycles/min (N=15, s.d. = 0.597). The most common rate of breathing as participants' RF was 4.5 cycles/min. A maximum rate of 6.5 cycles/min and a minimum rate of 4.5 cycles/min as RF's were observed.

Figure 6 provides an example of heart rate data during a breathing assessment as well as the PSD associated with specific breathing rates for a participant whose RFB is 5.0 cycles/min. The figure provides data on two breathing speeds to illustrate in a simpler way how a RF is determined. In actuality, the six breathing speeds were compared on the dimensions described in the rest of this paragraph. From the two top panels, the amplitude of the heart rate waveform can been seen to increase as the participant breathes at slower rates (moving from left to right on the x-axis). The top left panel shows the heart rate curve during a breathing rate of 7.0 cycles/min in the highlighted section while the top right panel has the heart rate curve at a breathing rate of 5.0 cycles/min. Directly below the left and right panels are close-up views of the heart rate waveform from the highlighted sections at the breathing rates of 7.0 and 5.0 cycles/min, respectively. The increased amplitude and smoothness of the heart rate waveform are evident at 5.0 cycles/min when compared to 7.0 cycles/min, indications of breathing at or near one's RF. Finally, the two bottom panels provide the PSD for each of the breathing rates. The peak around 0.1 hz for 5.0 cycles/min is over twice as large as the peak for 7.0 cycles/min, indicating there is more power concentrated in the low-frequency range when the participant breaths at 5.0 cycles/min. The power in the low-frequency range in the two rates in this case is 2 248 ms^2 for 7.0 cycles/min and 14 714 ms^2 for 5.0 cycles/min. As the power at 5.0 cycles/min was in fact greater than at any other breathing rate, it was concluded that this participant's RF was 5.0 cycles/min.

a.

b.

c.

d.

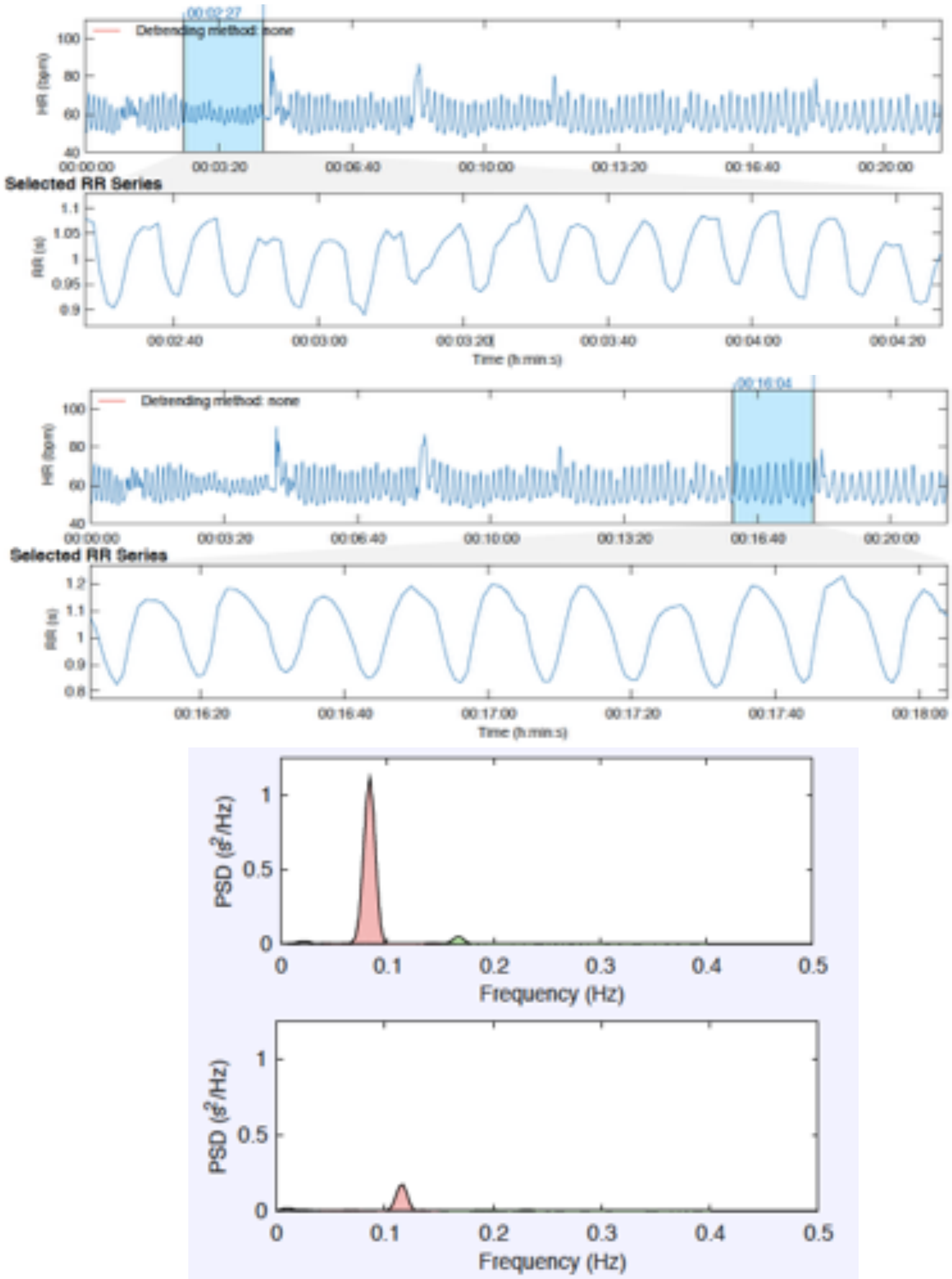


FIGURE 6. Panels a and b display heart rate data during a breathing assessment. Sections highlighted in blue correspond to the heart rate curve at specific breathing rates (7.0 cycle/min in Panel A and 5.0 cycles/min in Panel B). Close-up views of the highlighted sections are also displayed. Panels c and d are the PSD graphs for 7.0 cycles/min and 5.0 cycles/min, respectively.

5.2 Heart rate variability outcomes

Descriptive statistics on global heart rate variability are in Table 1. The average SDNN was higher in the RFB condition (mean = 87.29, s.d. = 35.24) than the control condition (mean = 66.76, s.d. = 19.98). As expected, this difference was significant (t=13.178, p<.001, α=.01) suggesting participants had greater heart rate variability during the RFB condition than the control condition.

TABLE 1. Descriptive statistics for SDNN by condition.

	Mean	**Standard Deviation**	**Median**	**Mode**
Control	66.756	19.887	63.200	53.500
RFB	87.290	35.244	80.450	113.900

Average SDNN values during different portions of the study are displayed in Table 2. As anticipated, average SDNN values were highest during the periods of RFB, with the average SDNN value being 118.282. Additionally, a one-way ANOVA showed that SDNN values were significantly different across the four breathing bins in the RFB condition (F=8.648, p<.001, α=.01, Figure 7). The largest SDNN values occurred in the final breathing bin (SDNN mean =124.491, SD=15.686) and the smallest SDNN values were in the initial breathing bin (SDNN mean=108.527, SD=23.271).

The average SDNN value in the control condition during the periods of sitting quietly was 75.139. During the tapping portions of the study, the average SDNN values were 56.298 for the RFB condition and 58.373 for the control condition. A paired-samples t-test showed the SDNN values in the control and RFB condition were not statistically different during the tapping portions of the study (t=-15.235, p=.712), supporting the conclusion that the RFB periods were driving the observed differences in SDNN between the conditions.

TABLE 2. Mean and standard deviation of SDNN by condition and task.

	Mean	SD
RFB		
Breathe	118.282	19.684
Tap	56.298	12.652
Control		
Sit	75.139	22.109
Tap	58.373	12.944

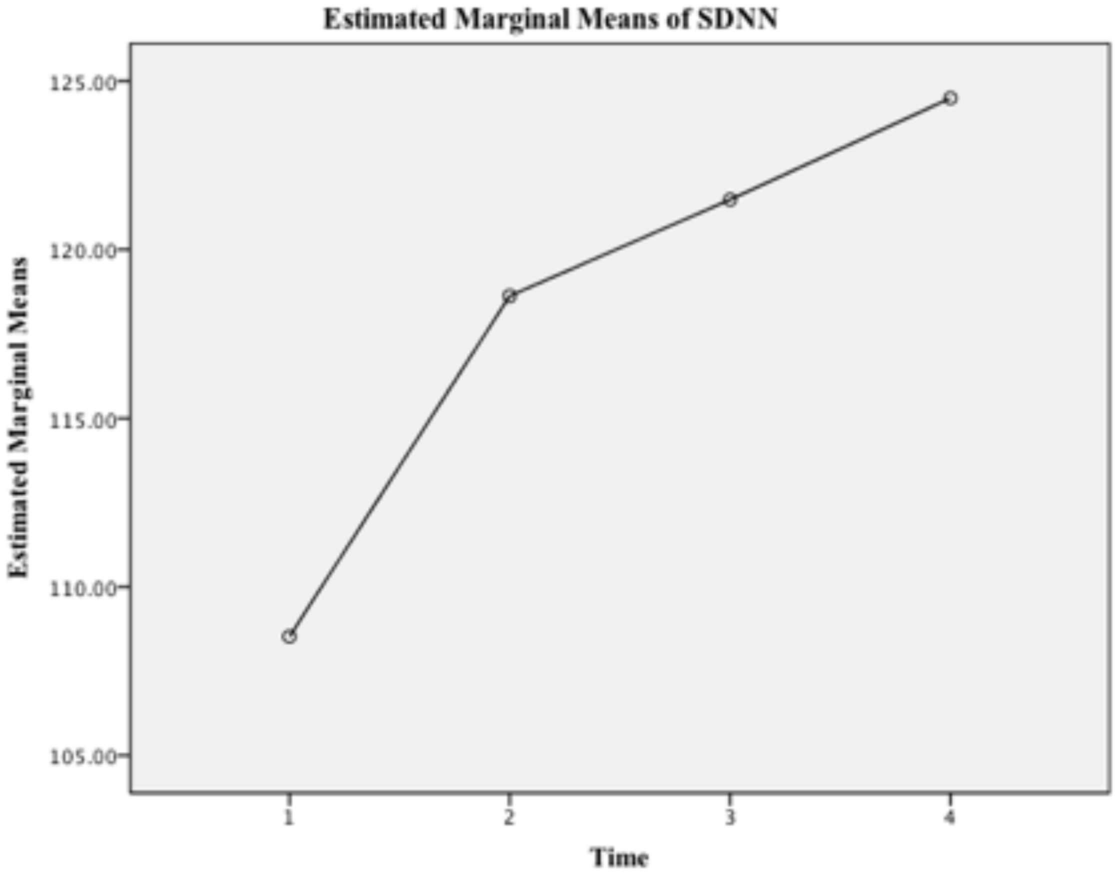


FIGURE 7. Average SDNN value at the first, second, third, and fourth periods of RFB.

5.3 Physiological arousal

Results from the SAM were coded to correspond to values from 1 to 9 with 1 representing the lowest level of arousal and 9 representing the highest level of arousal. A paired samples t-tests showed that there was no difference in pre-task arousal levels between conditions (p=.32, α=.01), suggesting subjects were not systematically more or less physiologically aroused in one specific condition prior to the start of the tapping task. Within the RFB condition, a significant decrease in arousal occurred from the start to the end of the study (p<.001, α=.01). A significant decrease arousal also occurred in the control condition (p=.0083, α=.01). Together, these two findings suggest that both conditions resulted in a significant decrease in participants' physiological arousal level (Figure 8). There was no difference in post-task

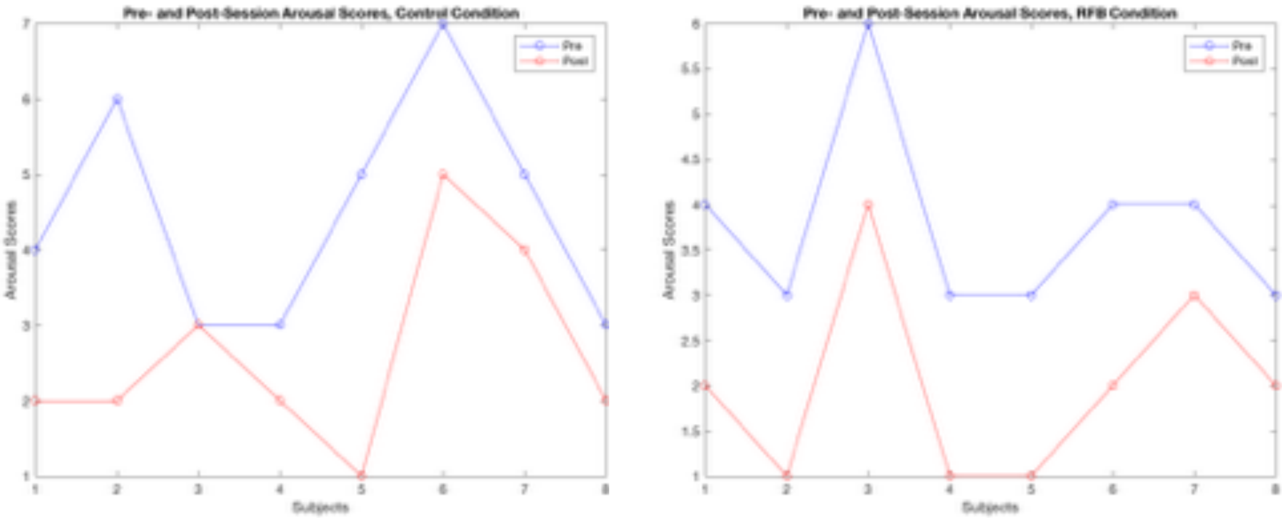


FIGURE 8. The graph on the left shows participants' self-reported physiological arousal level in the control condition while the graph on the right shows the scores in the RFB condition. Both conditions resulted in a significant decrease in participants' arousal level.

arousal level between conditions (p=.18, α=.01), indicating that neither condition resulted in participants' absolute physiological arousal rating being lower than in the other condition. Finally, there was no difference in the relative change in physiological arousal level between conditions (p=.80, α=.01). Overall, the findings support the idea that each condition had a similar effect on participants' physiological arousal level.

5.4 Accuracy and stability of synchronisation

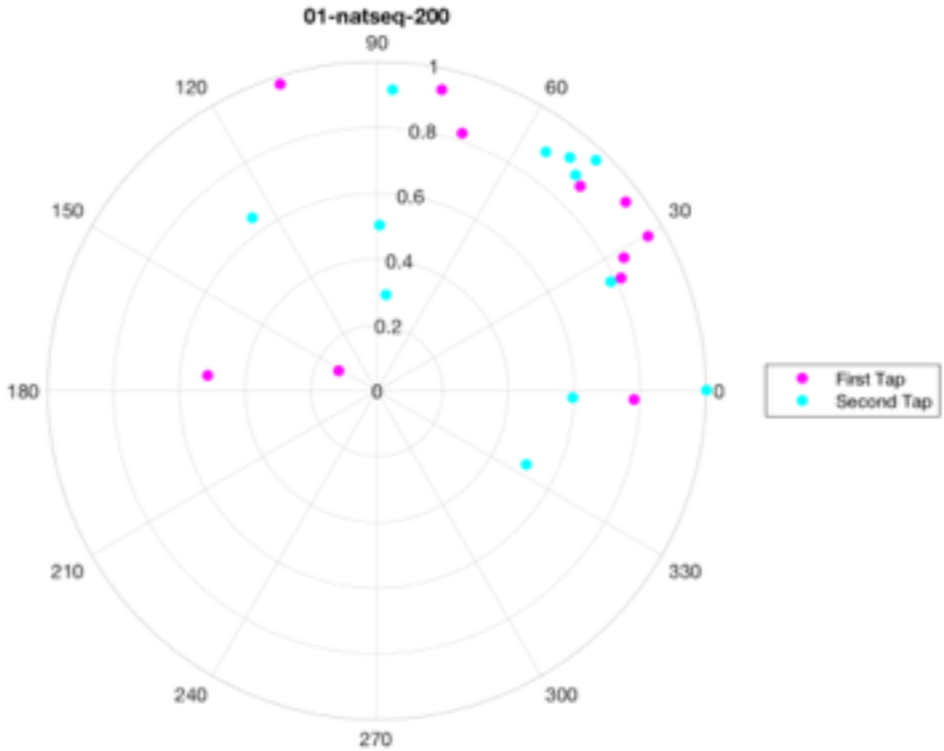
The null hypothesis of the Rayleigh test that the data is uniformly distributed, conducted at each tempo level in each condition (yielding a total of eight tests), was rejected. Table 3 and Table 4 provide the z statistic and associated p-value for each test. Rejection of the null hypothesis supports the conclusion that the tapping data was not uniformly distributed. The tapping data plotted on the unit circle for each sequence and condition are in Figures 9 to 12. From these graphs, it is clear that synchronisation was better for the 1000 ms and 1800 ms IOI sequences. Given that the data was not uniformly distributed, the mean resultant vector (angle) and the mean resultant vector length data points were computed for all natural sequences in each condition. The Hotelling's T2 sample test returned no significant differences in neither the mean resultant vector nor the vector length between the first and second time participants tapped to a sequence of the same tempo (Table 5 and Table 6). This supports the conclusion that participants' taps were not significantly different between the first and second time they heard a sequence. Similarly, no significant differences were observed in the mean resultant vector or the vector length of finger taps to sequences of the same tempo level between conditions (Table 7).

TABLE 3. Results of the Rayleigh test for the RFB condition data.

	Z Statistic	**p-value**
NS 200	15.924	<.001*
NS 1000	19.489	<.001*
NS 1800	23.646	<.001*
NS 2500	23,514	<.001*

TABLE 4. Results of the Rayleigh test for the control condition data.

	Z Statistic	**p-value**
NS 200	14.780	<.001*
NS 1000	23.215	<.001*
NS 1800	23.731	<.001*
NS 2500	23,011	<.001*



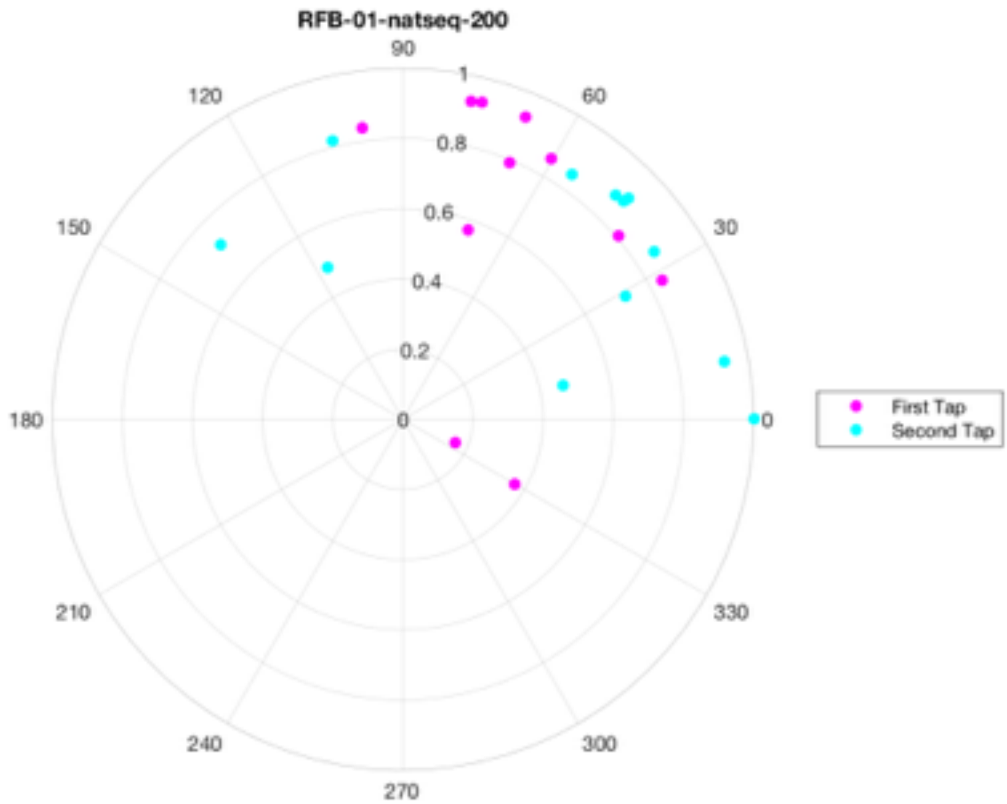
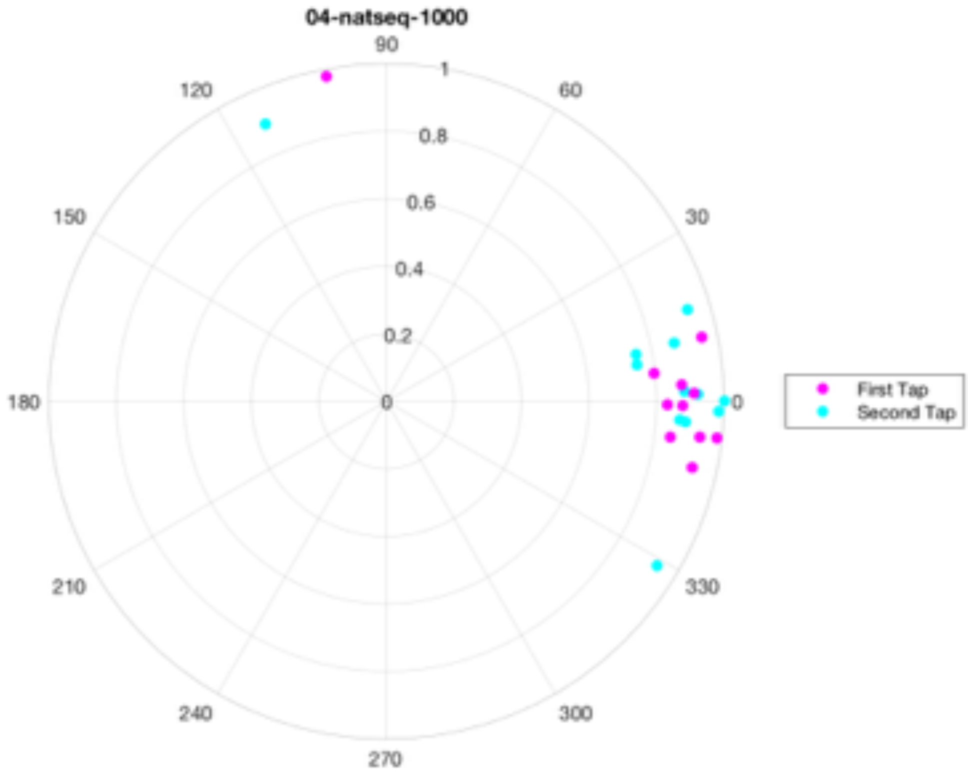


FIGURE 9. Average tap phase for the control (top) and RFB conditions for the natural 200 ms IOI sequences.



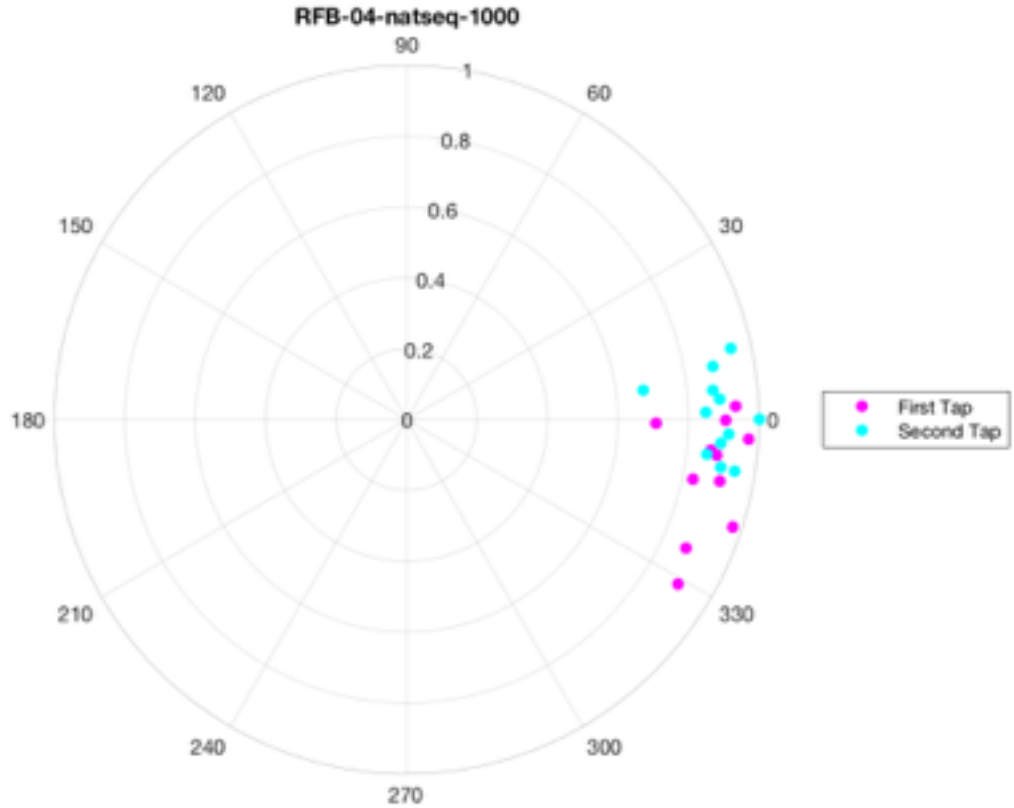


FIGURE 10. Average tap phase for the control (top) and RFB conditions for the natural 1000 ms IOI sequences.

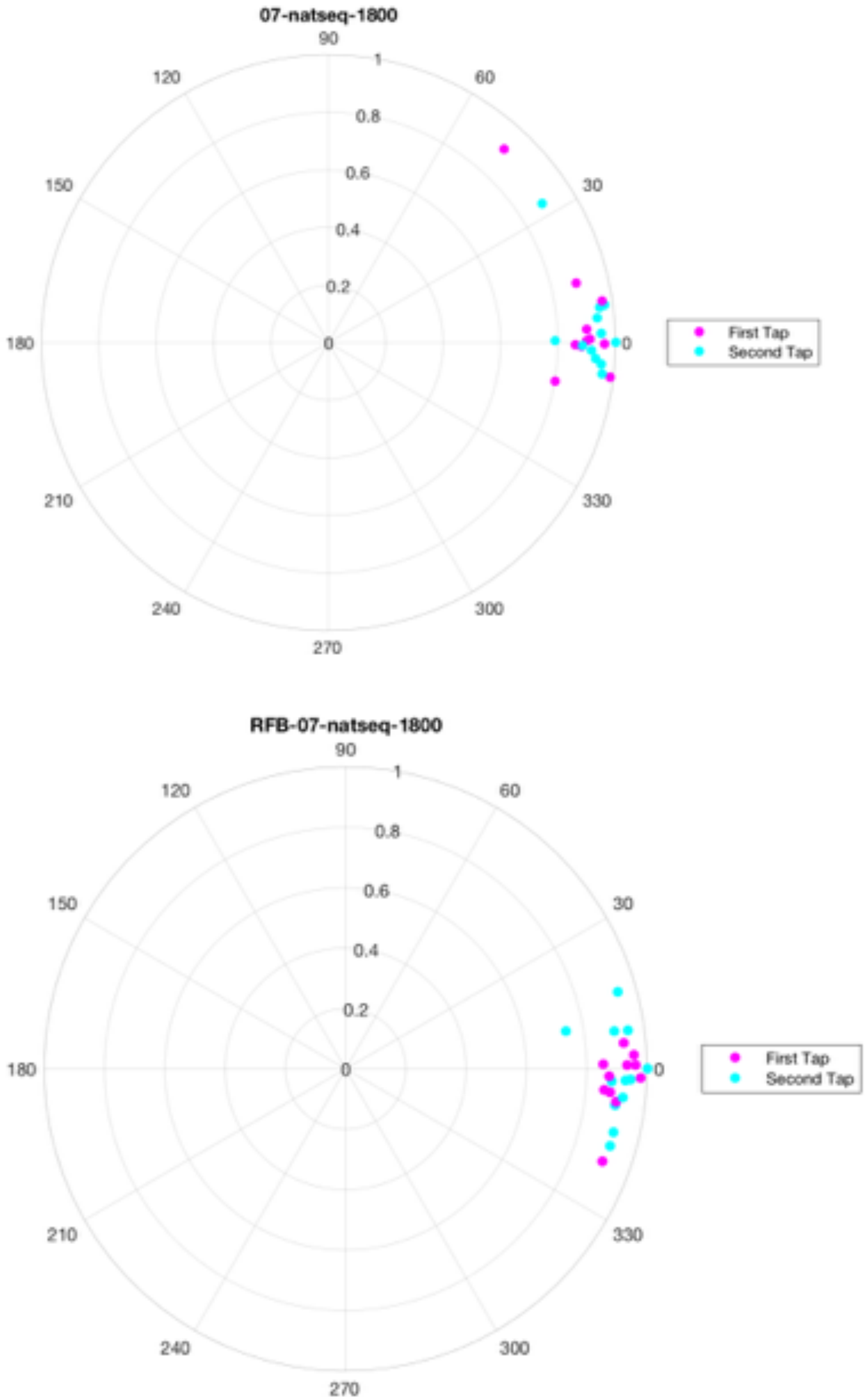


FIGURE 11. Average tap phase for the control (top) and RFB conditions for the natural 1800 ms IOI sequences.

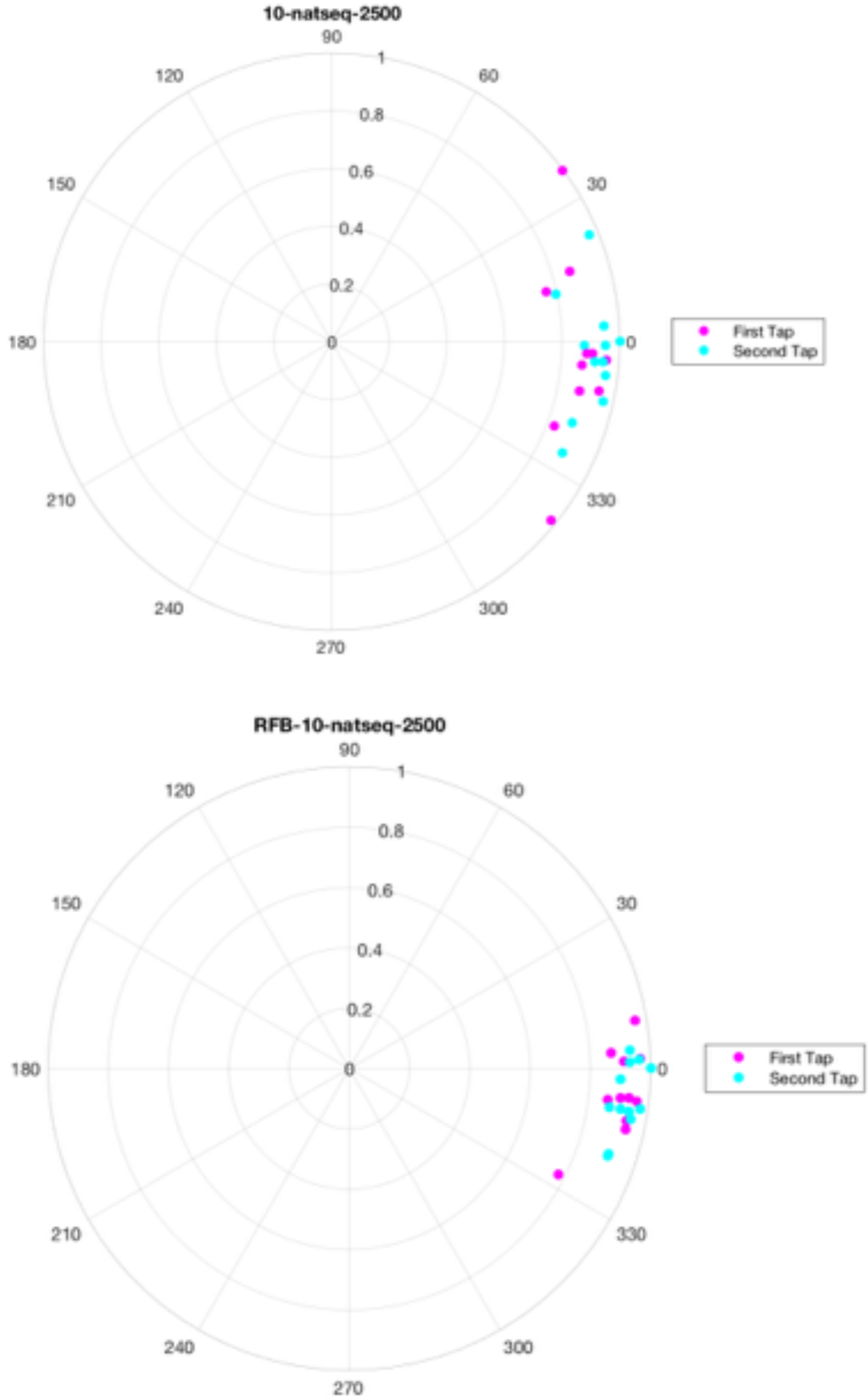


FIGURE 12. Average tap phase for the control (top) and RFB conditions for the natural 2500 ms IOI sequences.

TABLE 5. Descriptive and inferential statistics for natural sequences in the RFB condition. Columns one and two refer to the first time participants heard and tapped to a sequence while columns three and four refer to the second time participants heard and tapped to the sequence of the same tempo. Differences in mean resultant vector from the first to the second listen are indicated in the final two columns.

	Mean Resultant Vector (Radians)	**Mean Resultant Vector Length**	**Mean Resultant Vector (Radians)**	**Mean Resultant Vector Length**	**F**	**p**
NS 200	.931	.867	.833	.744	.557	.590
NS 1000	6.156	.988	.016	.991	7.490*	.010*
NS 1800	6.240	.995	.011	.991	.982	.408
NS 2500	6.184	.986	6.166	.993	1.482	.273

TABLE 6. Descriptive and inferential statistics for natural sequences in the control condition. Columns one and two refer to the first time participants heard and tapped to a sequence while columns three and four refer to the second time participants heard and tapped to the sequence of the same tempo. Differences in mean resultant vector from the first to the second listen are indicated in the final two columns.

	Mean Resultant Vector (Radians)	**Mean Resultant Vector Length**	**Mean Resultant Vector (Radians)**	**Mean Resultant Vector Length**	**F**	**p**
NS 200	1.050	.641	.940	.765	.271	.768
NS 1000	.080	.889	.119	.857	1.396	.292
NS 1800	.083	.968	.060	.984	1.068	.380
NS 2500	6.235	.947	6.225	.976	.528	.606

This finding suggests that there was no effect of condition on accuracy or stability of finger taps.

TABLE 7. Hotelling's T2 sample tests for a difference in mean resultant vector and mean resultant vector length across conditions. No differences are significant.

	F	**p**
Mean Resultant Vector		
NS 200	.368	.696
NS 1000	1.103	.350
NS 1800	.494	.617
NS 2500	2.627	.095
Mean Resultant Vector Length		
NS 200	.310	.737
NS 1000	.791	.466
NS 1800	.121	.887
NS 2500	.263	.095

5.5 Error correction

Table 8 provides descriptive statistics for taps coinciding with and following a temporal perturbation of positive 100 ms for each IOI level by condition. These values are aggregates of the two times that participants heard and tapped to a sequence of a particular baseline tempo. With respect period correction, participants had the tightest synchronisation following a perturbation in the baseline sequences with 1000 ms IOI (mean resultant vector = -.148) and 1800 ms IOI (mean resultant vector = -.147) in both conditions. Similarly, the sequence with baseline IOI of 1800 ms shows the least variance in the phase of finger tap onsets in each condition (var_{RFB}=.008, var_{cont}=.004). Across both conditions, the sequences with baseline IOI of 200 ms and 2500 ms showed the greatest variance and the least accurate synchronisation following a perturbation, respectively. Hotelling's T2 sample tests did not indicate a significant difference in the mean resultant vector between sequences of the same baseline IOI assessed by condition (Table 9). The same test was applied for phase correction and similarly no significant differences emerged in the mean resultant vector between conditions (Table 10).

TABLE 8. Descriptive statistics for finger taps during and following a 100 ms period shift, by condition.

	Mean Resultant Vector (Radians)	**Circular Variance**
RFB		
Period Shift 200	.376	.030
Period Shift 1000	-.148	.019
Period Shift 1800	-.147	.008
Period Shift 2500	.938	.011
Control		
Period Shift 200	.275	.090
Period Shift 1000	-.135	.021
Period Shift 1800	-.133	.004
Period Shift 2500	.995	.017

5.6 SDNN and tapping performance

The relationship between global SDNN values within condition and participants' mean resultant vector and mean resultant vector length at each IOI level for the natural sequences was assessed using a circular-linear correlation. No significant correlations were found, suggesting that amount of heart rate variability, as quantified by the SDNN, is not related to tapping accuracy or stability.

TABLE 9. Hotelling's T2 sample test for a difference between mean resultant vectors during and following a 100 ms period shift, within tempo and between condition.

	F	**p**
Baseline IOI		
200	1.770	.220
1000	.239	.792
1800	.355	.708
2500	1.376	.297

TABLE 10. Hotelling's T2 sample test for a difference between mean resultant vectors during sequences with a 100 ms phase shift, within tempo and between condition.

	F	**p**
Baseline IOI		
200	.201	.822
1000	.406	.677
1800	1.370	.298
2500	1.507	.268

6 DISCUSSION

6.1 Main findings

This study sought to explore how RFB and increased HRV impact sensorimotor synchronisation to sounds through the use of a finger tapping paradigm. Non-specific hypotheses were made as to the precise ways in which SMS may be impacted by the changes in physiological state induced by RFB. As anticipated, heart rate variability was greater overall in the RFB condition than the control condition. This indicates that RFB increased HRV in participants. However, this effect did not extend to the tapping task, meaning participants' HRV was not statistically different when they did the tapping task in the control and RFB conditions. This lack of difference between conditions during the tapping portion of the study could be due to a suppression of HRV during a task requiring focused attention, as has been observed by Porges (2007). This is particularly plausible since previous work showing sustained increases in HRV after paced breathing have only examined individuals in resting conditions (Zucker et al., 2009). To address this challenge, a future study could focus on identifying contexts that sustain the increase in HRV generated by RFB or other paced breathing exercises once the breathing periods have finished. If tasks requiring focused attention tend to attenuate HRV, then perhaps a passive SMS task in which individuals merely listen to sound sequences with the option to tap along would more effectively probe any HRV-associated changes to SMS due to decreased focused-attentional demands.

It was also observed that physiological arousal decreased in both conditions from pre-task to post-task. There was no difference between conditions in pre- and post-arousal levels and no difference in relative decrease in arousal, suggesting RFB was not more effective in decreasing arousal level than was sitting quietly. This indicates that RFB and sitting quietly had a similar effect on subjective feelings of physiological arousal. These findings are in contrast to typical ideas about RFB facilitating a more subjective relaxed state (Brabant, van de Ree, & Erkkila, 2017) as well as a decrease in systolic blood pressure (Steffan et al., 2017) relative to control conditions. So, it may be that in the current study the requirement to focus on an SMS task between breathing periods counteracted a stronger relaxation effect from the RFB periods relative to the sitting quietly periods. It may be useful in future designs to include a subjective arousal rating at the end of each breathing and sitting quietly period to measure, in a more on-line fashion, changes in physiological arousal as a result of the experimental manipulation. In this way, a higher resolution correlation between arousal level and tapping performance may be investigated.

With respect synchronisation, participants did indeed synchronise to the sounds in the sequences, as evidenced by the rejection of the null hypothesis of the Rayleigh test that the data was uniformly distributed. While the Rayleigh test does not indicate if participants were synchronised in phase with the sound sequences (as opposed to in anti-phase, for example), visual inspection of the circular data plots as well as the mean phase angle of taps suggests that subjects were in fact synchronised in phase with the sounds.

No difference in tapping accuracy or stability was observed between the first and second presentation of a sound sequence, supporting the conclusion that tapping performance did not improve or worsen with practice at a specific tempo. Similarly, one of the main hypotheses that RFB would influence tapping accuracy and stability was not supported as no difference in mean phase or variability in the timing of finger taps relative to the referent sound was observed between conditions at each tempo level. It thus appears that RFB had no effect on prediction and synchronisation accuracy for isochronous sequences of sounds. Finally, there was again no difference found between conditions in the average phase of synchronisation during and following neither a period perturbation nor a phase perturbation. This suggests that RFB did not have an effect on participants' ability to detect and respond to a temporal perturbation in the period of the sound sequences. Furthermore, it suggests that the more automatic process of phase correction was not altered across conditions. Combining these two findings with the findings indicating that RFB did not impact prediction and accuracy of finger taps, it seems to be the case that RFB did not change any of the main parameters used in this study to measure SMS.

There are a few potential reasons why an effect of RFB on SMS was not observed in this study. While a number of RFB and paced breathing studies include participants who do not have experience with the breathing style of interest, many of these same studies involve a learning or practice phase. Karavidas et al.'s (2007) and Zucker et al.'s (2009) studies both had a learning phase that employs biofeedback to teach participants to breathe at a particular rate and in a particular manner. Similarly, Lehrer, Vaschillo, and Vaschillo (2000) report on the effectiveness of using multiple RFB biofeedback sessions to increase HRV in a more sustained manner. Finally, Brabant and Erkillä's (unpublished) study that looked at RFB in a music therapy setting had between 10 and 18 sessions involving RFB, giving participants the ability to refine their breathing practice. In contrast, the study from Steffan et al. (2017) reports that the significant decrease in systolic blood pressure (interpreted as decreased physiological responsiveness), improvement in mood, and increase in HRV during an RFB versus control condition was achieved after a single session of RFB in RFB-naive participants. The implications here are twofold: first, RFB does seem to impact physiological and psychological parameters. However, it may be the case that a single session of using RFB is insufficient to generate significant changes in arousal and time perception given the number of studies using multiple sessions.

This idea is reflected in the meditation literature wherein a distinction between state and trait effects is drawn. As mentioned in a previous section, state effects refer to the effects experienced immediately after performing some task such as paced breathing whereas trait effects can refer to long-term changes in behaviour or cognition as a result of routinely performing something like paced breathing (Srinivasan & Baijal, 2007). As can been seen in the meditation literature, there is conflicting evidence as to the state versus trait effects of meditation practices, with some studies identifying state effects (Kramer, Weger, & Sharma, 2013; Srinivasan & Baijal) and others identifying primarily trait effects (Berkovich-Ohana et al., 2011; Schötz et al., 2015; Wittman & Schmidt, 2014). Bringing this back to RFB, the number of studies that involve multiple breathing sessions and biofeedback outnumber those using a single session, suggesting that large physiological and psychological effects of RFB may be principally trait effects. Going forward, studies wishing to probe how RFB might impact SMS and time perception may wish to utilise a multiple-session design so as to probe possible trait effects of RFB on SMS.

One other possible reason for the null findings in the current study concerns the lack of an explicit attention manipulation through RFB. Though participants had to focus on the breathing cue, they were not instructed to pay attention to their breath or given any other attentional task as they might be during a meditation. As attention is known to play a role in time perception (Burle & Casini, 2001; Fraisse, 1984; Mella et al., 2011), the absence of a clear attentional manipulation through the RFB task may have prevented an effect of RFB on SMS from occurring. This may also explain why some meditations have been shown to influence time perception while RFB did not in the current study. Three categories of meditation have been generated by those interested in studying it in a psychological context: focused-attention (FA), open-monitoring (OM), and transcendental meditation (TM) (Lutz et al., 2008; Shear, 2014; Sperduti, Martinelli, and Piolino, 2011; Travis & Shear, 2010). Focused-attention involves the direction of one's attention to some object, real or abstract, to the exclusion of other information while OM involves detached monitoring of one's awareness field. Finally, TM lacks an intentional route of meditation to the final meditative state (Shear). In at least FA and OM, an explicit attentional manipulation occurs. It may be that this intentional shift in attention is needed to produce, in conjunction with physiological changes, an alteration in time perception. It is possible to incorporate this type of attentional shift into an RFB design by simply directing participants to pay attention to their breath as they follow the breathing cue. This would be a useful addition to a future study looking to establish a relationship between RFB and SMS/time perception as it would incorporate both attentional and physiological manipulations.

The last finding of no correlation between SDNN and the accuracy or stability of synchronisation was again a little unexpected due to HRV being altered by meditation too and meditation studies have observed changes in time perception. However, similar to the ideas in the above paragraph, HRV may not be sufficient on its own to alter time perception. Instead, attention shifts or longer-standing practices may be required.

6.2 Limitations

Two general limitations are worth discussing here. First, the sample size for the final analyses was quite small (N=11). It is therefore possible that the inferential analyses were underpowered. All participants were also university students which means the sample is not entirely representative of the general population. Increasing the sample size and diversifying the background of participants would be useful in future studies to capture a wider range of behavioural and cognitive profiles. Second, the set-up of the study was such that the experimenter was in the same room as the participant during the sessions. There was a sound-dampening divider placed between the participant and the experimenter, but nonetheless it is possible that participants could not either feel wholly absorbed or felt monitored during the RFB and tapping periods. As experimenter effects have a longstanding history in psychology (Sheldrake, 1998), the presence of the experimenter (though hidden) in the room during this study may have been problematic. In this case, rather than confirming a hypothesised outcome of the study, the experimenter may have acted as an unintentional observer of participants' performance during the sessions. Since individuals have been found to alter their behaviour in a variety of settings when they are under observation, ranging from externalising a pain response (Kleck et al., 1976) to poorer recall memory (Geen, 1973), the presence of the experimenter in the same room as the participants may have impacted their performance on the SMS task or their relaxation during the breathing task.

6.3 Future directions

One fruitful avenue of research may be to compare RFB on its own against varying meditative practices to see how subjective experiences are different. This might help to give some indication as to how to modify RFB to induce perceptual changes similar to how meditation does or to help explain why it might not lead to similar perceptual changes as meditation does. Using stronger manipulations for arousal and attention shifts to probe time perception, prediction, and EC may also be warranted. This is in line with the state-trait dichotomy mentioned above as a routine use of RFB may lead to detectable shifts in perception.

Alternatively, RFB might also be used in conjunction with another manipulation such as substance ingestion or sensory deprivation. This pairing could amplify some of the physiological effects of RFB in order to produce larger shifts in physiological and psychological parameters. Lastly, comparing musicians and non-musicians as well as practiced meditators and non-practiced meditators during RFB interventions may highlight more individual or group differences in effects of RFB on time perception or SMS. This is because musicians have been shown to have better synchronisation in SMS paradigms than non-musicians (Aschersleben, 2003) and because of the previously-mentioned trait effects of meditation on time perception. Indeed, information regarding musicianship and meditation experience was collected in this study, but it was not utilised in any of the analyses. This may prove a useful approach to dividing the data in order to probe for condition effects on SMS in a more refined manner.

7 CONCLUSION

The current study showed no relationship between RFB and increased HRV and altered SMS capacities. Specifically, no differences in prediction of upcoming stimuli in a sequence of sounds was observed between a condition involving RFB and a control condition involving sitting quietly. There was also no difference in participants' ability to adapt their finger tapping to temporal perturbations during the sound sequences. Furthermore, HRV was unrelated to tapping performance. These findings suggest that a single session of RFB may not be a sufficiently strong manipulation to induce changes in time perception, change detection, and response inhibition. Future research should focus on delineating more precisely the limits of RFB on perceptual changes as well as investigating larger shifts in physiological state and consciousness to explore in which contexts and physiological states SMS can be disrupted or enhanced.

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APPENDIX A: SESSION ONE QUESTIONNAIRE

Adapted from Laborde et al. (2017)

Session One Questionnaire

Please answer the following questions to the best of your ability. If a question does not apply to you, please leave it blank.

1) Subject Number and Time (for Experimenter)

2) How long ago did you last consume coffee or caffeinated tea?

2a) How many cups of coffee and/or caffeinated tea do you typically drink per day?

3) Do you smoke cigarettes? Check one.

Yes

No

3b) If yes, when did you last smoke a cigarette (one hour ago, 30 minutes ago, etc.)?

3c) How many cigarettes do you typically smoke per day?

4) When was the last time you took part in intensive physical exercise?

5) Have you had an alcoholic beverage in the last 24 hours? Check one.

Yes

No

6) At what time did you wake up this morning?

Time:

7) At what time did you go to sleep last night?

Time:

8) Did you practice RFB between the assessment and this session? Check one.

Yes

No

8a) If yes, how many times did you practice it?

Thank you!

APPENDIX B: SESSION TWO QUESTIONNAIRE

Adapted from Laborde et al. (2017)

Session Two Questionnaire

Please fill out each question to the best of your ability. If you do not understand a question, please alert the researcher and they will assist you. If a question does not apply to you, leave the space blank. Finally, if you do not wish to answer a question, leave the answer space blank. Answers to the questions will be tied only to your subject number and never to your name.

Subject Number and Time (for Experimenter)

1) What is your age?

2) What is your gender?

3) Do you play a musical instrument? Check one.

Yes

No

4) If you play a musical instrument, approximately how many hours per week do you spend playing?

5a) Do you have formal musical training? Check one.

Yes

No

5b) If yes to 5a, please indicate in which style(s) you have formal training:

5c) If yes to 5a, how many years of formal training (years, months, etc.)? Please indicate per-instrument, if applicable.

5d) If yes to 5a, at what ages did your formal training take place? Please indicate per-instrument, if applicable.

6a) Do you have formal dance training? Check one.

Yes

No

6b) If yes to 6a, please indicate the styles in which you have dance training and the amount of formal training (years, months, etc.).

6c) If yes to 6a, at what ages did your formal training take place? Please indicate per-style, if applicable.

7) Regardless of formal training, approximately how many hours do you spend dancing to music per week? Check one.

Zero

0-1

1-2

2-3

3-4

4+

8) Regardless of formal training, approximately how many hours do you intentionally listen to music per week? Check one.

Zero

0-1

1-2

2-3

3-4

4-5

5-6

6-7

7-8

8+

9a) Prior to this study, did you have experience with resonant frequency breathing? Check one.

Yes

No

No, but I had heard of it.

9b) If yes to 9a, please indicate how many months you have practiced it and how frequently you practice it (daily, once per week, etc.)

10a) Do you have experience meditating? Check one.

Yes

No

10b) If yes to 10a, please indicate 1) the type of meditation you practice or have practiced 2) how many months you (have) practiced it for and 3) how frequently you currently practice it or practiced it in the past (daily, once per week, etc.)

11) How long ago (one hour, 30 minutes, etc.) did you last consume caffeine (coffee, tea, etc.)?

12a) Do you smoke cigarettes? Check one.

Yes

No

12b) When did you last smoke a cigarette (one hour ago, 30 minutes ago, etc.)?

13) How many cups of coffee and/or caffeinated tea do you typically drink per day?

14) How many cigarettes do you typically smoke per day?

15) Please list any other medications you are currently taking.

16) When was the last time you took part in intensive physical exercise?

17) Have you had an alcoholic beverage in the last 24 hours? Check one.

Yes

No

18) At what time did you wake up this morning?

Time:

19) At what time did you go to sleep last night?

Time:

20) Did you practice RFB between experimental sessions? Check one.

Yes

No

20a) If yes, how many times did you practice RFB?

Thank you!