8-16-2023 10:00 AM

Spontaneous Intrapersonal Synchrony and the Effect of Cognitive Load

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A thesis submitted in partial fulfillment of the requirements for the Master of Science degree in Psychology

Abstract

Spontaneous intrapersonal synchronization is the spontaneous synchronization of periodic behaviors within an individual. It is less investigated than spontaneous interpersonal synchronization, the synchronization of periodic behaviors that occurs spontaneously between individuals integrated into a single system through coupling, caused by the exchange of sensory feedback between them. It was therefore hypothesized that periodic behaviors produced by an individual, a single system by default, would spontaneously be more synchronous through exchange of sensory feedback, coupling and integration within the individual, when the behaviors are produced simultaneously, compared to separately. Based on a postulate that explains spontaneous interpersonal synchronization as a strategy by the brain to conserve resources, and predicts individuals under high cognitive load to spontaneously synchronize their behaviors with others to conserve resources, it was hypothesized that spontaneous intrapersonal synchronization would increase under additional cognitive load. We tested our hypotheses through two experiments, each with a different pair of periodic tasks, and a different cognitive load task. In each experiment, we compared the phase coherence of two periodic tasks, tapping-walking or tapping-ticking, when produced by an individual simultaneously versus separately; we also compared the same when produced simultaneously with additional cognitive load versus without load. Here, ticking was a periodic task where the word “tick” was uttered repetitively. Counting backwards and visual pattern-matching were used as cognitive load tasks. Results showed that spontaneous intrapersonal synchronization between periodic tasks was higher when produced simultaneously, compared to separately, and the same was lower with additional cognitive load, compared to without load.

Keywords

Spontaneous intrapersonal synchronization, spontaneous interpersonal synchronization, temporal coordination, cognitive load, coupling, sensory feedback, phase coherence, cognitive overload, finger-tapping, tapping, walking, counting backwards, visual pattern-matching

Summary for lay audience

People walking side by side synchronize their footsteps spontaneously with each other; this phenomenon is called spontaneous interpersonal synchronization, which occurs due to exchange of sensory feedback between individuals, causing their movements to get coupled. Based on that, we hypothesized[1] that coupling of simultaneous periodic movements, such as walking and clapping, would occur within an individual as well, triggering spontaneous synchronization between periodic behaviors produced by the individual, called spontaneous intrapersonal synchronization. Furthermore, spontaneous interpersonal synchronization has been postulated as a strategy by the brain to conserve resources, as tracking one periodic behavior at a time is more economical, compared to tracking multiple; it is predicted that a high cognitive load in addition to, say, walking or clapping together, will cause individuals to synchronize more, to conserve resources. Given how, musicians, when asked to track two beats simultaneously, show a tendency to combine the two beats rather than track them independently, we argued that this could be to conserve resources as well, and predicted this tendency to extend beyond perception into production. We therefore hypothesized[2] that spontaneous intrapersonal synchronization would increase with additional cognitive load. We tested the hypotheses by comparing the synchronicity between finger-tapping and walking in Experiment 1, and between finger-tapping and ticking (uttering the word “tick” repetitively) in Experiment 2. We tested hypothesis[1] by comparing the synchronicity between the periodic task pairs when they were performed simultaneously, versus when they were performed separately. We tested hypothesis[2] by comparing the synchronicity between the periodic task pairs when they were performed simultaneously with additional cognitive load, versus without additional load. We induced additional cognitive load by using the counting backwards task (in 3’s & 7’s) in Experiment 1, and a visual pattern-matching task (4 to 9-block patterns) in Experiment 2. In both experiments, results supported Hypothesis 1: Spontaneous intrapersonal synchronization between the periodic tasks was higher when performed simultaneously, compared to separately. In both experiments, results failed to support Hypothesis 2: Spontaneous intrapersonal synchronization decreased with additional cognitive load.

Acknowledgements

Firstly, I would like to thank my supervisor, Dr. Jessica Grahn for her unflinching support and guidance for the past two and half years, right from the day we had our first Zoom call, till today when she sent me her latest feedback on my thesis. She was there during the most challenging admission process, thanks to the pandemic. She was also there when I couldn't travel to Canada for my first term, thanks again to the pandemic. And she has been there throughout. Jessica, whether it be an intellectual conversation about research, or an inconsequential one with a beer, you rock! Your students benefit every day from your intellect, guidance, patience, and understanding. You are a great teacher, a wise mentor, and a wonderful friend. You're one hell of a human being. Thank you!

I also would like to thank my supervisory committee, Dr. Ryan Stevenson and Dr. Blake Butler, for their input and support over the last two years. To my lab mates, I know we don't spend as much time as we should due to our schedules. But whenever we've managed to find time, it's been fun. Thank you all! Special thanks to Rebekka for always answering my unrelenting, and most annoying questions with a smile. (That reminds me, I really gotta learn stats from you one of these days, 'coz I suck!). I also would like to give special thanks to Lisa Drysdale, Denise Soanes and Haitao Yang for their support with admin and tech stuff.

Lastly, to my family, you are the reason because of which I exist, and the reason for which I exist. I go forward every day because you have my back. This one is for you guys!

Cheers!

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Chapter 1

1 Introduction

Imagine an audience at a musical, watching musicians and dancers perform, and grooving along with the artists by tapping their feet, snapping their fingers, clapping their hands, and bobbing their heads. Such an event would be a fine demonstration of art, community, and human spirit. But, in a way, it is actually a demonstration of just one thing, and that is the over-arching, as well as under-appreciated, theme of the event – synchronization. Therefore, if we reconstruct the imagination in terms of synchronization, it would be the artists performing in synchrony, audience perceiving that synchrony, and, in turn, joining the artists in synchrony. Synchronization is such an integral component of human nature that it often goes unnoticed – we enjoy a beautiful song without noticing the role of synchronization in that experience, just like we enjoy a delicious meal without noticing the role of salt.

1.1 Interpersonal Synchronization

Interpersonal synchronization refers to the synchronization of behaviors between individuals, that is both intentional, as in the case of the artists in the above example, performing consciously in synchrony with each other, as well as spontaneous, as in the case of the audience, grooving along with the artists unintentionally; spontaneous interpersonal synchronization, the more relevant of the two to the current study, has been observed in humans across various activities, including swinging a handheld pendulum, swaying in a rocking chair, walking, and running (Schmidt & O'Brien, 1997, Richardson et al., 2007; Oullier et al., 2008; Lopresti-Goodman et al., 2008; Harrison & Richardson, 2009; Zivotofsky et al., 2007, 2012).

Defining ‘synchronization’

Lexically, ‘synchronization’ means ‘happening at the same time or rate’. However, in the context of interpersonal synchronization, the word “coordination”, especially of a “temporal” nature, is often used by researchers to define synchronization: “Rhythmic coordination of perception and action” (Repp, 2005, p. 969), “coordination of rhythmic movement with an external rhythm” (Repp & Su, 2013, p. 403), and “temporal coordination between humans” (Tranchant et al., 2022), are some of the definitions of synchronization found in the literature as on date. Researchers have not opted for the lexical definition because synchronization between individuals, at most times if not all, is not as straightforward as ‘happening at the same time or rate’.

In-phase and out-of-phase synchronization

In dyads walking together, spontaneous synchronization of footsteps has been found to be in-phase, as well as 180° out-of-phase (Zivotofsky, 2007). During in-phase synchronization, the partners walk at the same rate, where each step with either foot by one partner happens at the same time as that with the corresponding foot by the other partner. However, during out-of-phase synchronization, although the partners walk at the same rate, each step with either foot by one partner does not happen at the same time as that with the corresponding foot by the other partner. For example, during 180° out-of-phase synchronization as mentioned above, every right footstep of one partner happens at the same time as a left footstep of the other partner, and vice-versa. Here, 180° is the phase angle by which each partner either lags or leads the other, and it corresponds to half the gait cycle, where a full gait cycle (360°) starts with a step with either foot, right or left, and lasts until the next step with the same foot. Phase angle (in degrees) is calculated as $|t_1 - t_2| * F * 360°$ (the same in radians is

$|t_1 - t_2| * F * 2\Pi$), where t_1 and t_2 are the timings of the corresponding footsteps (either right vs. right, or left vs. left) of partners 1 and 2 respectively, walking at the same rate (F – number of gait cycles per unit time); for in-phase synchronization, $t_1 - t_2 = 0$, and for out-of-phase synchronization, $t_1 - t_2 \neq 0$, with 180° out-of-phase being the case when, $t_1 - t_2 = 1/2F$.

Synchronization in reality

It is important to note that for both in-phase as well as out-of-phase synchronization as described above, both partners have to walk exactly at the same rate in order to maintain a common value for 'F'. In reality, it is unreasonable to expect two individuals to walk at exactly the same rate, step after step, as that means their stride time variabilities must be exactly zero. Research shows that stride time variability is not zero even in healthy young adults: It is under 3% in general (Beauchet et al., 2009), but not zero. That means, at most times if not all, partners 1 and 2 will likely have different walking rates, say, f_1 and f_2 respectively instead of the common rate (F), and therefore, the timings of their corresponding footsteps – t_1 and t_2 respectively, will likely be different as well, such that $t_1 - t_2 \neq 0$. Consequently, almost every step taken together, if not all, will generate two relative phase angles, one for each partner relative to the other. Lower the variabilities of the walking rates and the timing differences between corresponding footsteps of the partners, lower the variabilities of the relative phase angles, measured as phase coherence, a value that falls between 0 and 1, where 1 means total synchrony and 0 means no synchrony at all.

This applies not only to synchronization involving walking, but also to other periodic tasks such as finger-tapping – Inter-tap interval varies with every tap (Yamada, 1995). Therefore, in reality, interpersonal synchronization is the coordination of periodic behaviors between individuals, towards achieving and maintaining maximum phase coherence.

1.2 Intrapersonal Synchronization

Now, consider an individual member of the audience at our imaginary musical, humming one of the tunes right after the concert while walking back to the car, and also, at the same time, bobbing his head along and snapping his fingers in a coordinated fashion. In that scenario, any synchronization that occurs between walking, head-bobbing, and finger-snapping, is the temporal coordination of periodic behaviors *within* an individual, hereafter referred to as intrapersonal synchronization. Intrapersonal synchronization can be intentional, such as in the case of the drummer at our imaginary musical, coordinating periodic hand and feet movements intentionally while drumming, or unintentional, such as in the case of our imaginary audience member walking back to the car after the concert, coordinating his footsteps, finger-snapping, and head-bobbing unintentionally. Unintentional intrapersonal synchronization, hereon referred to as spontaneous intrapersonal synchronization, is the phenomenon of interest for the current study.

1.3 Study Overview

To date, as a field of inquiry, spontaneous intrapersonal synchronization remains largely unexamined. There is evidence of temporal coupling between speech and finger-tapping in individuals (Parrell et al., 2011), and earlier evidence that speaking and finger-tapping mutually influence each other's rates (Smith et al., 1986). Finger-tapping also gets slower and more variable with concurrent speaking (Hiscock et al., 1985). But the inquiries above do not venture past interactions between speech and finger-tapping into the realm of synchronization. However, spontaneous intrapersonal synchronization is observably similar in concept to its interpersonal counterpart in the way it temporally aligns multiple periodicities such that only a single periodicity must be processed. Therefore, it is possible to draw inferences about spontaneous intrapersonal synchronization from findings on spontaneous interpersonal synchronization.

While, as mentioned, little is known about spontaneous intrapersonal synchronization, interpersonal synchronization has attracted researcher attention over the years. Spontaneous interpersonal synchronization is triggered by the coupling of periodicities through exchange of sensory feedback between the interacting individuals producing those periodicities (Schmidt & O'Brien, 1997, Richardson et al., 2007; Oullier et al., 2008; Harrison & Richardson, 2009; Zivotofsky & Hausdorff, 2007, Zivotofsky et al., 2012, 2018; Sylos-Labini, 2018). The coupling integrates the periodicities into a single system, biasing the interacting individuals to adopt a common rate through spontaneous synchronization. The current study is an inquiry into whether this mechanism applies to spontaneous intrapersonal synchronization: It tests whether multiple periodicities produced simultaneously by the same individual, a single system by default, are spontaneously synchronized, with exchange of sensory feedback, coupling, and integration occurring within the individual, instead of between individuals as in the case of spontaneous interpersonal synchronization.

Also, intentional interpersonal synchronization can enhance certain cognitive abilities, such as problem-solving and memory (Miles et al., 2017; Valdesolo et al., 2010; Von Zimmermann & Richardson, 2016; Woolhouse et al., 2016). This suggests that intentional interpersonal synchronization helps individuals handle cognitive load in these areas. However, little is known about whether cognitive load triggers interpersonal synchronization spontaneously. Koban and colleagues suggest such a converse to be true; they predict that a high cognitive load, such as during a demanding working memory task, would increase spontaneous interpersonal synchronization in individuals who, for example, clap hands or walk together (2019). Again, considering the observable similarity between interpersonal and intrapersonal spontaneous synchronization, the current study tests whether the prediction by Koban and colleagues applies to spontaneous intrapersonal synchronization, where periodicities performed simultaneously by an individual could spontaneously synchronize more under additional cognitive load.

The following sections will discuss findings that shed light on possible relationships shared by synchronization with two key factors – coupling and cognitive load, and also how these relationships form the bases for the rationales behind the inferences, as well as consequent predictions, about spontaneous intrapersonal synchronization for the current study.

1.4 Synchronization and Coupling

1.4.1 Coupling

Coupling refers to the influence between two systems, where the nature of the influence can be either unidirectional or bidirectional. Unidirectional coupling, or drive-response coupling, is a one-way influence exerted by the independent evolution of the driving system on the dependent evolution of the responding system; bidirectional coupling is a two-way influence, or a mutual influence, between the two systems on the evolution of each other’s behavior (Boccaletti et al., 2002). For example, the tempo fluctuations in the performance of an artist driving those of the periodic movements, such as head-bobbing and clapping, of an audience member, is unidirectional coupling, a one-way influence of the artist on the audience member. On the other hand, in the case of a dyad walking side by side, the fluctuations in the cadence of each partner influencing those of the other is bidirectional coupling. In both cases, spontaneous synchronization refers to the temporal coordination that can emerge unintentionally between the periodicities produced by the two systems, as a result of the exerted influence/s. The earliest observation of spontaneous synchronization dates back to 1665, when Christiaan Huygens observed that two pendulums, otherwise out of sync, synchronized when they were mounted on a common beam (Huygens, 1893). Huygens realized that the synchronization of the pendulums was due to the exchange of energy between them in the form of vibrations across the common beam, causing the pendulums to be coupled (Ramirez & Nijmeijer, 2020). This suggests that, when coupled, the two pendulums are no longer separate entities; they constitute a single integrated entity capable of oscillating at only one rate at any given time, causing them to adjust their individual rates and adopt a common one for oscillation. This underlying mechanism causing spontaneous synchronization in a non-biological system such as Huygens' pendulums appears to apply to biological systems as well. The main difference seems to lie in the way coupling is achieved: while coupling in pendulums happens through the exchange of energy between them, coupling in humans is typically achieved through exchange of sensory feedback – visual, auditory, or tactile.

1.4.2 Coupling triggers synchronization

<u>In experimental settings</u>

All three modalities of sensory feedback have been manipulated using various techniques across studies. For example, in a 2007 study on spontaneous synchronization of gait between partners, white noise on headphones, and sideblinders have been used to prevent exchange of auditory and visual feedback respectively; to facilitate exchange of tactile feedback, partners have been made to hold hands while walking together. Exchange of tactile feedback by holding hands has proved to be the most effective in eliciting spontaneous synchronization of gait (Zivotofsky & Hausdorff, 2007). Subsequent studies using the hand-holding paradigm have also showed increase in spontaneous synchronization of gait when tactile feedback is available to the partners compared to when it is not (Zivotofsky et al., 2012, 2018; Sylos-Labini, 2018). Although not as consistent as their tactile counterpart, visual and auditory feedback have, in some cases, been effective in triggering an increase in spontaneous interpersonal synchronization of various activities, including swinging a handheld pendulum, swaying in a rocking chair, walking, and running (Schmidt & O'Brien, 1997, Richardson et al., 2007; Oullier et al., 2008; Lopresti-Goodman et al., 2008; Harrison & Richardson, 2009; Zivotofsky et al., 2012).

In naturalistic settings

Even in naturalistic observations, when sensory feedback is not manipulated, spontaneous synchronization seems to follow the natural exchange of sensory feedback between interacting entities. Audiences spontaneously synchronize their applause – what begins as random, incoherent clapping soon morphs into synchronized clapping (Neda et al., 2000, 2003). Also, humans synchronize their footsteps spontaneously when walking with others; such observations have been reported in dyads (Zivotofsky & Hausdorff, 2007), as well as in crowds of pedestrians (Fujino et al., 1993; Ma et al., 2021). Analysis has revealed that perceptual coupling between Usain Bolt and Tyson Gay during the 2009 World Championship, possibly due to running in adjacent lanes, could have caused them to spontaneously synchronize their steps (Varlet & Richardson, 2015). The relationship between synchronization and coupling is evident even in in non-human animals. Japanese monkeys rely on social bonds, developed through visuo-motor or auditory-motor coupling, to spontaneously synchronize with each other (Nagasaka et al., 2013).

1.4.3 Synchronization triggers coupling

The relationship between synchronization and coupling could be a two-way affair, as findings show that interpersonal synchronization triggers social coupling, a mutually affective influence in the form of empathy between the interactors, "so as to sustain the dynamics of the interaction" (Luo & Gui, 2022, p. 388). This happens through "bodily resonance coupling the empathizer and the empathizee", as each experiences "the kinetics and emotional intensity" of the other through one's "own bodily kinaesthesia and sensation" (Luo & Gui, 2022, p. 387; Fuchs & Koch, 2014). For example, "rhythmicity of the mother's interaction can re-orient her infant's attention and responsiveness towards her" (Luo & Gui, 2022, p. 388; De Jaegher & Di Paolo, 2007, pp. 498-99).

In experimental settings

Group singing improves trust (Anshel & Kipper, 1988) and bonding despite lack of familiarity (Pearce et al., 2016). Synchronous arm-waving with group singing bolsters bonding, affiliation, and cooperation (Wiltermuth & Heath, 2009). Chanting synchronously promotes entitativity, affiliation, and cooperation; combining synchrony with shared intentionality further enhances cooperation (Reddish et al., 2013). Walking synchronously with a partner triggers feelings of affiliation that are not triggered when walking alone or asynchronously (Fessler & Holbrook, 2016).

<u>In naturalistic settings</u>

Although not a lot is known in terms of experimental outcomes in naturalistic settings, daily observations suggest that interpersonal synchronization triggers social coupling. National anthems use group singing to bolster bonding and affiliation amongst the citizens. Army marches use walking in synchrony, as well as group chanting, to trigger feelings of affiliation in soldiers. Political and revolutionary speeches use vociferous chants to muster trust and affiliation amongst the supporters. Religious sermons use group singing and chanting to trigger entitativity amongst the followers. Music and dance, art forms founded on synchronicity, bring audiences together regardless of diversities that otherwise divide people.

Although the current study is interested in whether coupling triggers synchronization, evidence supporting the converse, as discussed in this section, suggests that synchronization and coupling could share a two-way relationship, and therefore go hand-in-hand. Here, we acknowledge that social coupling is different from sensory coupling discussed in the previous section. However, given how it binds the interacting individuals like sensory coupling does, although through affective means instead of sensory means, the two forms of coupling could have more in common than what meets the eye at first glance, and therefore intuitively feels worthy of mention in the context of the premise of this study.

1.5 Synchronization and Cognitive load

1.5.1 Cognitive load

According to cognitive load theory (CLT), cognitive load is imposed by processing demands on the cognitive system; here, ‘mental load’ refers to task demands, whereas ‘mental effort’ refers to the “cognitive resources allocated to accommodate the task demands," (Sweller et al., 1998, p. 266; Paas & van Merrienboer, 1994); "mental effort can be considered to reflect the actual cognitive load" (Paas et al., 2016; Sweller et al., 1998). Therefore, when cognitive load is imposed by processing demands, cognitive resources are allocated to handle the load. In the current study, the term 'cognitive resources', or simply 'resources', refers in particular to working memory; consequently, we use the term 'cognitive load' to refer to working memory load, as Sweller et al. (1998) do when they refer to intrinsic cognitive load as "working memory load imposed by the intrinsic nature of the information" (2011, p. 57). CLT shares one of its central assumptions, the limited capacity assumption, with the Working Memory Theory (WMT) by Baddeley and Hitch (1974).

Working Memory Theory

According to WMT, and its subsequent improvements (Baddeley, 1996, 2000a, 2000b, 2010), the working memory is comprised of 3 components: the 'phonological loop' that handles auditory information, the 'visuospatial sketchpad' that handles the visual and spatial information, and the 'central executive' that controls various processes, including attention, information retrieval, manipulation and updating. The central executive also includes the 'episodic buffer' that temporarily stores and integrates information from the phonological loop, the visuospatial sketchpad, as well as from long term memory for processing. For example, consider a task involving counting backwards from a given number using a given negative counter; according to WMT, such a task will require attention, as well as maintenance of the current number in the phonological loop until the negative counter is applied to compute the next number in the sequence, thus employing the phonological loop and the central executive to perform the task. In support of WMT, evidence suggests that counting backwards requires working memory resources (van den Hout et al., 2010). WMT is also supported by comparisons between the Corsi Block Test (Corsi, 1972) and the Visual Patterns Test (Della Sala, 1997), where evidence suggests that the Corsi block test tests the visuospatial component of the working memory, whereas the Visual Patterns Test tests only the visual part of the visuospatial component (Della Sala et al., 1999). Further, WMT's central executive component is supported by evidence suggesting that "shifting (attention) between mentals sets or tasks, updating and monitoring of working memory contents are clearly distinguishable executive functions" (Miyake et. al., 2000, p. 86).

<u>Limited working memory capacity</u>

One of the basic assumptions of WMT is that each component has a limited capacity, and therefore, consequently, working memory capacity is limited. This assumption, in line with the finding on the working memory limit of 7 items plus or minus two (Miller, 1956), is shared by CLT. According to CLT, when limited working memory capacity is exceeded by the cognitive load imposed by processing demands, cognitive overload occurs as not enough resources are available to be allocated to accommodate the demands (Mayer & Moreno, 2003). This suggests that, to avoid cognitive overload, conservation of resources is a logical choice. Therefore, the prediction by Koban and colleagues (2019) is reasonable in that, when cognitive load is induced in individuals performing a demanding working memory task simultaneously with a periodic task, conservation of resources can happen through spontaneous interpersonal synchronization.

1.5.2 Synchronization aids ability to handle cognitive load

Although findings suggesting the possible relationship between synchronization and cognitive load are not as extensive as those between synchronization and coupling, there is evidence to suggest that interpersonal synchronization aids the ability of the individuals to handle cognitive load; this could be due to conservation of resources through interpersonal synchronization.

In experimental settings

Moving synchronously, compared to asynchronously, makes group members more effective in cognitive tasks involving problem-solving (Miles et al., 2017). Dyads take less time to complete a joint-action maze task when rocking together synchronously compared to asynchronously (Valdesolo et al., 2010). In large groups, verbal synchrony enhances memory performance (Von Zimmermann & Richardson, 2016). Dancing to the same piece of music, rather than individually to different pieces, makes partners perform better in a memory test (Woolhouse et al., 2016).

In naturalistic settings

Although not a lot is known in terms of experimental outcomes in naturalistic settings, daily observations suggest that interpersonal synchronization aids the ability of individuals to handle cognitive load. In early education across countries and cultures, song and rhymes in the classroom, mainly through group singing, have proven to be efficient in helping children learn, and especially memorize various kinds of learning material. Singing with accompanying movement helps first-graders memorize and retain the lyrics of the song better, compared to without accompanying movement (Martinovic-Trejgut, 2010). Preschool instruction with rhythmic music activities helps four-year olds achieve better language acquisition, compared to instruction without rhythmic music activities (Raisner, 2002). Instruction of English as a second language with chanting helps non-native learners achieve better language comprehension, compared to without chanting (Chiang, 2003). For thousands of years, ancient cultures, such as India, have maintained their oral traditions in education, using interpersonal synchronization as the key pedagogical tool: To date, Vedas and Indian classical music are taught exclusively through group chanting and group singing.

1.5.3 Does cognitive load aid synchronization?

It is unclear whether high cognitive load would cause individuals to spontaneously synchronize their periodic behaviors interpersonally. However, as mentioned, Koban and colleagues predict that high cognitive load, such as during a demanding working memory task, would increase spontaneous interpersonal synchronization in individuals who, for example, clap hands or walk together (2019); they base this prediction on the postulate that spontaneous interpersonal synchronization is a strategy employed by the brain to "minimize coding costs by reducing the mismatch between the representations of observed and own motor behavior" (Koban et al., 2019, p. 1).

1.6 Evidence for the postulate

Although the postulate seems to be untested to date, there is evidence in its favor. Findings show that, when performed simultaneously, periodic behaviors as well as cognitive tasks suffer in terms of performance, suggesting that they could be drawing from the same pool of resources.

1.6.1 Walking shares resources with cognitive tasks

Performing concurrent cognitive load tasks, such as enumerating animal names and smartphone gaming, while walking, affects gait variability in healthy young adults (Dubost et al., 2008; Stockel & Mau-Moeller, 2020). Evidence showing how older adults need more cognitive resources to maintain their gait (Holtzer et al., 2006; Ble et al., 2005; Hausdorff et al., 2005, Yogev-Seligmnn, 2008) supports that taxing cognitive resources while walking could affect performance across age groups. Studies have used a dual task paradigm involving walking and counting backwards, and the findings show that the concurrent cognitive task affects gait speed and variability (Li et al., 2014; Beauchet et al., 2005), as well as counting backwards performance (Beauchet et al., 2005). According to the central capacity-sharing model, such degradation is due to dual task interference between concurrent tasks drawing from the same pool of cognitive resources (Tombu & Jolicœur, 2003), suggesting that walking and counting backwards could be sharing the same resources. Walking has been shown require attention (Yogev-Seligman et. al., 2008), a function of the central executive, according to WMT. Also, as discussed in section 1.5.1, counting backwards requires working memory resources as well, including attention. Therefore, walking and counting backwards could be sharing attentional resources of the central executive component of working memory.

1.6.2 Finger-tapping and repetitive vocalization share cognitive resources

Studies have also used finger-tapping and repetitive vocalization of nonsense syllables in dual task paradigms. With the n-back task (Kirchner, 1958) or mental arithmetic tasks, finger-tapping has shown performance degradation, especially in terms of tapping variability (Irie et al., 2022; Bååth et al., 2016). With visuospatial memory tasks, such as the Multiple Object Tracking (MOT) task that requires tracking the positions of moving target items among distractors, findings show that finger-tapping repeatedly in a given sequence (little finger, middle finger & thumb), as well as vocalizing three nonsense syllables repeatedly in a given sequence (“Ta, Heff, Doh”), interfere with performance at the MOT task (Trick et al., 2006). Here again, the central capacity-sharing model can be applied to attribute the overall performance degradation to dual task interference between concurrent tasks drawing from the same pool of cognitive resources (Tombu & Jolicœur, 2003). Given that MOT requires active tracking of the positions of moving target items among distractors, it is reasonable to assume that MOT requires attention. Also, rhythmic timing involved in tasks such as finger-tapping requires attention (Bååth et al., 2016). Therefore, finger-tapping and repetitive vocalization could be sharing attentional resources of the central executive component of working memory with visuospatial tasks like MOT.

1.6.3 Testing the postulate

In the studies mentioned in the above two sections, the walking tasks were at natural rates, also known as spontaneous motor tempos (SMTs), whereas finger-tapping and vocalization were at subjected rates as determined by the experimenters; this suggests that cognitive load could influence periodic movements at their SMTs, as well as at the subjected rates. That means, when individuals produce periodic movements together, such movements could be vying for resources to maintain their own SMTs, as well as to process the rates of others they are subjected to perceive. This alone could tax resources enough to trigger spontaneous interpersonal synchronization, making it logical to posit that a high cognitive load on top of this could further bias individuals towards spontaneous interpersonal synchronization in order to conserve resources. Overall, the evidence renders the postulate worth testing.

1.7 Rationale

As discussed, spontaneous interpersonal synchronization occurs when periodicities, produced simultaneously by interacting individuals, are integrated into a single system through coupling caused by exchange of sensory feedback between the individuals, triggering spontaneous adjustment of individual rates to adopt a common one. It is therefore logical to infer, that multiple periodicities produced simultaneously by the same individual, a single system by default, could be spontaneously synchronized, with exchange of sensory feedback, coupling, and integration occurring within the individual, making spontaneous intrapersonal synchronization a tenable prediction. This leads to the first research question: Do individuals spontaneously synchronize two periodic behaviours more when producing them simultaneously, compared to separately?

Spontaneous synchronization could be a single phenomenon, manifesting itself in two forms: interpersonal and intrapersonal. That means spontaneous intrapersonal synchronization could conserve computational resources, and therefore increase with high cognitive load. Research does suggest that when tracking two different beats simultaneously, musicians combine the beats into a single composite pattern, rather than tracking them independently (Poudrier & Repp, 2013). This preference for a single periodicity to track over multiple simultaneous ones could be to conserve resources, and therefore could extend beyond perception into production, triggering spontaneous intrapersonal synchronization. This leads to the second research question: Does spontaneous intrapersonal synchronization, if triggered by simultaneous production of periodic behaviours, increase with additional cognitive load, such as during a demanding working memory task while performing the periodic behaviours?

1.8 Hypotheses

1) Individuals producing two periodic behaviours separately at different spontaneous rates will spontaneously synchronize them when producing them simultaneously.

2) Spontaneous intrapersonal synchronization will increase with additional cognitive load, such as during a demanding working memory task.

1.9 Current study

The current study aimed to contribute to the understanding of spontaneous intrapersonal synchronization, a relatively unexplored field of study as of date. To do so, we conducted two experiments. In each experiment, we tested Hypothesis 1 by comparing levels of synchronicity between two periodic behaviors, produced simultaneously versus separately; we tested Hypothesis 2 by comparing levels of synchronicity between two periodic behaviors produced simultaneously, with additional cognitive load versus without additional cognitive load. Each experiment employed a different pair of periodic behavior tasks, hereafter referred to as periodic tasks. Also, to manipulate cognitive load, each experiment employed a cognitive load task with multiple difficulty levels. Choices of tasks were informed by the earlier section on the evidence for the postulate by Koban and colleagues.

1.9.1 Periodic tasks

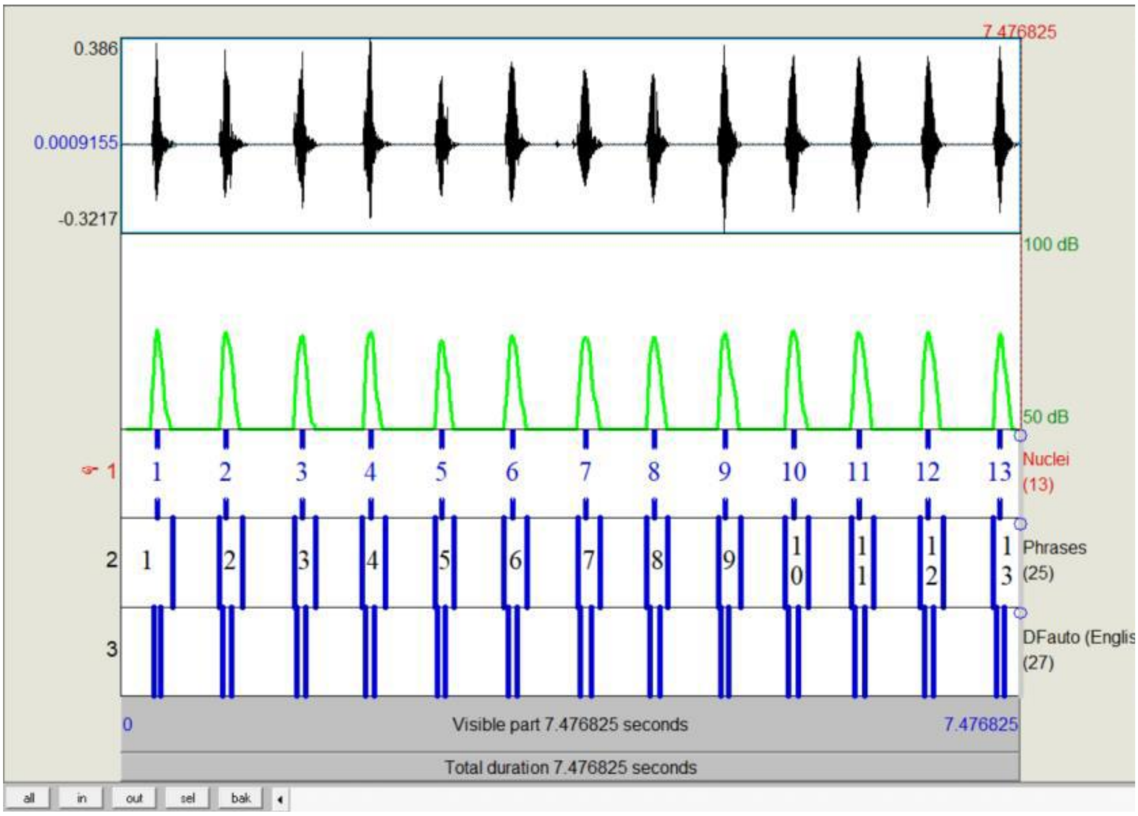
Walking, finger-tapping, and vocalization were chosen as periodic tasks because they have natural rates, they can synchronize with external rates, and they have been shown to share resources with cognitive load tasks. Experiment 1 involved walking and finger-tapping, hereon referred to as tapping. Experiment 2 involved tapping and vocalizing the word “tick” repetitively, hereon referred to as ticking. The periodic tasks chosen for Experiment 2 were similar to the one by Trick and colleagues discussed earlier (2006); the differences were that, in this experiment, tapping was unimanual with a single finger of the dominant hand, and vocalization was of a single monosyllabic word “tick”; also, both tasks were non-sequential, and at natural rates.

Why the word “tick”?

As the rate of word utterances was extracted from audio recordings, it was imperative that the durations between successive peak intensities in the waveform were straightforward to extract and corresponded to those between successive perceptual centers (p-centers) of the utterances. Location of the p-center of a word does not coincide with the any particular acoustic onset, such as that of the vowel, consonant, or the peak intensity of the waveform (Morton et al., 1976); also, it varies across consonants and vowels, as well as their durations (Marcus, 1981; Fowler, 1979). Therefore, a single monosyllabic word was required to keep the consonant, vowel, and their durations constant across utterances. To further ensure that vowel duration did not fluctuate between utterances, a short vowel with a glottal stop was used. Based on these requirements, the word “tick” was chosen; sample recordings of short sequences of ‘tick’ utterances were created; for each sample recording, every single pair of successive utterances was tapped along with individually, and repeatedly enough, on a free-to-use android metronome app to get a series of perceptual rates. Then, the rates of utterances for each recording, as extracted from the peak intensities in the waveform (as shown in Figure 1), were compared with the respective perceptual rates in order to confirm they matched. Upon confirmation, the choice of the word “tick” was finalized.

<u>Figure 1</u>: Sound intensity curves of the audio waveform of the word “tick” –

(screenshot of the console on Praat, showing the consistency of the peaks)



1.9.2 Cognitive load tasks

Experiment 1 employed a counting-backwards task, a highly-validated working memory task (Li et al., 2014; Beauchet et al., 2005). Two levels of cognitive load were induced by using two different numbers to count backwards, 3 and 7. Experiment 2 employed a visual working memory task instead of the counting backwards task as uttering the word “tick” repeatedly and counting backwards out loud at the same time would not be possible. In visual working memory tasks, patterns on matrices make it harder to memorize through verbalization or phonology (Della

Sala et al., 1999). Therefore, a visual pattern-matching task on two adjacent matrices was created. The task involved determining whether sequentially presented patterns presented on two adjacent 6x6 matrices were the same or different. Six levels of cognitive load were induced by manipulating the number of blocks in the patterns, from 4 to 9. The task was designed based on a 2005 study where simultaneous presentation of patterns were used in a matching task, where subjects were allowed 1 second to encode each block on the pattern: for example, 5 seconds would be allowed to encode a 5-block pattern (Lecerf & Ribaupierre, 2005). This was in line with the most common block-tapping rate of 1 second per block, used widely in the administration of the Corsi Block Test (Arce & McMullen, 2021; Corsi, 1972). Based on that, we allotted 6.5 seconds to encode each pattern with 4 to 9 blocks, as 6.5 was the average of 4 and 9. This was also similar to the Visual Patterns Task introduced by Della Sala and colleagues (1997); the main difference here was, instead of reproducing the patterns from memory, the subjects had to recognize and point out the differences between the patterns.

1.9.3 Metrics

In both experiments, relative phase angles were extracted for each periodic task. The global order parameter of the Kuramoto model (Acebrón et al., 2005; Kuramoto, 1975) was then applied to calculate phase coherence (r) as the measure of synchrony between the periodic tasks ($0 \leq r \leq 1$, where 0 is no synchrony, and 1 is total synchrony). Therefore, each trial yielded two phase coherence (r) values, one for each periodic task relative to the other. Phase coherence was then compared across conditions. Illustration and explanation of the model as well as calculations are presented in section 2.4.5.

1.9.4 Predictions

Based on Hypothesis 1, we predicted the phase coherence between the periodic tasks to be higher when performed simultaneously, compared to separately. Based on Hypothesis 2, we predicted the phase coherence between the periodic tasks to be higher when performed simultaneously with additional cognitive load, compared to without the load.

Chapter 2

2 Method

2.1 Participants

Twenty-four participants (mean age = 22.58 years; range = 18 to 33; SD = 5.5; 10 males & 14 females) were recruited for the study. Age and gender details were collected as self-reported by participants. Fourteen of the participants were recruited from the SONA Psychology research participation pool at Western University; each of them received 1 course credit for their participation in the study. The remaining 10 participants were recruited from students and the general public, and compensated $10 for the 1-hour study. The study was approved by the Non-Medical Research Ethics Board at Western University.

2.2 Design

The study comprised two experiments. Each experiment had two periodic tasks, and one cognitive load task. The study design (as shown in Figure 2) was common to both experiments.

<u>Figure 2</u>: Study design for both experiments – *(showing 6 conditions across 3 stages, and the order of trials)*

<table>
<tr><th>STAGE</th><th colspan="3">Pre-load</th><th colspan="2">Load</th><th colspan="3">Post-load</th></tr>
<tr><th>CONDITION</th><td colspan="2">Single task</td><td>Dual task</td><td>Dual + Expecting-load</td><td>Dual + Enduring-load</td><td>Dual task</td><td colspan="2">Single task</td></tr>
<tr><th>PERIODIC TASKS</th><td>Task 1</td><td>Task 2</td><td>Task 1 + Task 2</td><td colspan="2">Task 1 + Task 2 (continuous trial)</td><td>Task 1 + Task 2</td><td>Task 2</td><td>Task 1</td></tr>
<tr><th>COGNITIVE TASK</th><td colspan="3">No</td><td>Expecting</td><td>Yes</td><td colspan="3">No</td></tr>
<tr><th>ORDER OF TRIALS</th><td colspan="8"></td></tr>
</table>

2.2.1 Experiments and Tasks

Experiment 1 had tapping and walking as periodic tasks, and counting backwards as the cognitive load task. Experiment 2 had tapping and ticking as periodic tasks, and visual pattern-matching as the cognitive load task. As shown in Figure 2, each experiment had 3 load stages (pre-load, load, and post-load). Pre-load and post-load stages had 2 periodic task conditions each (single task [periodic tasks performed separately], and dual task [periodic tasks performed simultaneously]). Load stage had 2 cognitive load conditions (expecting-load, and enduring-load) where periodic tasks were performed simultaneously in both conditions. Therefore, there were 6 six conditions overall. Both experiments were completed in a single session lasting 1 hour; the order of completion of the experiments was counterbalanced across participants. Also, as shown in Figure 2, within each experiment, the order of completion of single task and dual task conditions, as well as that of the individual tasks in the single task condition was counterbalanced within participants across pre-load and post-load stages.

Task Instructions

Tapping: Each participant was instructed to hold a hand mic with the non-dominant hand, and tap on the mic repetitively with the index finger of the dominant hand at whatever rate felt natural; they were instructed to start and stop tapping as prompted by the experimenter running Experiment 1, or as prompted by the MATLAB application running Experiment 2. The dominant and non-dominant hands were as self-reported by the participant.

Walking: The participants were instructed to start walking at whatever rate felt natural from just behind a tape on the floor, marking 1.78 meters off a 16-foot Zeno pressure-sensor gait mat, and continue walking across the mat to its other side; they were instructed to maintain their stride as they walked off the mat a further 1.78 meters on the other side, marked by another tape on the floor, before making a wide U-turn to walk back onto the mat for the next lap. They were instructed to start and stop walking as prompted by the experimenter.

Ticking: The participants were instructed to repeat the word “tick” into a stand mic at whatever rate felt natural; they were instructed to start and stop ticking as prompted by the MATLAB application running Experiment 2.

Counting backwards: At the start of each trial involving the counting backwards task, the participants were given a 3-digit number as well as a negative counter (3 or 7). They were instructed to count backwards from the given 3-digit number using the given negative counter (in 3’s or 7’s). For each trial, the 3-digit number / negative counter combination was unique.

Visual pattern-matching: The participants were instructed to (1) memorize a pattern comprised of yellow blocks that would appear on a blue 6x6 matrix on the left side of a computer screen for a few seconds before disappearing off the screen, (2) remember the pattern for a few more seconds immediately following its disappearance, (3) match the pattern in memory against the one that would appear on a blue 6x6 matrix on the right side of the computer screen, and determine whether or not the second pattern was different from the first in the form of a single displaced block, and (4) if different, enter the number on the displaced block as the answer, and if not, enter the number ‘0’ as the answer; the answers were to be entered into the MATLAB application running the task.

Dual tasks: During dual task conditions that involved performing the two periodic tasks at the same time, the participants were instructed to perform the two tasks simultaneously at whatever rates felt natural for each task; they were instructed to start and stop both tasks at the same time, as prompted by the experimenter running Experiment 1, or as prompted by the MATLAB application running Experiment 2.

2.2.2 Stages and Conditions

Pre-load stage

The pre-load stage was completed before the introduction of additional cognitive load through the cognitive task. It had 2 conditions: single task and dual task, completed in that order. During the single task condition, the periodic tasks were performed separately. During the dual task condition, they were performed simultaneously.

Load stage

The load stage was completed along with the additional cognitive load induced through the cognitive task. It had 2 conditions: expecting-load and enduring-load, completed in that order. The conditions ran continuously such that, each trial of the expecting-load condition was followed by the enduring-load condition without any break in between the conditions. Accordingly, during the expecting-load condition, the periodic tasks were performed simultaneously while participants were aware the concurrent cognitive task would begin shortly, at the onset of the enduring-load condition. The expecting-load condition was followed, without any break, by the enduring-load condition, during which the periodic tasks were performed simultaneously along with the cognitive task.

Post-load stage

The post-load stage was completed after cessation of the cognitive load task. It had single task and dual task conditions like the pre-load stage, but the conditions were completed in the reverse order: dual task followed by single task. Thus, the two conditions, single task and dual task, were counterbalanced across the two stages, pre-load and post-load. Also, in the single task condition, the periodic tasks were completed in the reverse order to counterbalance them across the pre-load and post-load stages.

Why the expecting-load condition?

Research suggests that the anticipation of dealing with the imminent demands of cognitive functioning causes performance degradation in working memory tasks (Hyun et al., 2019). Therefore, in the current study, we assessed whether performance deteriorated in the periodic tasks because of the anticipation of performing the cognitive tasks concurrently with the periodic tasks; given that research suggests, as discussed in sections 1.6.1 and 1.6.2, that periodic tasks and cognitive tasks could share resources. We treated the anticipation of the cognitive task as another kind of possible cognitive load, different from the enduring-load condition, and also different from the dual task conditions of the pre-load and post-load stages, where the periodic tasks were performed simultaneously without the cognitive task. Accordingly, we analyzed the first half of each trial in the load stage as the expecting-load condition, during which the periodic tasks were performed simultaneously without the cognitive task, but with the expectation to perform it during the second half of the trial.

Why the post-load stage?

We expected the synchronicity between the periodic tasks to increase across the conditions of the pre-load and load stages: We expected it to increase during dual task compared to single task, followed by a further increase during expecting-load, reaching its maximum during the enduring-load condition. We then decided to test for any immediate effects of the removal of cognitive load, and therefore employed the post-load stage right after the load stage, where, in the post-load stage, the periodic tasks were performed simultaneously (dual task) and separately (single task) without the cognitive task. We employed the post-load stage to also test for any possible effects of the order of completion of conditions and tasks during the pre-load stage: We did this by counterbalancing, respectively, the order of the conditions (single task / dual task), and the order of the periodic tasks during the single task condition, across the pre-load and post-load stages.

2.3 Materials

For Experiment 1, walking data was captured using the Zeno Walkway gait mat and ProtoKinetics Movement Analysis Software (PKMAS); tapping was audio recorded in version 3.3.3 of Audacity®, a free software distributed under the terms of the GNU General Public License (https://audacityteam.org). For Experiment 2, a custom MATLAB application was created; the application was used to present the visual pattern-matching task and record audio of tapping and ticking. For all audio recordings, Fifine Technology Bluetooth receivers and wireless microphones, Focusrite Scarlett 2i2 audio interface, and Windows laptop were used. A short musicianship survey on Qualtrics was created and used to gather musicianship data. Sound intensity data were extracted from audio recordings using version 6.2.14 of

Praat, a speech analysis software in phonetics (Boersma & Weenink, 1992–2022). Data were sorted in Microsoft Excel (2016). Metrics were calculated using code written for the study in MATLAB (R2022a). Data analyses were done in Jamovi (2.3.21). Graphing was done in Jamovi and Excel.

2.4 Procedure

The participants were seated at a table on which the laptop running Audacity was placed. The Bluetooth receivers were plugged into the Focusrite audio interface, one on each channel. There were two wireless microphones; one of them was used as a hand mic for tapping (Experiments 1 and 2), and the other one was used on the stand for ticking (Experiment 2). The hand mic was paired to the receiver on line 1 of the audio interface, and the stand mic was paired to the receiver on line 2; this was to make sure the signal from the hand mic was always recorded onto the left stereo channel, and that from the stand mic was always recorded onto the right. Participants were instructed to perform the tapping tasks by tapping repetitively on the hand mic with the index finger of the dominant hand, if they had one, while holding the hand mic with the non-dominant hand. For participants without a dominant hand, the plan was to instruct the participants to perform the tapping tasks by tapping on the hand mic with whichever hand they preferred, while holding the hand mic with the other hand. However, all the participants, self-reportedly, had a dominant hand. Audio input levels were checked and optimized for each participant before the start of the trials, so that the signals were neither too low nor high. Signed informed consent was obtained from each participant upon arrival.

2.4.1 **Experiment 1 –** Walking vs. Tapping

Synchronization-tap exercise for dual task trials: At the start of each trial involving the simultaneous performance of the periodic tasks, the hand mic was tapped gently on the gait mat by the experimenter to create two events of reference at the same timepoint, one on the gait mat recording of the walking task, and the other on the audio recording of the tapping, to create a synchronization trigger between the audio and gait data.

To begin with, participants practiced counting backwards. Then, they completed the tasks in the following order.

Pre-load stage

Single task condition

Tapping task: The participants held the hand mic with the non-dominant hand and tapped on the mic with a single finger of the dominant hand. They tapped at whatever rate felt natural. For each trial, they started and stopped tapping on cue from the experimenter. They completed 2 trials, lasting 20 seconds each, with a 20 second break between trials.

Walking task: The participants walked 4 laps during each trial, where each lap was the length of a 16-foot Zeno pressure-sensor gait mat. They started 1.78 meters off the mat, walked across it, and maintained their stride as they walked off the mat a further 1.78 meters on the other side of the mat before making a wide U-turn to walk back onto the mat for the next lap. They completed 2 trials with a 20 second break between trials.

Dual task condition

The participants started and stopped the tapping and walking tasks simultaneously, both at natural rates. They completed 2 trials of 4 laps each, with a 20 second break between trials.

Load stage

Cognitive load task

For each trial, the participants counted backwards from a given 3-digit number between 600 and 999, using a given negative counter that was either 3 or 7, representing cognitive load levels 1 and 2 respectively. The 3-digit number – negative counter combination was unique for each trial.

Trials

Each trial, lasting 6 laps, ran across the two conditions, expecting-load and enduring-load, without a break between conditions. That meant, during the first half (laps 1 to 3), the participants followed the expecting-load condition, and during the second half (laps 4 to 6), they followed the enduring-load condition. During the expecting-load condition, they tapped and walked simultaneously, both at natural rates, while waiting to begin counting backwards from lap 4, which was the start of the enduring-load condition; during the enduring-load condition, they continued tapping and walking simultaneously, both at natural rates, while counting backwards from the 3-digit number using the negative counter, both given at the start of the trial. They completed 4 trials, 2 at cognitive load level 1 followed by 2 at level 2.

Why 3 laps per trial instead of 4 in the load stage?

During piloting, some participants indicated it was taxing to keep track of which lap they were in during the expecting-load condition, which they needed to do to know when to begin counting backwards for the enduring-load condition. To avoid such taxation, if needed, the experimenter visually cued the participants to count backwards as they were about to start the enduring-load condition. Such cueing was more seamless at the start of the even-numbered laps, when the participants faced the experimenter, than the odd-numbered ones, when they faced away. This made lap 4 more preferable, instead of lap 5, to begin counting backwards; such a preference was therefore accommodated in the trials. During piloting, 6 laps versus 8 laps did not make practical differences to data analyses.

Post-load stage

The dual task condition was performed first, followed by the single task condition, with no cognitive load. In the single task condition, the walking task was performed first, followed by the tapping task.

2.4.2 Experiment 2 – Tapping vs. Ticking

The participants received the trial instructions and completed their task performance through the MATLAB application. Performance on the periodic tasks was recorded as audio, and the visual pattern-matching task was recorded as 1's & 0's, indicating right and wrong answers respectively. Before the trials, the participants were briefed about the visual pattern-matching task, after which they practiced the task through the 'demo' version on the application. The participants then completed the tasks in the following order.

Pre-load stage

Single task condition

Tapping task: The participants held the hand mic with the non-dominant hand and tapped on the mic with a single finger of the dominant hand, at whatever rate felt natural. For each trial, they started and stopped tapping on cue from the application. They completed 2 trials, lasting 15 seconds each, with a 15-second break between trials.

Ticking task: The participants repeated the word “tick” into the stand mic at whatever rate felt natural. For each trial, they started and stopped ticking on cue from the application. They completed 2 trials, lasting 15 seconds each, with a 15-second break between trials.

Dual task condition

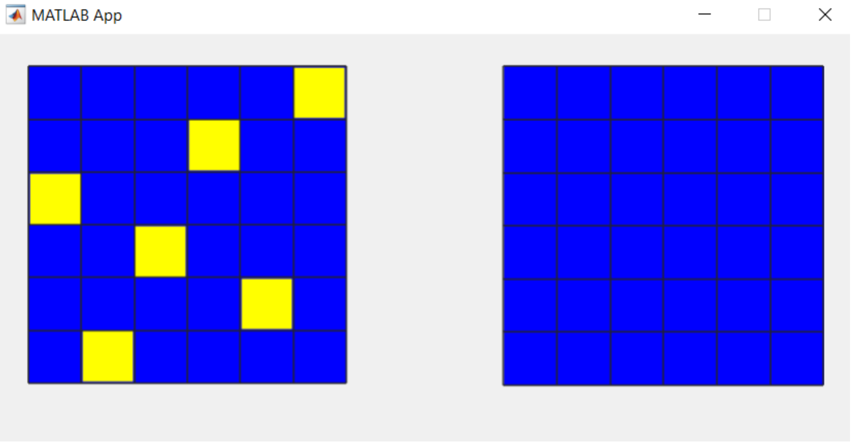
The participants started and stopped the tapping and ticking tasks simultaneously, both at natural rates. They completed 2 trials of 15 seconds each, with a 15-second break.

Load stage

Cognitive load task

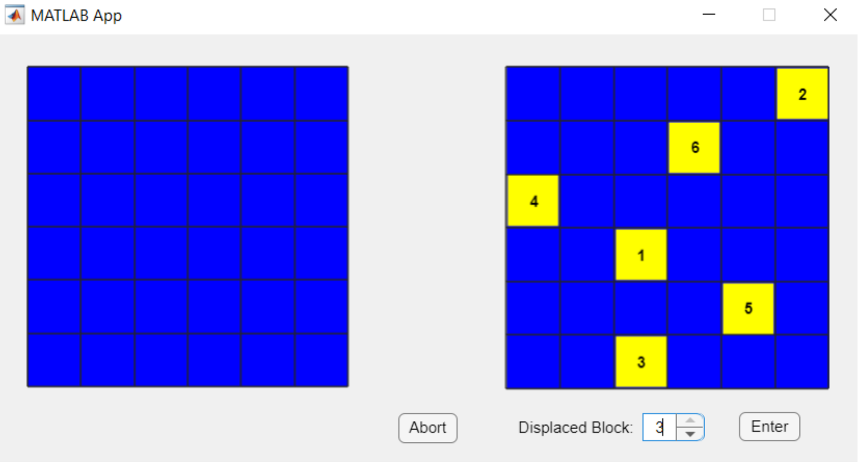
The task would begin with encoding a pattern, comprised of yellow blocks, appearing for 6.5 seconds on a blue 6x6 matrix on the left side of the application on the computer screen (as shown in Figure 3).

Figure 3: Pattern Encoding – Visual pattern-matching task



The pattern would then disappear to prompt retention for the next 3.5 seconds; it would then prompt recognition and matching by reappearing on a similar matrix on the right side, but with the yellow blocks numbered, and one of them possibly displaced (as shown in Figure 4).

Figure 4: Pattern Recognition & Matching – Visual pattern-matching task



The pattern would stay on the screen until the participants identified the displaced block, and entered the number on it as the answer, or entered '0' if none was displaced. Based on piloting, recognition was expected to take ~5 seconds on average per pattern. Total task time was therefore estimated to be ~15 seconds. The cognitive load level of the task, from 1 to 6, was based on the number of blocks in the pattern, from 4 to 9 respectively.

Trials

Each trial, lasting ~30 seconds, ran across the two conditions, expecting-load and enduring-load, without a break between conditions. That meant, during the first 15 seconds, the participants followed the expecting-load condition, and for the rest of the trial, they followed the enduring-load condition. During the expecting-load condition, the participants tapped and ticked simultaneously, both at natural rates, while waiting for a pattern to appear on the matrix on the left side of the computer screen. The appearance of the pattern marked the end of the expecting-load condition, and the start of the enduring-load condition. During the enduring-load condition, they continued tapping and ticking simultaneously, both at natural rates, while encoding the pattern for 6.5 seconds, retaining the pattern in memory for the next 3.5 seconds, followed by matching it for differences against the pattern that appeared on the matrix on the right side of the computer screen; matching lasted for ~5 seconds on average per pattern. They completed 12 trials, 2 at each cognitive load level, from 1 to 6.

Post-load stage

The dual task condition (tapping and ticking) was performed first, followed by the single task condition. In the single task condition, the ticking task was performed first, followed by the tapping task.

2.4.3 Data extraction

Experiment 1

Walking: For each participant, timings of individual footsteps for each trial were extracted with PKMAS movement analysis software, using the 'first contact' time for each footstep in the recorded gait mat data, and exported to Excel.

Tapping: For each participant, the recorded stereo track of the testing session was split into left and right mono tracks. The left mono track with the tapping audio was exported as a wave file, which was then imported into Praat. In Praat, sound intensity data for the session was extracted from the intensity listings; for each trial, start and end times, as well as the number of repetitions, were extracted from the intensity waveform. The extracted data were imported into Excel, sorted, and imported into the MATLAB program that extracted the timing of each sound intensity peak for each tap on each trial.

Experiment 2

Tapping and Ticking: For each participant, the stereo wave file output from the MATLAB application was imported into Audacity, and split into left (tapping) and right (ticking) mono tracks. The tracks were exported as wave files, imported into Praat, and sound intensity data for the session was extracted. For each trial, start and end times, as well as the number of repetitions, were extracted from the intensity waveform. The extracted data were imported into Excel, sorted, and imported into the MATLAB program that extracted the timing of each sound intensity peak for each tap and each tick on each trial.

Normalization

In Experiment 1, for each dual-task trial, the extracted timings of individual tap and step times of the periodic tasks were normalized to the time of the synchronization gait/audio trigger described in section 2.4.2. All tap and step times were set relative to the trigger time (which was set to time = 0).

Similarly, in both experiments, for each single-task trial, the extracted timings of individual events (taps, steps, or ticks), hereon referred to as periodic task timings (t), were normalized to the time of the first event (set to time = 0).

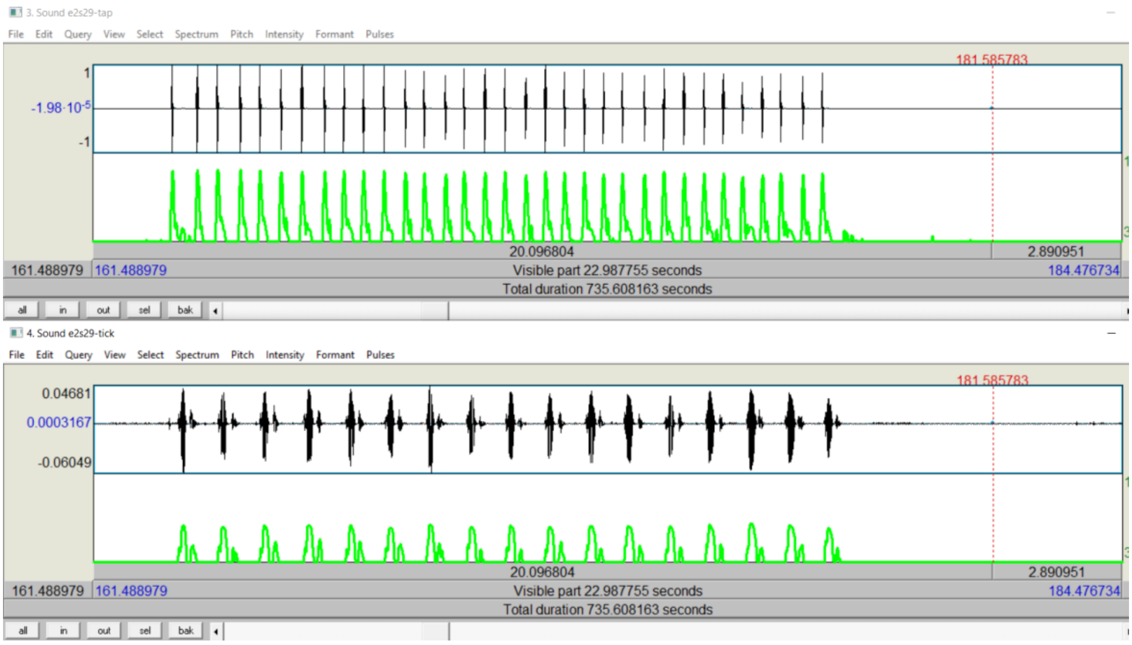
2.4.4 Phase coherence

Phase coherence was the metric of interest for the study. For each trial, for each task, based on periodic task timings (t) in seconds, momentary rates (f) in cycles per second were calculated: $f_n = 1/(t_n - t_{n-1})$, where t_n is the timing of an individual repetition, t_{n-1} is the timing of the previous repetition, and f_n is the momentary rate at t_n. An array of momentary rates (F_j) was thus calculated for each periodic task. Also, every repetition of one periodic task was paired exclusively with a repetition from the other task, such that each one in a pair was temporally the most proximal counterpart to the other.

For example, in a 15-second dual task trial of tapping and ticking by a subject in the study (as shown in Figure 5), the subject produced the taps and the 'tick's in approximately a 2:1 ratio. There were 17 ticks against 33 taps in the trial. Each of the ticks, from 1 to 17 in ascending order, was paired exclusively with the corresponding tap from the array comprised of the 17 odd-numbered taps, from 1 to 33 in ascending order. For each trial, after such pairings, a two-way difference in timing between the counterparts in each pair was calculated, yielding two time-difference arrays, one for each periodic task (td_j); the corresponding elements of the two arrays were identical in magnitude but opposite in sign. Arrays of relative phase angles, one for each periodic task, were then calculated:

$$\theta_j = td_j * F_j * 2\Pi$$

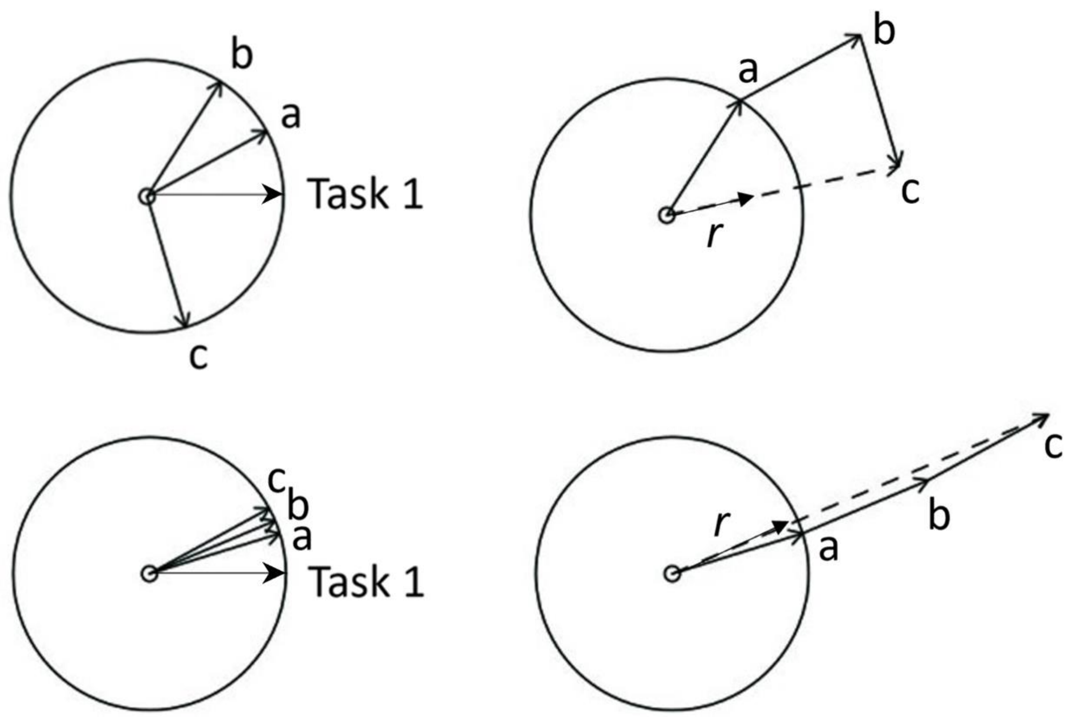
Figure 5: Sound intensity representations of a dual-task trial (tapping vs. ticking) – *(screenshot of Praat console)*



Synchronization model

For each trial, phase coherence was calculated for each periodic task from its relative phase angles (θ_j) by applying the global order parameter of the Kuramoto model (Acebrón, 2005; Kuramoto, 1975). As illustrated in Figure 6, here, each periodic task is a phase vector, and each individual repetition of a periodic task is a cycle. Imagine a case of tapping-ticking dual task, where tapping is task 1, and ticking is task 2. The instant a tap occurs, the current repetition ends and the next one begins; that means, the current cycle ends and the next one begins. Therefore, at that instant, the phase vector representing the tapping task, or say, the task 1 vector, is at 0° to the X-axis; also, at that instant, the phase vector representing the ticking task, or say, the task 2 vector, would make a relative phase angle with the task 1 vector, based on where task 2 is in its current repetition cycle. As task 1 is the reference in this illustration, the task 1 vector is fixed at 0°; a, b, c are relative phase angles made by the task 2 vector relative to the task 1 vector, such that, θ_j = [a, b, c].

<u>Figure 6</u>: Relative Phase Angle Clustering vs. Phase Coherence



Higher the relative phase angle clustering → Greater the average vector length (r)

→ Higher the phase coherence

→ Higher the synchrony

Applying the global order parameter of the Kuramoto model to θ_j,

$$re^{i\psi} = \frac{1}{N}\sum_{j=1}^{N} e^{i\theta_j}$$

(r = length of the average vector; ψ = phase angle of the average vector)

Here, 'r' represents phase coherence ($0 \leq r \leq 1$ for an array of unit vectors), indicating the degree to which the relative phase angles (θ_j) are clustered. Therefore, as clustering increases, the length of the average vector increases, indicating an increase in phase coherence, and thereby, an increase in synchrony.

<u>Application to the current study</u>

In the current study, as discussed earlier, the relative phase angles for each periodic task in a trial were calculated as, $\theta_j = td_j * F_j * 2\Pi$. Applying the model, 'r' can be derived as $| re^{i\psi} |$.

$$r = \left| \frac{1}{N}\sum_{j=1}^{N} e^{i\theta_j} \right|$$

Each trial thus produced two arrays of momentary rates (F_j), one for each periodic task, resulting in two arrays of relative phase angles (θ_j), and consequently, two phase coherence (r) values for each periodic task, relative to the other.

2.4.5 Statistical analyses

Hypothesis 1

For both experiments, phase coherence (r) of each periodic task, relative to the other, was analyzed with a 2x2 repeated measures ANOVA: (*task:* single task, dual task) x (*stage:* pre-load, post-load).

Hypothesis 2

For Experiment 1, phase coherence (r) of each periodic task, relative to the other, was analyzed with, (1) a 2x2 repeated measures ANOVA: (*load condition:* expecting-load, enduring-load) x (*load level:* 1, 2), and (2) a single factor repeated measures ANOVA: (*load condition:* dual task pre-load, dual task post-load, expecting-load (levels 1 & 2)).

For Experiment 2, phase coherence (r) of each periodic task, relative to the other, was analyzed with, (1) a 2x6 repeated measures ANOVA: (*load condition:* expecting-load, enduring-load) x (*load level:* 1 to 6), and (2) a single factor repeated measures ANOVA: (*load condition:* pre-load, post-load, expecting-load (levels 1 to 6 separately)).

Post hoc tests using Bonferroni correction, as well as no correction, were conducted as required. All hypothesis tests used $\alpha = .05$ for significance.

Based on the data from the musicianship survey, the 24 participants were split into two groups: 4 musicians (those with 5 or more years of formal music training), and 20 non-musicians (those with fewer than 5 years of formal music training). Due to the uneven numbers between groups, musicianship was not included as a factor in the analyses.

Chapter 3

3 Results

3.1 Experiment 1 – Tapping vs. Walking

3.1.1 Descriptive statistics

Figure 7 below shows phase coherence of each periodic task (Tapping / Walking) relative to the other, across conditions across subjects.

Figure 7: Phase Coherence across subjects – Tapping vs. Walking

(error bars indicate Standard Error)

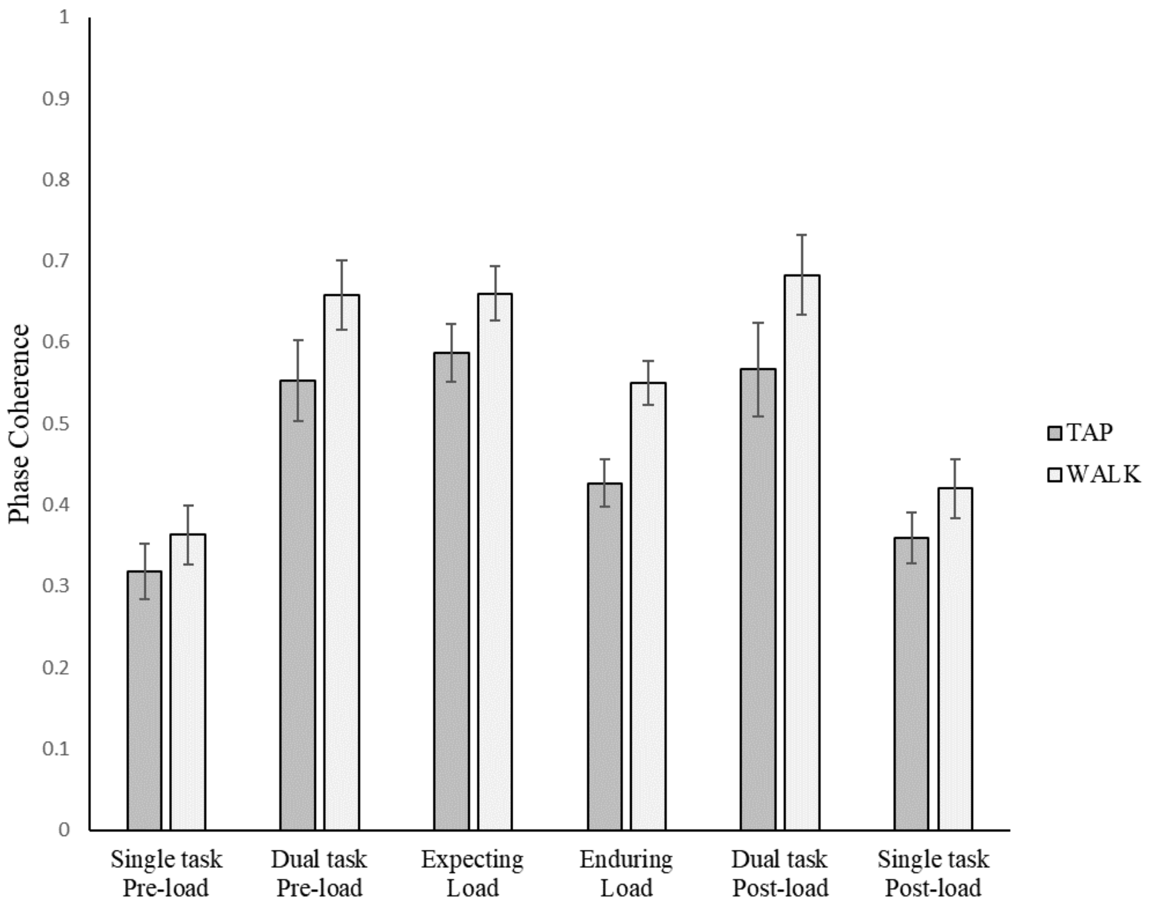


Figure 8 below shows standard deviation of relative phase angles (in degrees) of each periodic task (Tapping / Walking) relative to the other, across conditions across subjects.

<u>Figure 8</u>: Standard Deviation of Relative Phase Angles across subjects – Tapping vs. Walking *(error bars indicate Standard Error)*

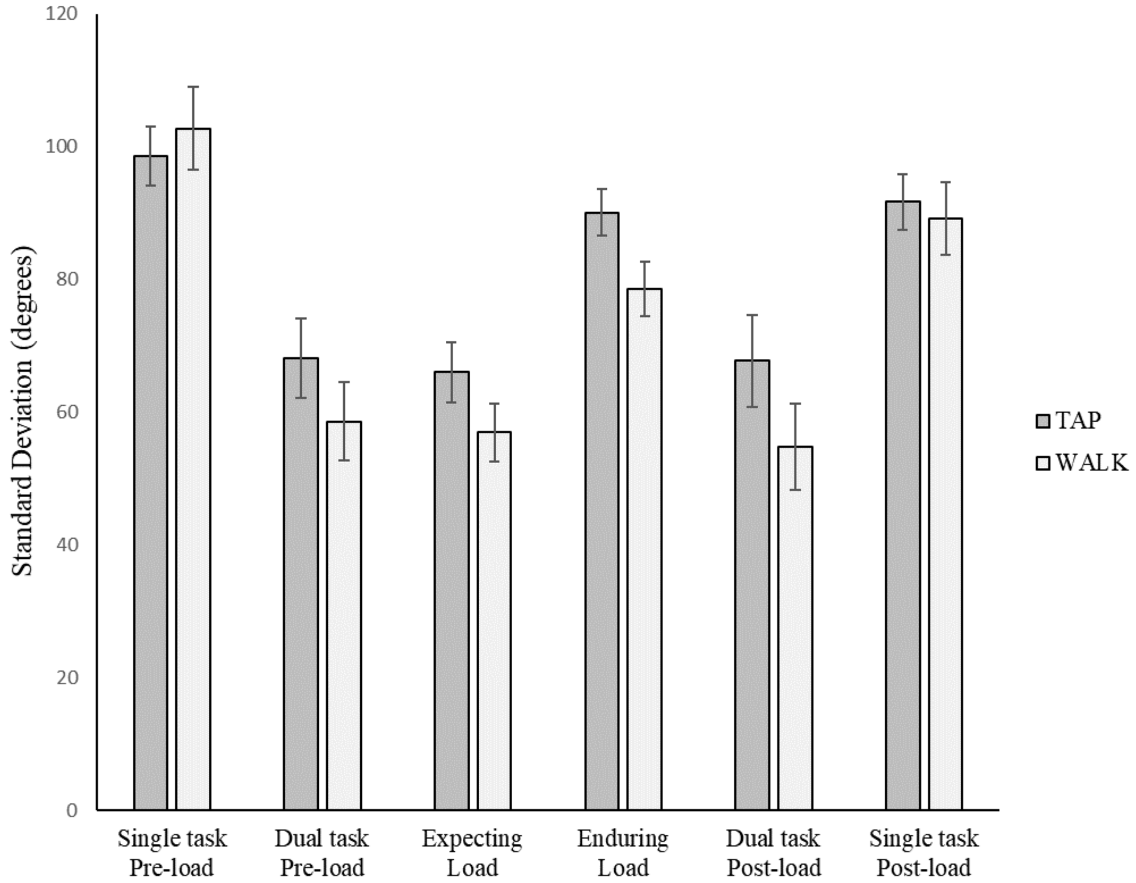
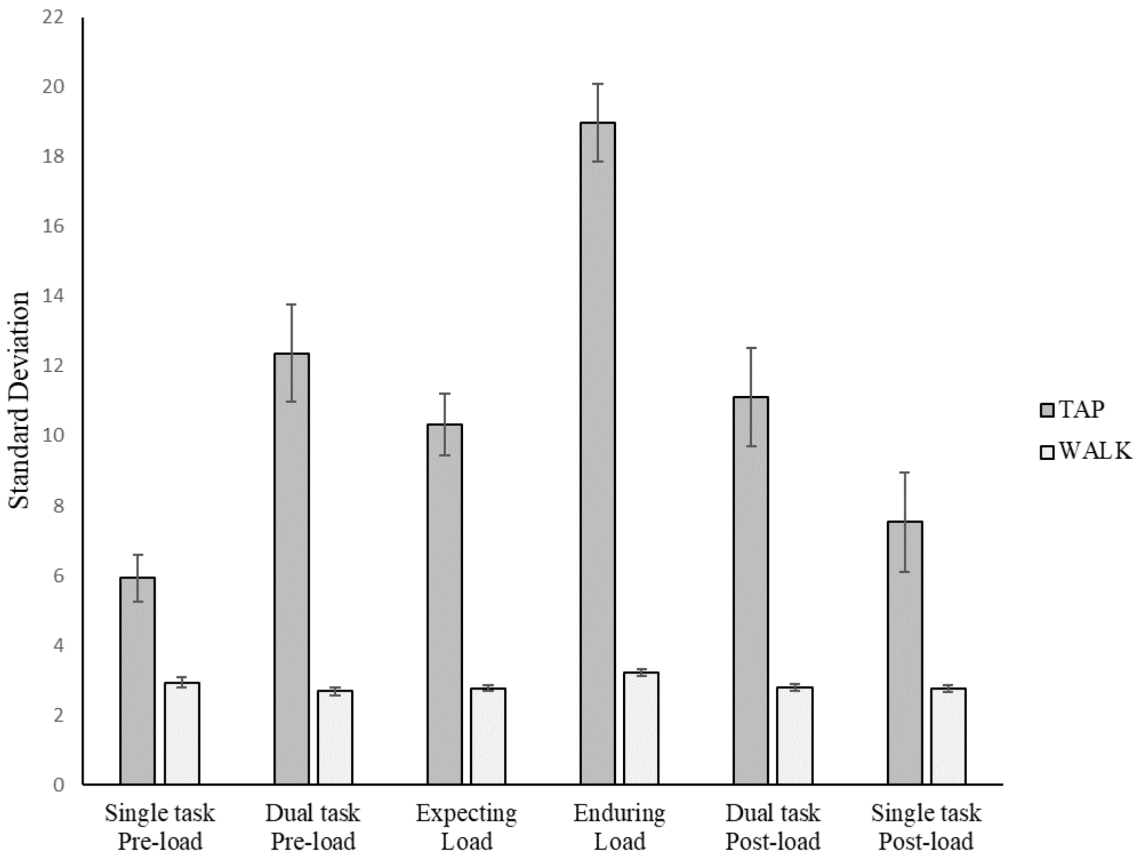


Figure 9 below shows standard deviation of mean rate (per minute) of each periodic task (Tapping / Walking), across conditions across subjects.

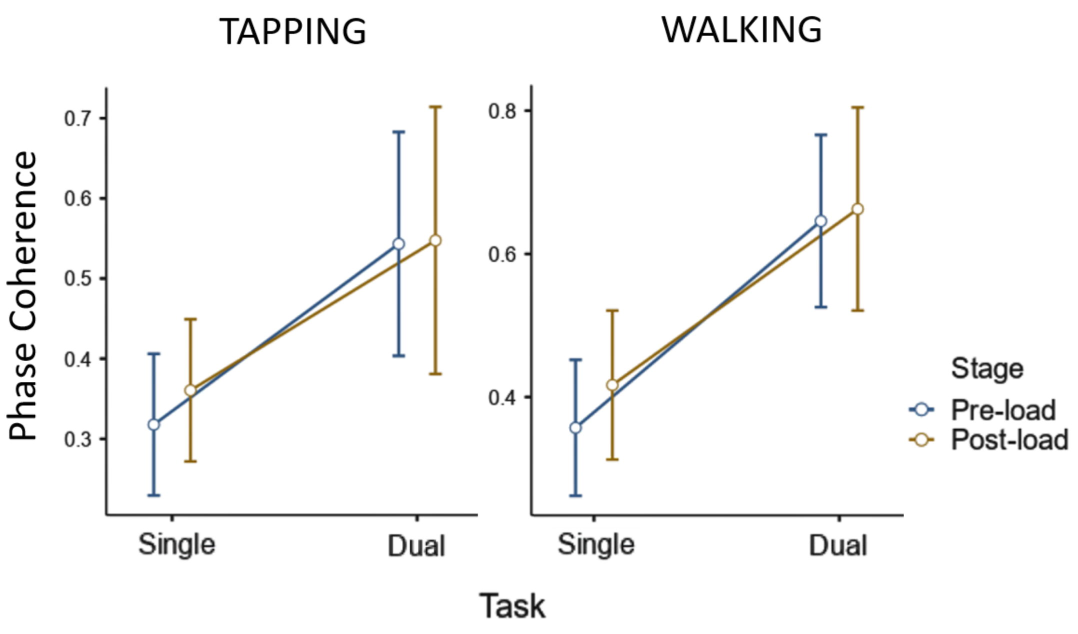
Figure 9: Standard Deviation of Mean Rate across subjects – Tapping vs. Walking *(error bars indicate Standard Error)*



3.1.2 Hypothesis 1

As shown in Figure 10, phase coherence was significantly higher during dual task than during single task, $F(1, 23) = 11.33$, $p = .003$, $\eta^2_p = .33$ for tapping, and $F(1, 23) = 19.69$, $p < .001$, $\eta^2_p = .46$ for walking. Phase coherence was not significantly different across pre-load and post-load stages, $F(1, 23) = 0.71$, $p = .407$, $\eta^2_p = .03$ for tapping, and $F(1, 23) = 1.51$, $p = .231$, $\eta^2_p = .06$ for walking. No significant effect was found for interaction between task and stage, $F(1, 23) = 0.25$, $p = .624$, $\eta^2_p = .01$ for tapping, and $F(1, 23) = 0.31$, $p = .586$, $\eta^2_p = .01$ for walking.

Figure 10: Exp 1: (Single task / Dual task) * (Pre-load stage / Post-load stage) – *Estimated Marginal Means*

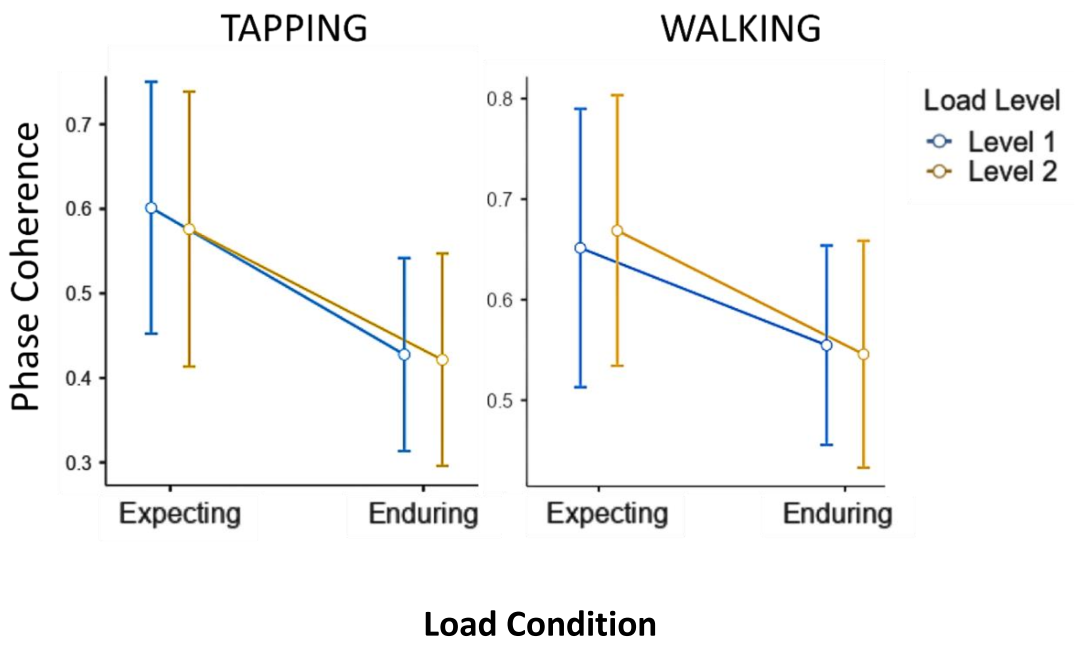


3.1.3 Hypothesis 2

As shown in Figure 11, phase coherence was significantly lower while enduring load than while expecting load, $F(1, 23) = 18.58$, $p < .001$, $\eta^2_p = .45$ for tapping, and $F(1, 23) = 9.40$, $p = .005$, $\eta^2_p = .29$ for walking. Phase coherence was not significantly different across load levels 1 and 2, $F(1, 23) = 0.41$, $p = .53$, $\eta^2_p = .02$ for tapping, and $F(1, 23) = 0.06$, $p = .805$, $\eta^2_p < .01$ for walking. No significant effect was found for interaction between load condition and load level, $F(1, 23) = 0.56$, $p = .463$, $\eta^2_p = .02$ for tapping, and $F(1, 23) = 1.23$, $p = .279$, $\eta^2_p = .05$ for walking.

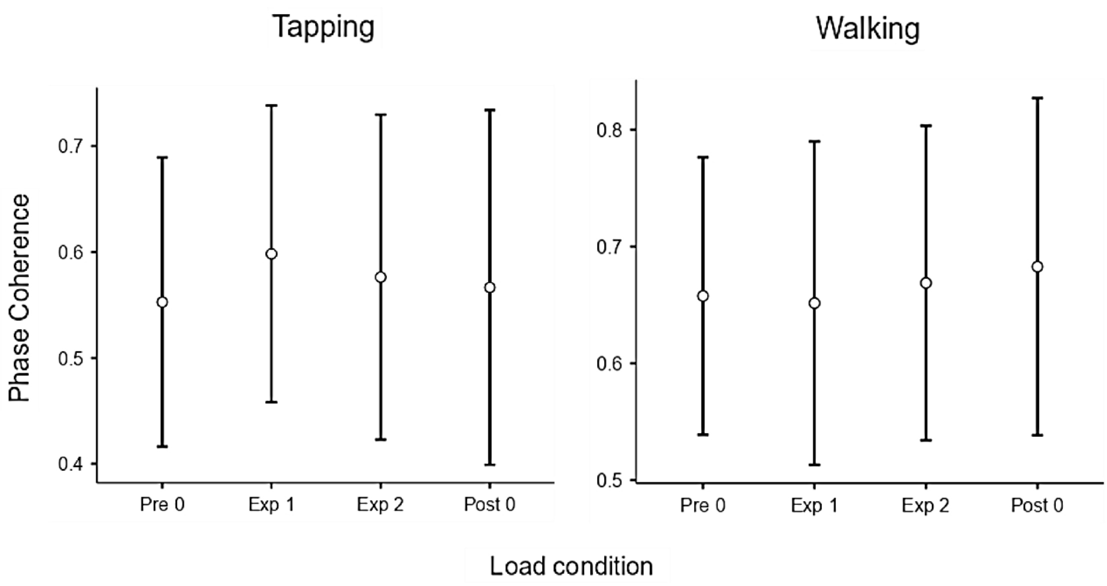
<u>Figure 11</u>: Exp 1: (Expecting load / Enduring load) * (Load level 1 / 2)

Estimated Marginal Means



As shown in Figure 12, phase coherence was not significantly different between pre-load dual task, post-load dual task and expecting-load (level 1 & 2) conditions, $F(3, 69) = 1.05$, $p = .377$, $\eta^2_p = .04$ for tapping, and $F(3, 69) = 0.71$, $p = .55$, $\eta^2_p = .03$ for walking.

<u>Figure 12</u>: Exp 1: Pre-load dual / Post-load dual / Expecting-load (level 1 & 2) – *Estimated Marginal Means*



Pre 0: Pre-load (not expecting load); Exp (1, 2): Expecting-load (levels 1, 2); Post 0: Post-load (not expecting load);

3.2 Experiment 2 – Tapping vs. Ticking

3.2.1 Descriptive statistics

Figure 13 below shows phase coherence of each periodic task (Tapping / Ticking) relative to the other, across conditions across subjects

<u>Figure 13</u>: Phase Coherence across subjects – Tapping vs. Ticking

(error bars indicate Standard Error)

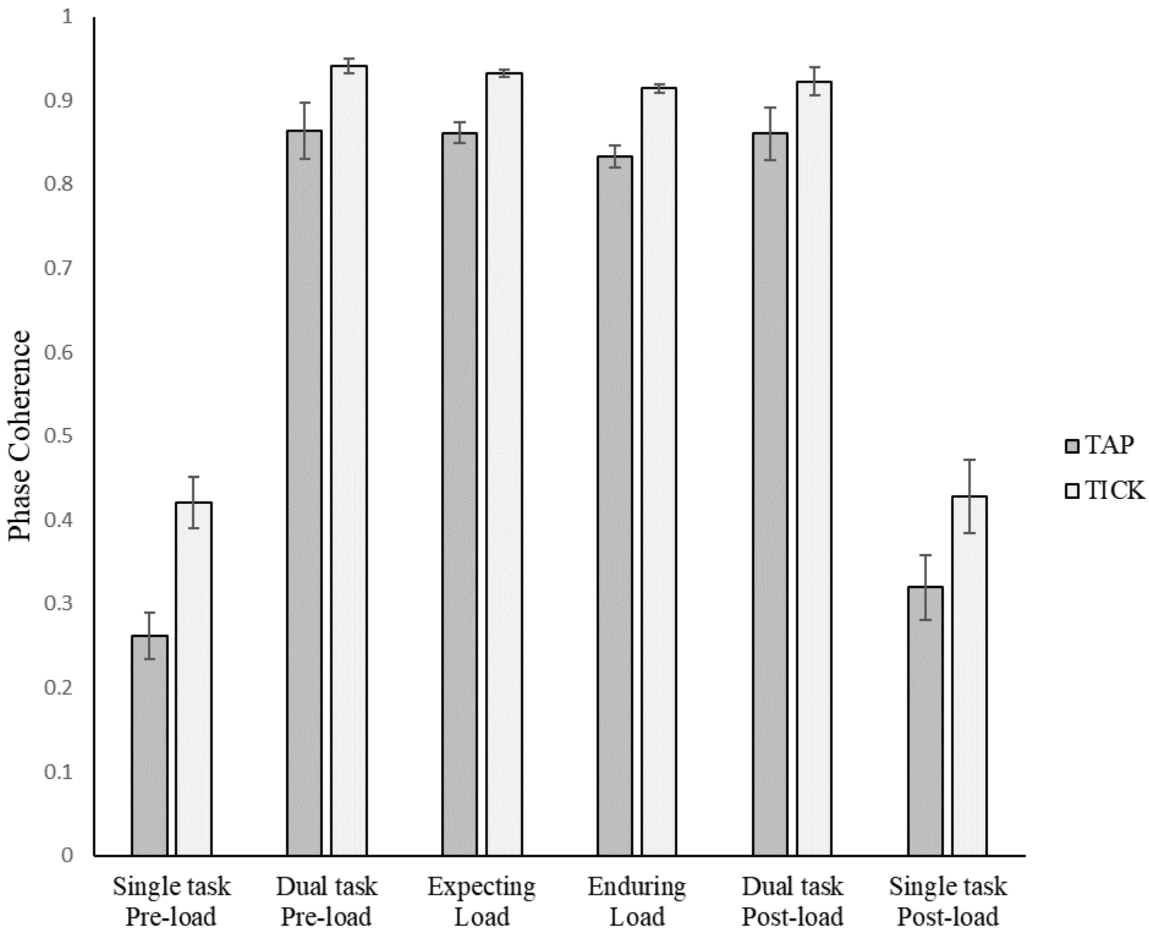


Figure 14 below shows standard deviation of relative phase angles (in degrees) of each periodic task (Tapping / Ticking) relative to the other, across conditions across subjects.

<u>Figure 14</u>: Standard Deviation of Relative Phase Angles across subjects – Tapping vs. Ticking *(error bars indicate Standard Error)*

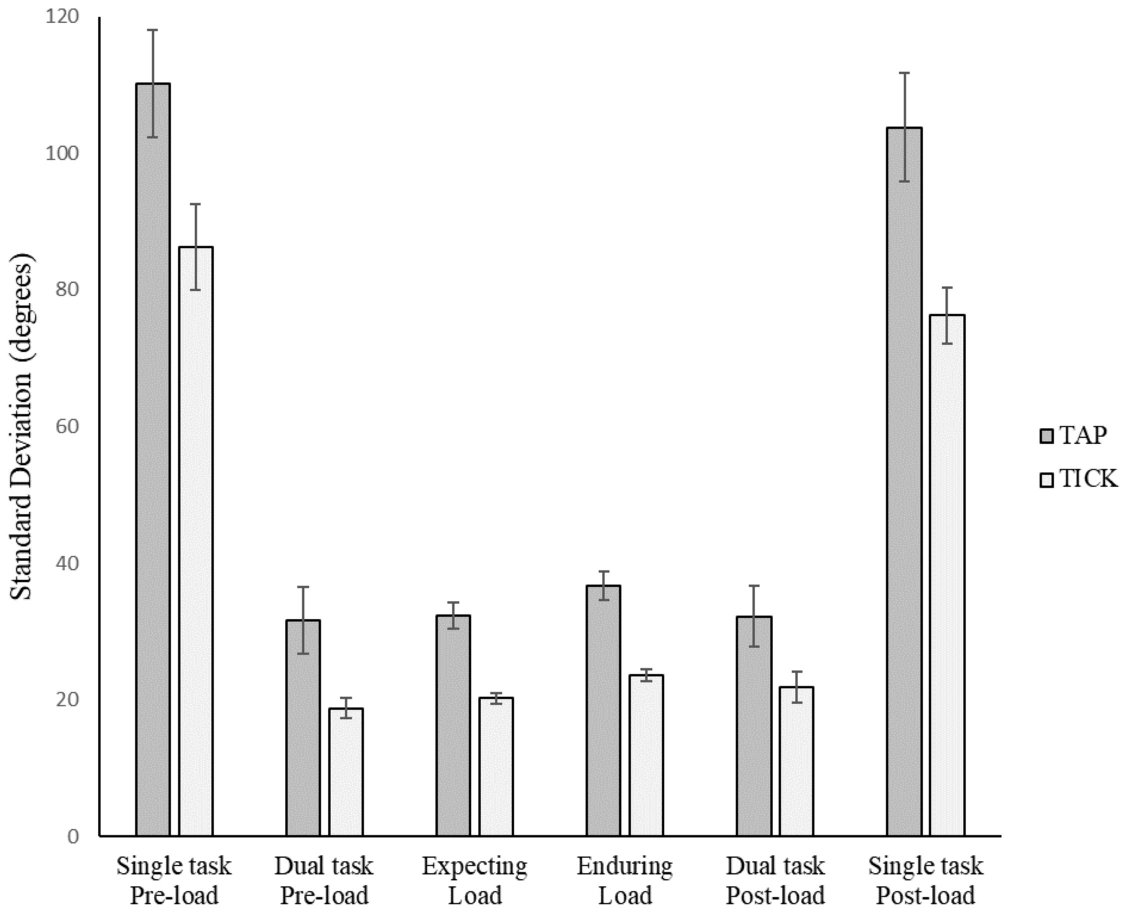
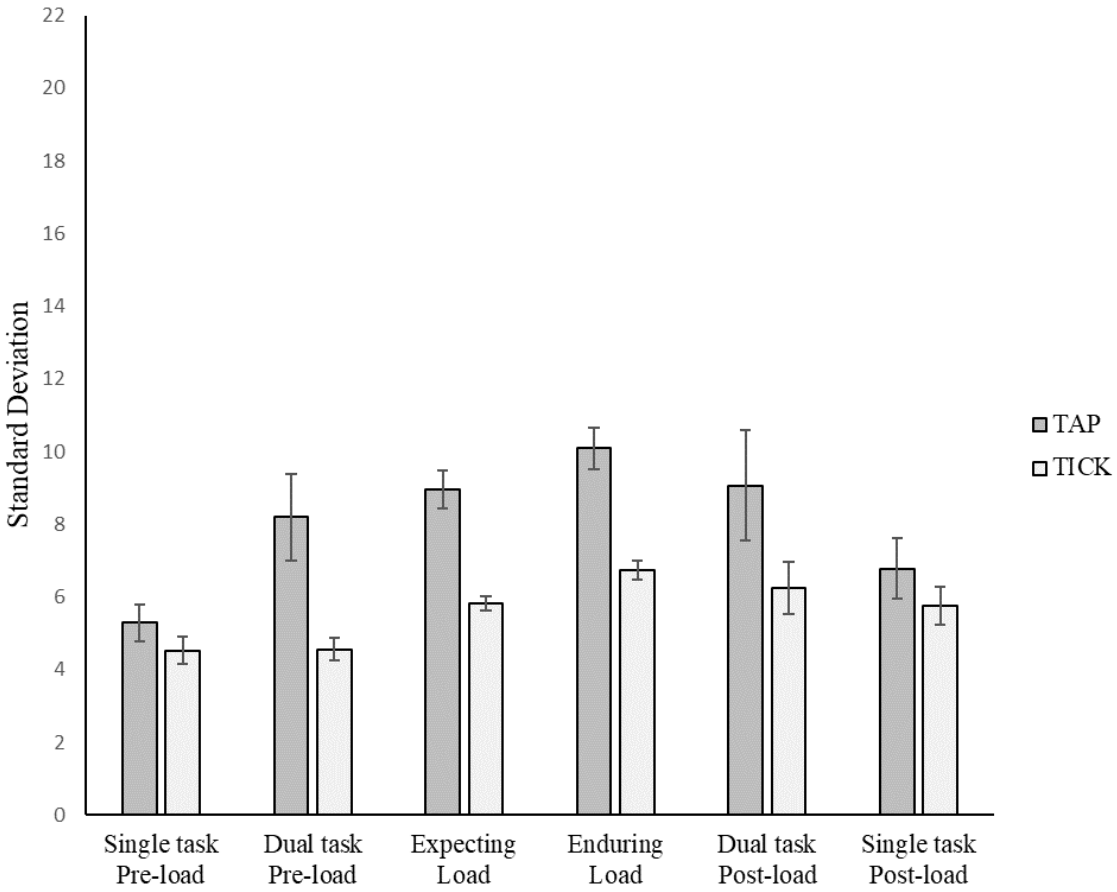


Figure 15 below shows standard deviation of mean rate (per minute) of each periodic task (Tapping / Ticking), across conditions across subjects.

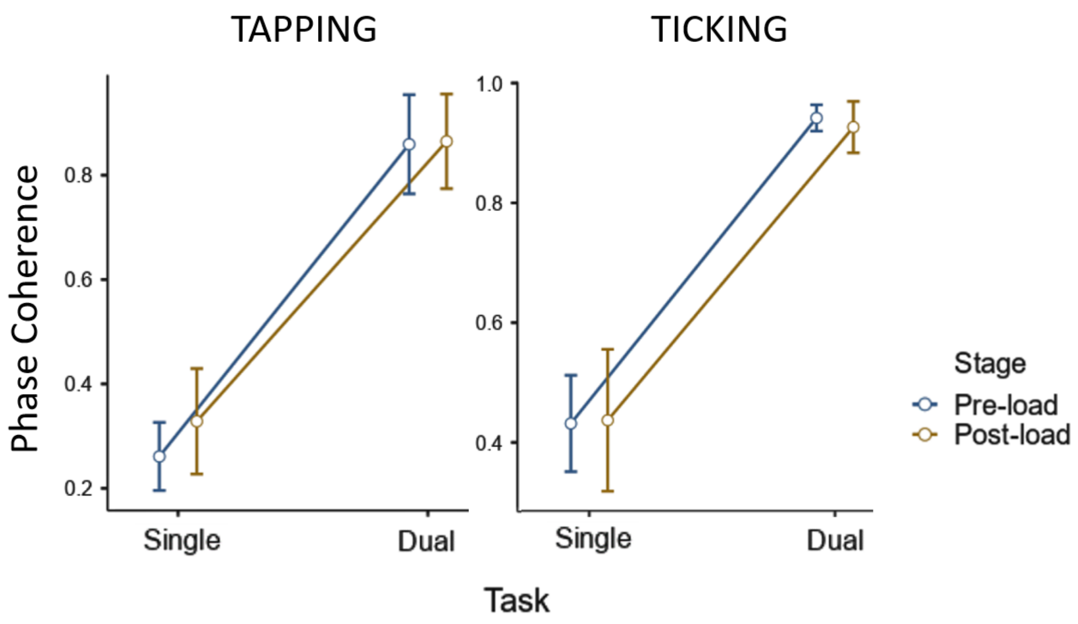
<u>Figure 15</u>: Standard Deviation of Mean Rate across subjects – Tapping vs. Ticking *(error bars indicate Standard Error)*



3.2.2 Hypothesis 1

As shown in Figure 16, phase coherence was significantly higher during dual task than during single task, $F(1, 23) = 129.13$, $p < .001$, $\eta^2_p = .85$ for tapping, and $F(1, 23) = 104.36$, $p < .001$, $\eta^2_p = .82$ for ticking. Phase coherence was not significantly different across pre-load and post-load stages, $F(1, 23) = 0.90$, $p = .352$, $\eta^2_p = .04$ for tapping, and $F(1, 23) = 0.05$, $p = .829$, $\eta^2_p = .002$ for ticking. No significant effect was found for interaction between task and stage, $F(1, 23) = 1.78$, $p = .195$, $\eta^2_p = .07$ for tapping, and $F(1, 23) = 0.25$, $p = .618$, $\eta^2_p = .01$ for ticking.

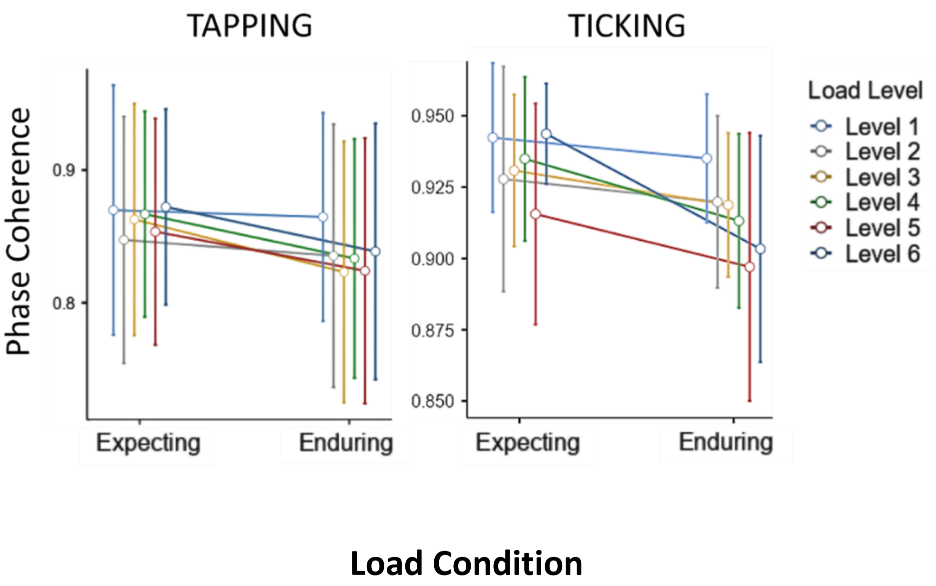
Figure 16: Exp 2: (Single task / Dual task) * (Pre-load stage / Post-load stage) – *Estimated Marginal Means*



3.2.3 Hypothesis 2

As shown in Figure 17, phase coherence was significantly lower while enduring load than while expecting load, $F(1, 23) = 7.97$, $p = .01$, $\eta^2_p = .257$ for tapping, and $F(1, 23) = 4.82$, $p = .04$, $\eta^2_p = .173$ for ticking. Across load levels 1 to 6, phase coherence was not significantly different for tapping, $F(5, 115) = 1.23$, $p = .298$, $\eta^2_p = .05$, but it was significantly different for ticking, $F(5, 115) = 2.69$, $p = .024$, $\eta^2_p = .11$. As shown in Table 1, post hoc tests with Bonferroni correction revealed that phase coherence of ticking was significantly lower for load level 3 compared to level 1, $t(23) = 4.45$, $p = .003$; with no correction, post hoc *t*-tests revealed that phase coherence of ticking, in comparison to load level 1, was significantly lower for level 3, $t(23) = 4.45$, $p < .001$, for level 4, $t(23) = 2.19$, $p = .039$, for level 5, $t(23) = 2.50$, $p = .02$, and for level 6, $t(23) = 2.83$, $p = .009$. No significant effect was found for interaction between load condition and load level, $F(5, 115) = 0.95$, $p = .451$, $\eta^2_p = .04$ for tapping, and $F(5, 115) = 1.39$, $p = .233$, $\eta^2_p = .06$ for ticking.

<u>Figure 17</u>: Exp 2: (Expecting load / Enduring load) * (Load level 1 to 6) – *Estimated Marginal Means*

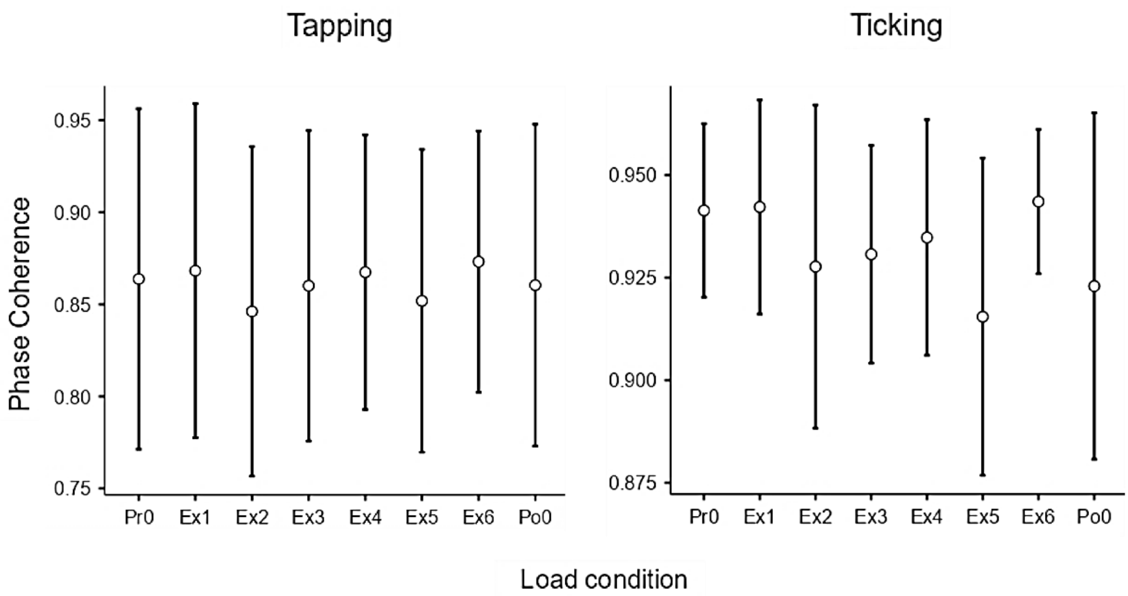


<u>Table 1</u>: Post hoc comparisons across load levels – Tapping vs. Ticking

Comparison								
Load level		**Load level**	**Mean Difference**	**SE**	**df**	**t**	**p**	**$p_{bonferroni}$**
Level 1	-	Level 2	0.01486	0.00786	23.0	1.8906	0.071	1.000
	-	Level 3	0.01391	0.00313	23.0	4.4452	< .001	0.003
	-	Level 4	0.01464	0.00670	23.0	2.1868	0.039	0.588
	-	Level 5	0.03236	0.01294	23.0	2.5007	0.020	0.299
	-	Level 6	0.01519	0.00536	23.0	2.8320	0.009	0.142
Level 2	-	Level 3	-9.48e−4	0.00702	23.0	-0.1350	0.894	1.000
	-	Level 4	-2.14e−4	0.00893	23.0	-0.0240	0.981	1.000
	-	Level 5	0.01750	0.01125	23.0	1.5561	0.133	1.000
	-	Level 6	3.30e-4	0.00906	23.0	0.0364	0.971	1.000
Level 3	-	Level 4	7.34e-4	0.00622	23.0	0.1181	0.907	1.000
	-	Level 5	0.01845	0.01215	23.0	1.5188	0.142	1.000
	-	Level 6	0.00128	0.00543	23.0	0.2353	0.816	1.000
Level 4	-	Level 5	0.01772	0.01125	23.0	1.5750	0.129	1.000
	-	Level 6	5.44e-4	0.00702	23.0	0.0775	0.939	1.000
Level 5	-	Level 6	-0.01717	0.01154	23.0	-1.4885	0.150	1.000

As shown in Figure 18, phase coherence was not significantly different between pre-load dual task, post-load dual task and expecting-load (levels 1 to 6) conditions, $F(7, 161) = 0.38$, $p = .912$, $\eta^2_p = .02$ for tapping, and $F(7, 161) = 1.72$, $p = .108$, $\eta^2_p = .069$ for ticking.

<u>Figure 18</u>: Exp 2: Pre-load dual / Post-load dual / Expecting-load (level 1 to 6) – *Estimated Marginal Means*



Pr0: Pre-load (not expecting load); Ex(1-6): Expecting-load (levels 1-6); Po0: Post-load (not expecting load);

Chapter 4

4 Discussion

4.1 Summary

The aim of the current study was to investigate whether spontaneous intrapersonal synchronization occurred between periodic behaviors within an individual, and also whether such synchronization increased with additional cognitive load. For this, we tested two hypotheses. In Hypothesis 1, we tested whether synchronization between two periodic tasks was greater when performed simultaneously, compared to separately. In Hypothesis 2, we tested whether spontaneous intrapersonal synchronization increased with additional cognitive load, induced through cognitive tasks performed concurrently with the periodic tasks. We conducted two experiments, each involving a different pair of periodic tasks, as well as a different cognitive task. Experiment 1 involved tapping and walking as periodic tasks and counting backwards as the cognitive task. Experiment 2 involved tapping and ticking as periodic tasks and matching visual patterns as the cognitive task. In both experiments, periodic tasks were performed at the participants' natural rates, and cognitive load tasks were performed at multiple levels of difficulty: The participants counted backwards in either 3's or 7's, and matched patterns with 4 to 9 blocks.

4.1.1 Hypothesis 1

In both experiments, results supported Hypothesis 1: spontaneous intrapersonal synchronization between the periodic tasks was significantly higher when the tasks were performed simultaneously than separately. In addition, synchronization of the periodic tasks did not differ before and after the addition of cognitive load. Also, the interaction between how the periodic tasks were performed, separately or simultaneously, and when they were performed, before or after the addition of cognitive load, had no significant effect on the synchronization between them.

4.1.2 Hypothesis 2

In both experiments, results did not support Hypothesis 2: spontaneous intrapersonal synchronization between the periodic tasks decreased, rather than increased, under additional cognitive load. It is important to note that the difference between synchronization during the expecting-load condition, and that during the enduring-load condition, was not as pronounced in Experiment 2, between tapping and ticking, as it was in Experiment 1, between tapping and walking. Therefore, despite its statistical significance, the decrease in synchronization between tapping and ticking while enduring load, compared to while expecting load, did not seem as practically significant as that between tapping and walking. Further, at this point, the lack of literature on spontaneous intrapersonal synchronization prevents any meaningful estimation of the practical significance of the results by comparing them against relevant results from previous studies.

In Experiment 1, the difficulty level of the concurrent cognitive load task had no significant effect on the synchronization between the periodic tasks. In Experiment 2, while there was no significant effect of the difficulty level of the cognitive load task on phase coherence of tapping, phase coherence of ticking was lower for load level 3, compared to level 1; this was revealed by post hoc tests with Bonferroni correction. However, with no correction, post hoc *t*-tests revealed that phase coherence of ticking, compared to load level 1, was lower for four of the five remaining levels, except level 2. In both experiments, results revealed that synchronization between the periodic tasks was not significantly different when they were performed while expecting load, compared to without such expectation. Also, in both experiments, the interaction between whether the additional cognitive load was expected or endured, and the level of difficulty of the concurrent cognitive load task, had no significant effect on synchronization between the periodic tasks.

4.2 Implications

4.2.1 Intrapersonally synchronizing periodicities: Perceived vs. Produced

Higher synchrony between tapping and walking, as well as between tapping and ticking, when the tasks were performed simultaneously, compared to separately, suggests that the exchange of sensory feedback as well as the consequent coupling and integration, could occur within a single system, such as an individual. Therefore, in the current study, the sensory feedback received from two periodicities produced simultaneously may have biased the participants to combine them into one, through spontaneous intrapersonal synchronization. This may be similar to the findings that suggest how musicians, when tracking two different beats simultaneously, combine the beats into a single composite pattern, rather than tracking them independently (Poudrier & Repp, 2013). In that study, the two periodicities were perceived, and in the current study, they were produced. Regardless of that difference, in both cases, the two periodicities were combined into one, supporting the earlier argument that the preference to track one periodicity, rather than multiple, could extend beyond perception into production. Therefore, spontaneous intrapersonal synchronization appears to occur for produced periodicities.

4.2.2 Spontaneous synchronization as one phenomenon

When spontaneous synchronization occurs between a produced and a perceived periodicity, it is reasonable to intuit that synchronization depends on the external periodicity being consciously perceivable, so that the produced periodicity can be temporally aligned with it. Over the years, this intuition has been the basis of the ‘threshold hypothesis’, which assumes the threshold of conscious perception is a limiting factor in sensorimotor synchronization (Michon, 1967; Mates, 1994), where sensorimotor synchronization refers to synchronization between a produced periodicity and a perceived periodicity of an external stimulus that could either be animate, such as an individual, or inanimate, such as a metronome. However, contradicting the ‘threshold hypothesis’, sensorimotor synchronization “seems to be an automatic, subconscious process” that adjusts to timing perturbations well below the threshold of conscious perception (Repp, 2001, p. 601, Thaut et al., 1998a, 1998b). As sensory feedback is necessary for sensorimotor synchronization to occur (Repp, 2002), the exchange of sensory feedback appears to occur subconsciously during sensorimotor synchronization. Spontaneous intrapersonal synchronization therefore also may be automatic and subconscious, or at least partially so, for keeping track of four periodicities simultaneously, two each in terms of production and perception, seems too taxing for conscious control. Therefore, spontaneous intrapersonal synchronization and sensorimotor synchronization could be sharing similar automatic and subconscious mechanisms. Thus interpersonal and intrapersonal synchronization could be different manifestations of the same phenomenon: spontaneous synchronization, with the goal of tracking a single periodicity.

4.2.3 Synchronization as an intrapersonal phenomenon

The perceivable difference between interpersonal and intrapersonal synchronization is, while interpersonal synchronization occurs between individuals, intrapersonal synchronization occurs within individuals. However, according to the Paillard-Fraisse hypothesis, synchronization between periodicities is guided by the superimposition of their temporal representations in the brain, called sensory codes (Aschersleben & Prinz, 1995; Fraisse, 1980). This hypothesis has been used to explain negative asynchrony in sensorimotor synchronization (Aschersleben & Prinz, 1995), suggesting that synchronization processes could be occurring within individuals, as they are achieved through the temporal coordination of periodicities as guided by the superimposition of their sensory codes. Therefore, whether the periodicities are perceived or produced could be merely incidental to synchronization as an exercise, making it fundamentally an intrapersonal phenomenon that subsumes its interpersonal counterpart in terms of the underlying mechanism.

4.2.4 Effects of cognitive overload on synchronization

The visual pattern-matching task was a sequential presentation of Corsi block patterns, where subjects were allowed 6.5 seconds to encode patterns containing 4 to 9 blocks, and therefore between 0.72 to 1.62 seconds to encode each block on the pattern. This was based on the most common block-tapping rate of 1 second per block, used widely in the administration of the Corsi Block Test (Arce & McMullen, 2021; Corsi, 1972). Given how the average Corsi block span for adults lies between five to seven blocks (Kessels et al., 2000), it is reasonable to expect performance degradation, possibly due to cognitive overload, to occur from 6 blocks on average. In the study, load level had a significant effect on the phase coherence of ticking. Post hoc tests with Bonferroni correction showed that phase coherence of ticking was significantly lower for load level 3, compared to level 1, suggesting that additional cognitive load endured during level 3, involving matching patterns comprised of 6 blocks, worsened phase coherence significantly. Further, given how the Bonferroni corrections can be too conservative, introducing the risk of type 2 error, post hoc *t*-tests with no correction were conducted. Results showed that compared to load level 1 involving 4-block patterns, phase coherence of ticking was significantly lower during all of the other levels, except level 2. That suggests, additional cognitive load endured during level 2, involving 5-block patterns, was within cognitive limits on average, while the load during level 3 and upwards, till level 6, involving patterns comprised of 6 blocks to 9 blocks, worsened phase coherence significantly. This is in line with the expected performance degradation discussed above, suggesting that cognitive overload could have contributed to the lower phase coherence in ticking.

Also, in both experiments, lower synchrony in general between the periodic tasks when the tasks were performed while enduring additional cognitive load, compared to expecting load, suggests that the additional cognitive load worsened performance on the periodic tasks, making them more variable in their relative phase angles, and therefore, less phase coherent. This was primarily due to higher rate variabilities of the periodic tasks while enduring additional cognitive load, compared to expecting load; this was expected based on previous findings showing how performance degradation in periodic tasks, when accompanied by cognitive tasks, is often indexed by higher rate variability (Dubost et al., 2008; Stockel & Mau-Moeller, 2020; Li et al., 2014; Beauchet et al., 2005; Irie et al., 2022; Bååth et al., 2016). However, we considered the possibility that the higher rate variability of periodic tasks when accompanied by cognitive tasks, could be because maintaining a consistent rate in itself could require cognitive resources, rendered unavailable due to dual-task interference (Tombu & Jolicœur, 2003), possibly causing cognitive overload. Therefore, our prediction was that the periodic task pairs, tapping-walking and tapping-ticking, would be more synchronous under cognitive load to conserve resources, and that, accordingly, phase coherence would increase. However, phase coherence decreased significantly under cognitive load.

As discussed in section 1.5.1, cognitive overload occurs when cognitive load imposed by processing demands exceeds the available resources (Mayer & Moreno, 2003). Mayer and Moreno (2003) list three scenarios under which cognitive overload can occur. Firstly, overload can be due to excessive demands in ‘essential processing’ in either channel, visual or auditory, relevant to the core demands of the task; this is equivalent to CLT’s ‘intrinsic cognitive load’ that is imposed by the nature of the presented task, such as an arithmetic problem (Sweller et al., 2011; 1998). The cognitive tasks used in the current study are somewhat straightforward, making it hard to imagine counting backwards in 3’s and 7’s, as well as matching visual patterns, causing cognitive overload. However, as discussed before, concurrent cognitive load tasks have been known to cause performance degradation in periodic tasks, especially in terms of rate variability. That suggests that maintaining a periodic task at a constant rate may need cognitive resources, in which case, an increase in variability during a concurrent cognitive task can be an indication of a drop in resources available for rate maintenance, possibly due to cognitive overload. Secondly, according to Mayer and Moreno, demands in ‘incidental processing’ irrelevant to the core task, on top of the essential processing demands, can cause overload; this is in line with CLT’s ‘extraneous cognitive load’ on top of ‘intrinsic cognitive load’, causing overload, where extraneous cognitive load is imposed by demands irrelevant to the core task, such as instructions that are hard to follow, or manner of task presentation, such as an illegible font in a reading comprehension task (Sweller et al., 2011; 1998). In the current study, there were aspects of the cognitive tasks that could fall under this category. For example, in the counting backwards task, there were walking instructions to follow, such as taking a wide U-turn at the specified distance off the gait mat to get back on the mat, as well as to stay on the specified part of the mat that contained pressure sensors. Also, most participants kept a count of the number of laps in the trials despite not having to do so; in the visual pattern-matching task, there were trial instructions to be followed as they appeared on the screen, as well as remembering to stay close to the microphone and to enunciate for a clear audio signal. Any extraneous load imposed by incidental processing demands such as these are common in research, and seem reasonable enough not to be considered a cognitive overload risk. However, the possibility cannot be ruled out. Lastly, according to Mayer and Moreno, cognitive overload can be due to demands in ‘representational holdings’ that refer to visual or auditory representations held in working memory, and such demands on top of essential processing demands can cause cognitive overload (2003). In the current study, the counting backwards task required the participants to remember the current number in working memory (representational holding), until the next number was computed by applying the negative counter (essential processing); the visual pattern-matching task required them to remember the first pattern which was removed after a brief presentation (representational holding), until the second one was presented for comparison between the two patterns (essential processing). In both cognitive tasks, the combination of the two demands, posed by essential processing and representational holdings, could have caused cognitive overload, rendering the required resources for synchronization unavailable.

4.3 Limitations

Lack of literature to date on spontaneous intrapersonal synchronization was the primary limitation of the study; therefore, inferences and predictions had to be made based on findings on spontaneous interpersonal synchronization. Both experiments had relatively small sample sizes; however, large effect sizes mitigated the potential limitations associated with small sample sizes. Participants in both experiments had a relatively small age range due to a majority of them being university students; only 2 out the 24 participants were from the general populace, and their age range was similar to that of the graduate students. This limited the analysis of data for effects of age on spontaneous intrapersonal synchronization. Customized quantifications of cognitive load levels for each participant based on individual ability would have been preferable for within-subject manipulations of cognitive load. However, such manipulations were limited by the fact that the quantification of load levels was common to all the participants. Given that spontaneity was the primary focus of investigation in the study, a reasonably comparable split of musicians and non-musicians would have been preferable, so that we could have analyzed for effects, if any, of formal music training on spontaneous intrapersonal synchronization; the lopsided musician / non-musician split limited such an analysis.

4.4 Future directions

More testing is needed to see if the findings of this study are replicated, supplemented, or contradicted, so that the inferences can be better informed and more reliable. We suggest testing larger samples with a wider age range, as well as with reasonably comparable musician / non-musician splits, to examine effects of age and music training on spontaneous intrapersonal synchronization. Whether cognitive overload occurred in the current study needs to be ascertained, and for that, we suggest using cognitive tasks with lower processing demands in the follow-up studies and compare results with those of the current study. To reduce the cognitive demands of a task, minimizing the need for representational holding, by presenting the task information simultaneously instead of sequentially, has been recommended (Mayer & Moreno, 2003). This can be applied in the visual pattern-matching task by presenting both patterns simultaneously instead of sequentially. To minimize any possible extraneous cognitive load imposed by the need to remember to stay close to the microphone for a clear audio signal during the ticking task, we suggest trying a lapel mic instead of the stand mic. To minimize any possible extraneous cognitive load imposed by involuntary lap counting in the tapping-walking experiment, we suggest trying two-lap trials for the expecting-load and enduring-load conditions instead of three laps each, running them discretely instead of continuously as one six-lap trial. Also, to minimize cognitive overload through customized cognitive load manipulations for each participant, pre-experiment individualized assessment of cognitive load capacity for each participant has been recommended (Mayer & Moreno, 2003; Elliott et al., 2009).

4.5 Conclusion

Spontaneous intrapersonal synchronization of periodic behaviors is greater when such behaviors are produced simultaneously, compared to separately; therefore, periodic behaviors may be inherently coupled within an individual. The observable similarity between spontaneous intrapersonal synchronization and spontaneous interpersonal synchronization suggests the two phenomena could be different manifestations of the same phenomenon: spontaneous synchronization. Cognitive load appears to decrease spontaneous intrapersonal synchronization in general, and this decrease was more pronounced between tapping and walking than it was between tapping and ticking. This could possibly be due to cognitive overload, suggesting that the synchronization process likely needs cognitive resources. Overall, the study has demonstrated that spontaneous intrapersonal synchronization is a potent field of inquiry into how periodic behaviors interact within individuals when such behaviors are performed simultaneously compared to separately, as well as how such interactions and cognitive load influence each other.

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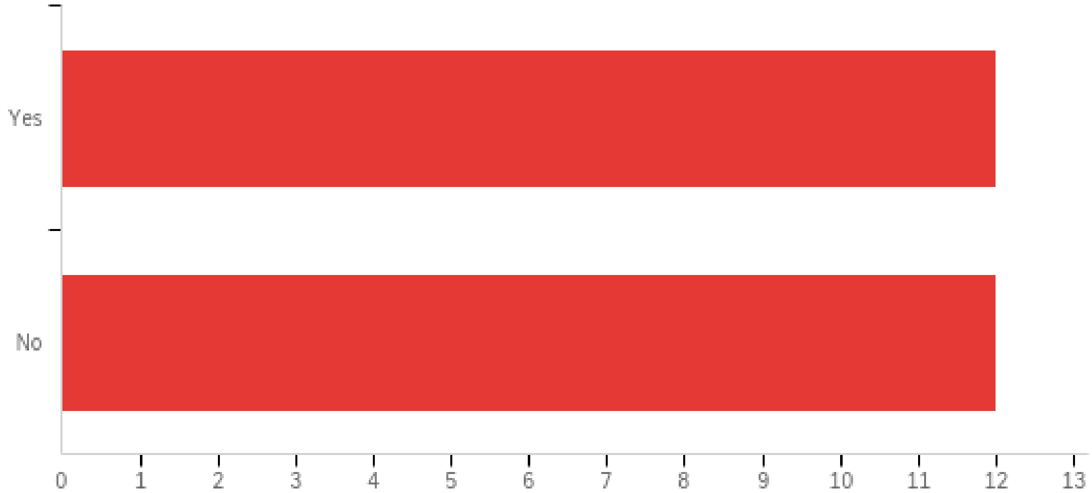
Appendix A: Participant Musicianship Survey Report

Participant Musicianship Survey

Spontaneous Intrapersonal Synchrony and the Effect of Cognitive Load

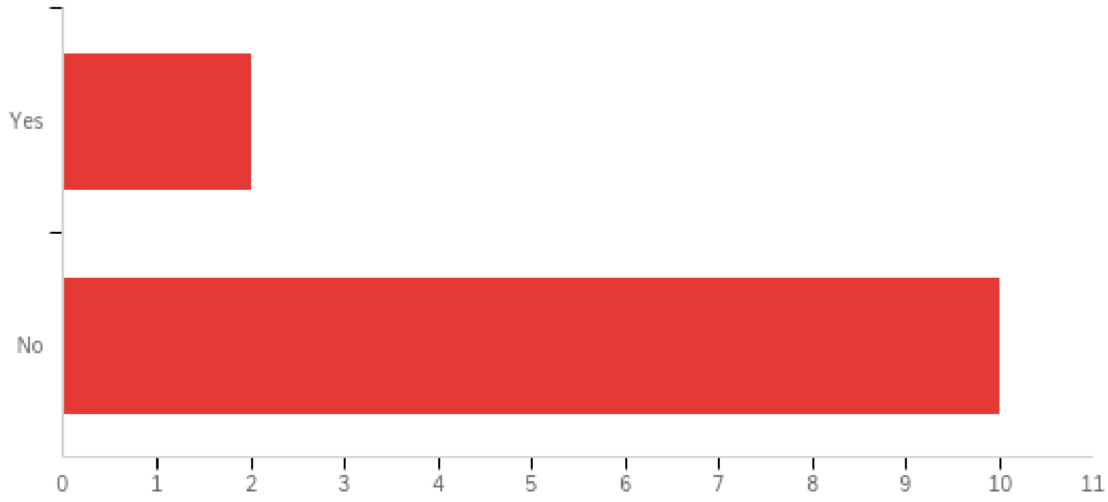
Q3 - Have you had formal music training?



#	Field	Minimum	Maximum	Mean	Std Deviation	Variance	Count
1	Have you had formal music training?	1.00	2.00	1.50	0.50	0.25	24

#	Answer	%	Count
1	Yes	50.00%	12
2	No	50.00%	12
	Total	100%	24

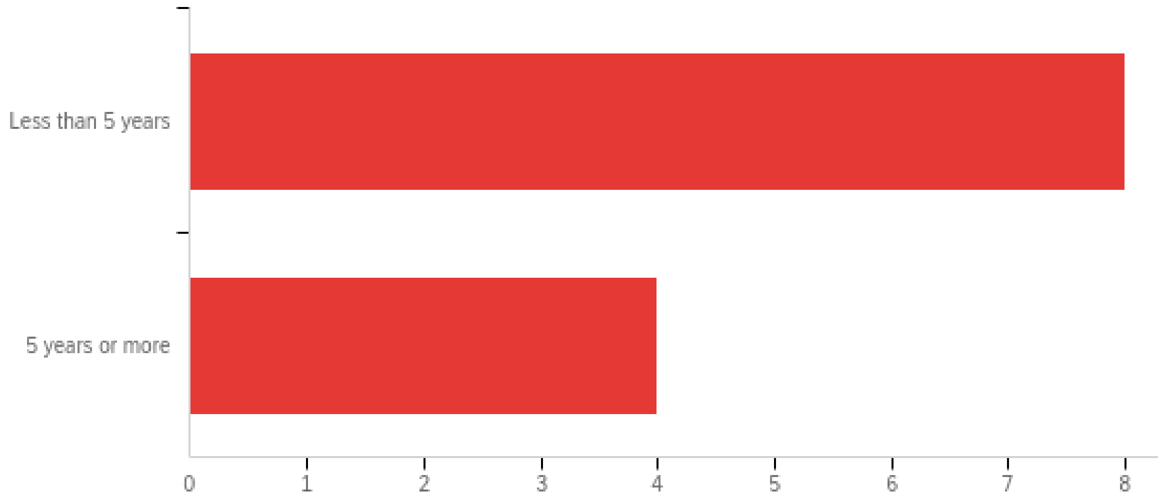
Q4a - Are you a self-taught musician?



#	Field	Minimum	Maximum	Mean	Std Deviation	Variance	Count
1	Are you a self-taught musician?	1.00	2.00	1.83	0.37	0.14	12

#	Answer	%	Count
1	Yes	16.67%	2
2	No	83.33%	10
	Total	100%	12

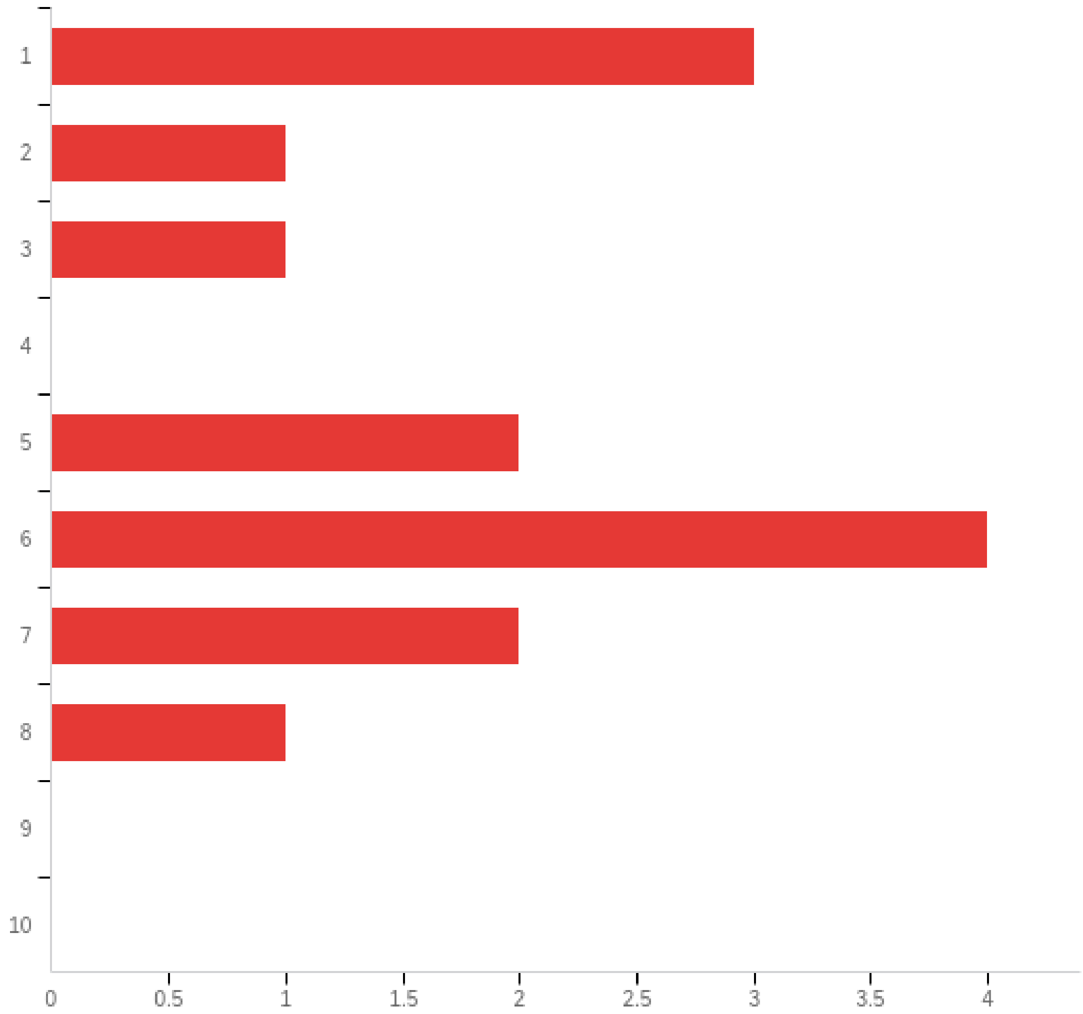
Q4b - If yes, how many years?



#	Field	Minimum	Maximum	Mean	Std Deviation	Variance	Count
1	If yes, how many years?	1.00	2.00	1.33	0.47	0.22	12

#	Answer	%	Count
1	Less than 5 years	66.67%	8
2	5 years or more	33.33%	4
	Total	100%	12

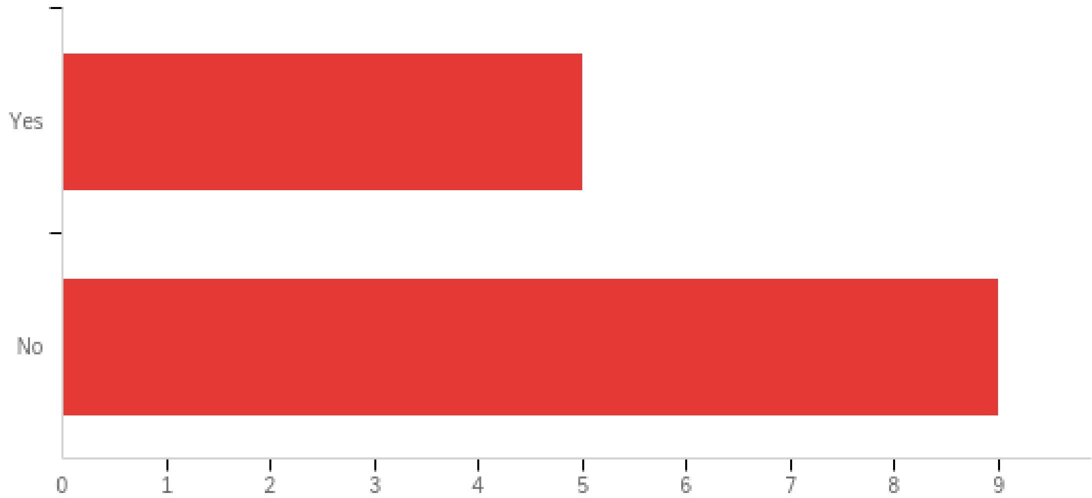
Q5 - How would you rate your skills as a musician on a scale of 1 to 10, with 10 being the highest?



#	Field	Minimum	Maximum	Mean	Std Deviation	Variance	Count
1	How would you rate your skills as a musician on a scale of 1 to 10, with 10 being the highest?	1.00	8.00	4.57	2.38	5.67	14

#	Answer	%	Count
1	1	21.43%	3
2	2	7.14%	1
3	3	7.14%	1
4	4	0.00%	0
5	5	14.29%	2
6	6	28.57%	4
7	7	14.29%	2
8	8	7.14%	1
9	9	0.00%	0
10	10	0.00%	0
	Total	100%	14

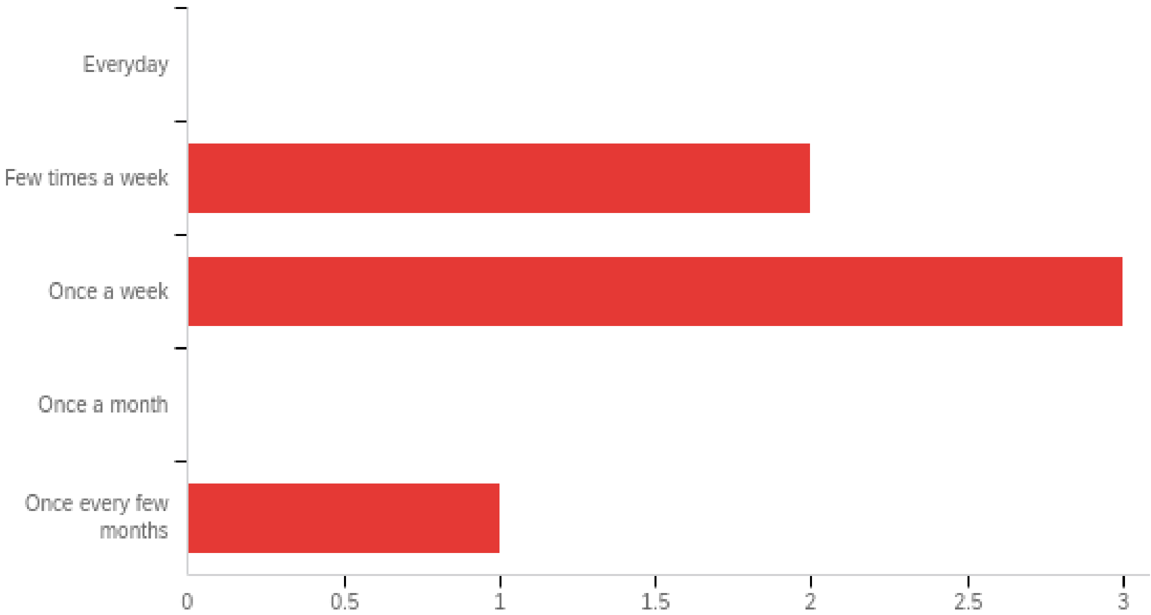
Q6 - Are you currently practicing music on a regular basis?



#	Field	Minimum	Maximum	Mean	Std Deviation	Variance	Count
1	Are you currently practicing music on a regular basis?	1.00	2.00	1.64	0.48	0.23	14

#	Answer	%	Count
1	Yes	35.71%	5
2	No	64.29%	9
	Total	100%	14

Q7 - If yes, how regularly?



#	Field	Minimum	Maximum	Mean	Std Deviation	Variance	Count
1	If yes, how regularly?	2.00	5.00	3.00	1.00	1.00	6

#	Answer	%	Count
1	Everyday	0.00%	0
2	Few times a week	33.33%	2
3	Once a week	50.00%	3
4	Once a month	0.00%	0
5	Once every few months	16.67%	1
	Total	100%	6

Appendix B: Ethics Approval

Western Research

Date: 22 March 2023

To: Dr. Jessica Grahn

Project ID: 106385

Study Title: Behavioral studies of rhythm and music perception

Application Type: Continuing Ethics Review (CER) Form

Review Type: Delegated

Date Approval Issued: 22/Mar/2023 12:49

REB Approval Expiry Date: 30/Mar/2024

Dear Dr. Jessica Grahn,

The Western University Non-Medical Research Ethics Board has reviewed this application. This study, including all currently approved documents, has been re-approved until the expiry date noted above.

REB members involved in the research project do not participate in the review, discussion or decision.

The Western University NMREB operates in compliance with the Tri-Council Policy Statement Ethical Conduct for Research Involving Humans (TCPS2), the Ontario Personal Health Information Protection Act (PHIPA, 2004), and the applicable laws and regulations of Ontario. Members of the NMREB who are named as Investigators in research studies do not participate in discussions related to, nor vote on such studies when they are presented to the REB. The NMREB is registered with the U.S. Department of Health & Human Services under the IRB registration number IRB 00000941.

Please do not hesitate to contact us if you have any questions.

Sincerely,

The Office of Human Research Ethics

Note: This correspondence includes an electronic signature (validation and approval via an online system that is compliant with all regulations).

Curriculum Vitae

<u>Name</u>: Ramkumar Jagadeesan

<u>Post-secondary Education</u>

- Bachelor of Science in Psychology – Troy University, Troy AL (Dec 2019)
- Master of Science in Psychology – Western University (Sep 2021 – present)

<u>Awards</u>

- NSERC CD-CREATE Award – 2021-‘23
- Graduated *summa cum laude* (4.0 GPA) from Troy University B.S program

<u>Related Work Experience</u>

- Teaching Assistant, Western University, (Jan 2022 – Apr 2023)