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# Effects of Auditory Rhythm on Movement Accuracy in Dance Performance

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Abstract

The present study addresses the impact of the rhythmic complexity of music on the accuracy of dance performance. This study examined the effects of different levels of auditory syncopation on the execution of a dance sequence by trained dancers and exercisers (i.e., nondancers). It was hypothesized that nondancers would make more errors in synchronizing movements with moderately and highly syncopated rhythms while no performance degradation would manifest among trained dancers. Participants performed a dance sequence synchronized with three different rhythm tracks that were regular, moderately syncopated, and highly syncopated. We found significant performance degradation when comparing conditions of no syncopation vs. high syncopation for both trained dancers ($p$ = .002) and nondancers ($p$ = .001). Dancers and nondancers did not differ in how they managed to execute the task with increasing levels of syncopation ($p$ = .384). The pattern of difference between trained dancers and nondancers was similar across the No Syncop and Highly Syncop conditions. The present findings may have marked implications for practitioners given that the tasks employed were analogous to those frequently observed in real-life dance settings.

*Keywords*: acoustic stimuli; movement error; sequence; synchronization; syncopation.

# Introduction

The ability to coordinate movements to complex musical rhythms is an essential skill for dancers. Synchronizing involves the conscious performance of repetitive movements in time with an auditory rhythm (Leman et al., 2013). The synchronization of bodily movements through feet-tapping, hand-clapping, swaying, and dancing represents natural responses to music that are observed across cultures (see Hennig, 2014; Sievers, Polansky, Casey, & Wheatley, 2013). Fung and Gromko (2001) suggested that natural rhythmic movements of the body in children might be the source of their perceptions of patterns and subtleties in music. In some cultures, such as that of the African Igbo Tribe, there is no distinction made between the concepts of music and dance (i.e., music is not solely about “sound”; Panksepp & Bernatzky, 2002). Music plays a central role in physical education and dance, as it not only stimulates the body to move but also evokes emotions that can be expressed through movement; thus giving motor performance an artistic purpose and a means of communication (e.g., Digelidis, Karageorghis, Papapavlou, & Papaioannou, 2014; Panksepp & Bernatzky, 2002).

## Effects of Music on Motor Learning

Auditory stimuli have been used extensively in the realm of sport and exercise sciences as a means by which to assuage negative bodily sensations and enhance task performance (see e.g., Karageorghis, Bigliassi, Guérin, & Delevoye-Turrell, 2018; Karageorghis, Cheek, Simpson, & Bigliassi, 2018). Nonetheless, research into the effects of music on motor learning has not attracted the same level of interest from the scientific community (see Karageorghis, 2017 for a review). There is emerging evidence that music might function as a tool that facilitates the execution of movements and expedites motor learning (Miendlarzewska & Trost, 2014). This is due to the fact that music has the potential to increase activation of brain regions that are also involved in the process of learning new movement patterns (Altenmüller, Wiesendanger, & Kesselring, 2006). Music also optimizes the execution of rhythmic motor patterns, leading to enhancements in skill acquisition.

Effenberg, Fehse, Schmitz, Krueger, and Mechling (2016) employed movement sonification (i.e., combining movement data with sound) to explore how rhythmic patterns could influence the learning of complex motor skills. The authors found that when participants were exposed to movement sonification, their learning experience was enhanced to a greater degree than when they were exposed to other forms of environmental sensory stimuli (i.e., video-only and video combined with natural motion-attendant sounds). Such results are supported by numerous studies in the field of psychophysiology and neuroscience, which provide a vista into the mechanisms that underlie the effects of rhythmic structures on the ability to execute and learn complex movement patterns (e.g., Brodal, Osnes, & Specht, 2017; Thaut et al., 2009).

**Synchronizing Movements to Music**

According to Roerdink (2008, p. 13), synchronization of movement to musical rhythms is a type of *auditory-motor* synchronization in which the *actor* (e.g., the dancer) and the acoustic stimuli are oscillators generating their own rhythms. The degree of synchronization depends upon the intensity of the interaction between the actor and the acoustic stimuli, and the initial frequency mismatch between them. The actor can adjust her or his movements to the beats per minute set by the auditory rhythm through *detuning* the frequency of their oscillation. A large body of research has investigated how people synchronize movements to music. Many of these studies have employed finger-tapping to facilitate measurement of motor behavior (e.g., Gebauer et al., 2016; Kamiyama & Okanoya, 2014; Okano, Shinya, & Kudo, 2017). Such studies have observed effects of age and training (Drake, Jones, & Baruch, 2000), tempo (Delevoye-Turrell, Dione, & Agneray, 2014), syncopation (Coey, Washburn, Hassebrock, & Richardson, 2016) and speech processing

(Falk, Volpi-Moncorger, & Dalla Bella, 2017). Even though the application of such findings might not generalize to other areas owing to the methods used to assess motor performance, they do provide valuable insight regarding rhythm and music perception, and the effects of such perception on movement. For example, Pflug, Gompf, and Kell (2017) examined preferences for relative movement frequencies through the use of bimanual tapping of a syncopated rhythm. This approach enabled the authors to test the influence of hemisphere specialization on motor behavior. Syncopation can be defined as "the lack of events (or sometimes the occurrence of unstressed events) on strong beats, accompanied by the placement of stressed events on weak beats" (Large, 2000, p. 545).

Results of the study by Pflug et al. (2017) indicated that fast tapping was less variable when performed by the right hand, which indicated a left hemispheric preference for controlling fast tapping rates. Interestingly, enhanced performance of the left hand during the slow-tapping task was not manifest. It has also been identified that slow tapping in syncopated rhythm is more easily reproduced by the left hand. Accordingly, Pflug and her coworkers suggested that an internal meter representation for syncopated tapping may likely involve both hemispheres, and that slow and fast rhythms are processed in parallel.

Dynamic Attending Theory (Jones & Boltz, 1989) indicates that attention to an auditory stimulus is directed by a single oscillator (Drake et al., 2000). In the presence of musical stimuli, the oscillator will synchronize itself to the periodicity of physical characteristics of the music, such as accents and a steady beat. It is important to emphasize that attentional focus is primarily driven by the physical features of the stimulus and the level of importance that oscillators derive to each subcomponent (e.g., music tempo, timbre, pitch, and etc.; Broadbent, 1958; Treisman, 1964). Therefore, the most salient features of the music that an individual hears will determine the particular part of the system that is activated.

Related to this, Brochard, Abecasis, Potter, Ragot, and Drake (2003) examined physiological evidence of *subjective accenting*. This refers to the phenomenon wherein as people listen to a succession of identical tones occurring at a regular pace, some tones are perceived as more salient (either louder, longer, or both) than others, even though no physical characteristics of the sounds account for the differences heard. Using electroencephalography (EEG), Brochard et al. (2003) found that musically trained listeners exhibited more efficient temporal processing. Along similar lines, Gaser and Schlaug (2003) reported that brain structures differ between musicians and nonmusicians, and lateralization differs between expert musicians and nonmusicians (Vuust et al., 2005); this is franked by evidence from rhythm perception tests (Wallentin, Nielsen, Friis-Olivarius, Vuust, & Vuust, 2010).

Large (2000) proposed a model of meter perception (meter refers to the temporal pattern created by the perception of beats at different time signatures), which postulated that as people listen to music, a stable psychological pattern occurs that serves as a dynamic representation of the temporal structure of the rhythm. In its simplest form, such as in finger tapping, a single periodicity is used to guide tapping along with rhythms. In other more complex forms, such as dance, more intricate metrical patterns may be employed to synchronize movements. Large used data from another investigation (Snyder & Krumhansl, 2001) in which participants were asked to listen to ragtime piano pieces and tap out the most "comfortable beat" (p. 530) on a piano keyboard. He found that increased syncopation disrupted synchronization. However, researchers have yet to investigate whether this result generalizes to more complex forms of movement, such as dance.

Keller and Repp (2004) found that bimanual finger tapping was more variable among musically trained participants for both synchronization and syncopation to the beat of the metronome and more pronounced during syncopation than synchronization. Their findings indicated that participants found syncopated bimanual tapping to be the most difficult. The authors proposed that this variability was due to the simultaneous presence of two levels of movement coordination (one between the rhythm stimulus and the hands, and the other between the hands). Nonetheless, it is once again difficult to generalize these findings to the effects of music on whole-limb coordination and whole-body movements as common to dance or gymnastics.

**Effect of Expertise on Brain Processing of Syncopation**

The effect of rhythmic expertise on brain processing of syncopation has been studied by Vuust et al. (2005) who used magnetoencephalography (MEG) to examine the strength and lateralization of pre-attentive responses to incongruent rhythm in expert jazz musicians and nonmusicians. MEG records magnetic fields to neuronal activity with a time resolution of around 1 ms allowing for localization of the neuronal sources of this activation with an accuracy of around 1 cm. Participants were played rhythmical stimuli in the form of drum sounds with increasingly syncopated rhythms. Vuust et al. found that rhythmic experts responded pre-attentively, with greater strength than nonmusicians to these deviations from a regular meter and that this activation was predominantly lateralized to the left hemisphere. Nonexperts, on the other hand, responded more strongly in the right hemisphere. This lends support to the hypothesis of the existence of a stronger and more fine-grained metric model in rhythmic experts compared with nonexperts (Jongsma, Quiroga, & Van Rijn, 2004; Vuust, Ostergaard, Pallesen, Bailey, & Roepstorff, 2009). This metric model, however, can be challenged by highly syncopated rhythms, as evidenced by a larger standard deviation and strong activation of frontal brain areas when participants are tapping the main meter in a polyrhythmic context (see e.g., Vuust & Witek, 2014).

**The Effect of Rhythm on Dancing**

While there is certainly burgeoning research regarding the effects of music on motor performance, there is almost no systematic investigation of such effects on the execution of a dance sequence. In the only previous study similar to the present one, Pollatou, Hiatzitaki, and Karadimou (2003) investigated whether rhythmic beats or a musical accompaniment would differentially affect the performance of a dance sequence. Thirty females in a physical education class performed dance steps in synchronization with a musical phrase across different meters. Participants were divided into two groups and Group A performed the dance sequence in synchronization with a single-beat rhythm, while Group B performed the same dance sequence in synchronization with a musical phrase. The authors found that Group A remained more synchronized to the stimuli than Group B across all meters, which suggests that beginners perform dance movements much better when accompanied by a rhythmic phrase consisting of single beats rather than a musical phrase.

The mechanisms underlying sensorimotor coordination in dancers are hitherto under-examined. However, Burger, Thompson, Luck, Saarikallio, and Toiviainen (2013) suggested that body movements are generally used to predict and reflect some of the musical characteristics such as rhythm, timbre, and tempo. Accordingly, complex processes involving sensorimotor synchronization appear to be primarily influenced by superficial and subcortical regions of the brain, such as the prefrontal cortex and thalamus, respectively (see Burzynska, Finc, Taylor, Knecht, & Kramer, 2017; Todd & Lee, 2015).

Recently, the influence of rhythmic complexity on groove ratings has attracted considerable research interest (e.g., Janata, Tomic, & Haberman, 2012; Madison, Gouyon, Ullén, & Hörnström, 2011). Such work has demonstrated that there is an inverted-U relationship between groove, defined as the pleasurable sensation of wanting to move, and the degree of syncopation in drum breaks (Witek, Clarke, Wallentin, Kringelbach, & Vuust, 2014), such that medium complexity yielded higher ratings for “wanting to move” and “pleasure” than low and high-complexity drum excerpts. No difference between musicians and nonmusicians was observed in the study conducted by Witek et al. (2014). A subsequent motion capture study showed that participants' ability to synchronize to a musical beat, when asked to move freely to the rhythm, was worse for high, than medium and low rhythmic complexity (Witek et al., 2017). In a follow-up study, in which three levels of harmonic complexity were coupled with three levels of rhythmic complexity, Matthews and colleagues (2019) found an influence of harmonic complexity on "wanting to move", mediated by increased pleasure for the low- and moderately complex chords. Importantly, an effect of musical expertise was observed, indicating that the musical richness of the stimuli may be important in terms of teasing out the differences between experts and nonexperts.

In sum, there are two central factors influencing synchronization to a beat, which are the complexity of the auditory stimulus and participants' level of expertise. As a further illustration of this, expert musicians with years of motor training appeared to process complex rhythms more efficiently (Vuust & Witek, 2014), and demonstrated shorter reaction times and superior sequence acquisition during sequence learning than nonexperts. The current experiment was designed to identify differences related to the influences of long-term dance-related expertise in synchronizing movement to simple and complex beats. Therefore, we investigated the behavioral effect of different levels of syncopation on expert, trained dancers' and nondancers' execution of a relatively simple dance sequence. Given both groups' regular experiences in syncing movement with music, it was hypothesized that in the condition with nonsyncopated rhythm, there would be no group differences in errors ($H_1$). However, it was hypothesized that nondancers would make more errors than the expert dancers in synchronizing dance movements with moderately syncopated rhythms ($H_2$) as well as highly syncopated rhythms ($H_3$). Moreover, there would be differences among all rhythm conditions for the nondancers ($H_4$), but no performance degradation would be observed across conditions for the expert dancers ($H_5$).

**Method**

**Participants**

A purposive sample of 34 women in the age range 18–49 years ($M_{age}$ = 33.6 years, *SD* = 8.5 years) was recruited to take part in the present study. Participants represented a range of ethnic backgrounds and recruitment was conducted via aerobics instructors, posters on health club noticeboards, and dance classes in the cities of London, UK and Detroit, MI. Any potential effect of handedness was assessed via a gender- and culturally-appropriate version of the Edinburgh Handedness Inventory (EHI; Oldfield, 1971).

Regular aerobics class attendees and dancers were informed of the time commitment required as well as the general purpose of the study. Participants in the nondancer group were: (a) females of 18 years of age and over (*M* = 37.3, *SD* = 6.4); (b) not professionally trained in dance; and (c) regular attendees (i.e., at least once a week) at aerobics classes. Nondancers who had professional training in dance were not recruited, as it has been found that women skilled in this area have superior strength, balance, kinesthesis, and motor ability than athletes or untrained participants (Brennan, 1980). Inclusion of participants skilled in these abilities would have represented a potential confound, however some experience of coordinating movements to music was thought beneficial. This was in order for participants to be able to adapt to a gross motor sequence, accompanied by auditory rhythm, more accurately than a control group (Huff, 1972), and therefore a sample drawn from regular attendees at aerobics classes was deemed appropriate. Moreover, this group was, in broad terms, physically comparable to the experimental group (i.e., in terms of general fitness). Two participants in the nondancer group were left-handed.

Participants in the dance groups were: (a) females of 18 years and over (*M* = 29.4, *SD* = 8.8); and (b) professionally trained in dance beyond the age of 18 years ($M_{years' training}$ = 7.8 years, *SD* = 4.0 years). All dancers were trained in ballet and contemporary dance with some having also trained in jazz and tap. One dancer reported having played the piano for 15 years beyond the age of 18 years. Initial attempts to recruit participants without inducement were unsuccessful therefore, each participant was offered a small sum (£20 in the UK and $30 in the USA) on completion of the protocol. Nine trained dancers were recruited in the UK and seven in the USA. All nondancers were recruited in the UK. The ethnicities represented in the sample were 19 White-UK/Irish (nondancers: 13; trained dancers: 6), 8 White (nondancers: 2; trained dancers: 6), 1 Black-Caribbean (nondancers: 1), 1 Black-African (trained dancers: 1), 3 Asian (trained dancers: 3), 1 Pakistani (nondancers: 1), 1 mixed race (nondancers: 1). All trained dancers were right-handed.

**Instrumentation**

**Experimental task.** Participants were required to perform a simple dance sequence consisting of movements synchronized with a rhythm track that had a nonsyncopated four-beat rock rhythm, a similar rhythm with moderate syncopation, or a similar rhythm that was highly syncopated. In light of feedback derived from earlier piloting of the protocol, the choreographed dance movements were relatively simple and similar in nature to the movements that are taught to beginner jazz dancers. The same movement phrase was taught to both the dancers and nondancers. The phrase consisted of four dance steps that could be considered simple enough to be taught to children who were beginner-level students of jazz or modern dance. In other words, children would learn these, or similarly simple steps, within their first few dance classes.

**Music Selection**

Three separate rhythm tracks at a tempo of 120 beats per minute (bpm) were specially composed and recorded by the fourth author. The stimuli were: No Syncop, a simple four-beat rock rhythm; Moderately Syncop, a variation of No Syncop with a weak departure from the rhythm; and Highly Syncop, a variation of No Syncop with a strong departure from the rhythm. The rhythm tracks are available via an online address (No Syncop condition: https://youtu.be/LOAbbk-2x84; Moderate Syncop condition: https://youtu.be/TkTS-6E5cK4; Highly Syncop condition: https://youtu.be/EnNTUuPNxcE). They were played at a distance of either 3.20 m or 3.35 m from participants, depending on their position relative to a digital audio player (iPod 80GB A1136; Apple Inc., Cupertino, CA) connected to a portable sound dock (mm50; Logitech, Romanel-sur-Morges, Switzerland). A decibel meter (GA 102 Sound Level Meter Type 1; Castle Associates, Scarborough, UK) was used to standardize music intensity at ~66 dBA.

## Measures

**Demographics questionnaire.** Age, ethnic origin, and years' experience of dance/musical instrument study were measured using a demographics questionnaire. Participants were asked their age (in years) and ethnic origin. They were asked to indicate if they had studied dance or music (inc. instrument details) beyond the age of 18 years and, if so, for how many years. The questionnaire referred to the study of dance and music in general terms (i.e., did not make explicit mention of the professional study of these art forms).

*Performance measurements.* Dance performances for each participant were videoed using a static high definition, widescreen, digital video camera (Everio GZ-HM200; JVC, Yokohama, Japan) set on a tripod. Videos were uploaded to a website and the ability of the participant to execute the required steps in synchronization with the rhythmic tracks was evaluated qualitatively by two independent, trained observers (29 years and 25 years) with experience in dance as performers (24 and 21 years of experience, respectively) and teachers (~10 years of experience). Observers were verbally instructed by the second author to award one point to the participant if she executed a required movement in each measure in synchronization with the rhythmic pattern. The verbal instruction was reinforced in writing on each mark sheet. A zero was given for any step that did not fall in synchrony with the rhythmic pattern, or if the participant stopped. The style of movement was not considered by the observers; only the ability of each participant to keep in time with the beat.

**Procedure**

Ethical clearance (under code 0628951/1) was obtained from the institutional review board of the first two authors. The 34 participants (16 trained dancers and 18 exercise participants [nondancers]) were randomly assigned to groups of two or three. Testing took place in an exercise or dance studio. The second author provided participants with an information sheet and a brief explanation of the procedure. Participants signed a consent form to indicate their willingness to engage in the study. In accordance with standard dance teaching methods and to facilitate efficient sequence learning, the dance sequence was designed and taught in smaller sequences of steps (Rhodes, Bullock, Verwey, Averbeck, & Page, 2004).

The second author demonstrated the first step and asked participants to repeat that step three times. She then demonstrated the second step and asked participants to repeat that three times. Thereafter, she asked participants to join together steps one and two and execute once. This was repeated until all four movements had been learned, strung together, and repeated without music to form a dance sequence consisting of eight movements across 16 musical measures. Finally, participants were asked to execute the eight-step sequence three times to ensure they were satisfied that it had been learned. The movement phrase was choreographed specifically for the present study. A video (see Supplementary File 1) can be downloaded from the journal platform, which provides an illustration of the task. It is also important to emphasize that nondancers were relatively familiar with the type of movements they were asked to execute. It was a simple dance routine that could be performed without prior lessons or specific instruction.

The exact instructions participants received as well as a full description of the experimental protocol are provided as a supplementary file (see Supplementary File 2). Participants were organised into groups of two or three both to learn the routine and be tested in an exercise or dance studio. To facilitate a clear view of all participants during videoing and to ensure they had a limited view of each other, groups of three were arranged beside each other at a 1-m distance, and groups of two were arranged beside each other at a 2-m distance. Trained dancers only performed the movement phrase with other trained dancers and similarly nondancers only performed with nondancers.

The rhythm tracks were administered to each group in a random order to control for order effects (Harris, 2008, pp. 252–255). Participants were asked to stand still and listen to the first rhythmic condition, which was played three times. The video camera was then switched on and participants were required to execute the sequence in strict time with the rhythmic stimuli. This was repeated under each experimental condition. There was a time gap of 2 min between trials during which participants were asked to perform a “filler” activity that comprised counting backwards in threes from a given number. The main purpose of the filler activity was to prevent any form of residual effect from one condition to another and also to prevent any mental or physical rehearsal of the routine in between conditions. They were fully debriefed following completion of the entire procedure. During debriefing, a manipulation check was carried out that involved asking participants if they found any of the three pieces of music more difficult in terms of performing the dance movements. Their answers were duly noted by the second author.

**Data Analysis**

Accuracy scores were computed by summing individual scores in each measure for the dance movements across the three rhythm conditions, with a minimum accuracy score of 0 and a maximum of 4 for each measure (musical bar). An interrater reliability analysis using the Spearman's rank correlation coefficient was computed to determine consistency among raters. In order to test whether both groups of participants performed differently in the condition with nonsyncopated rhythm ($H_1$), moderately syncopated rhythm ($H_2$), and highly syncopated rhythm ($H_3$) the Mann–Whitney U Test was used. Friedman's Two Way Analysis of Variance by Ranks Test was used to compare task performance among all rhythm conditions for nondancers ($H_4$) and trained dancers ($H_5$). Wilcoxon Signed-Rank Tests were used as a follow-up to locate any significant differences that emerged from comparisons within each group of participants (e.g., analysis of performance degradation in nondancers for nonsyncopated rhythm vs. moderately syncopated rhythm). The IBM Statistical Package for the Social Sciences (SPSS) 25.0 was used for data analysis.

## Results

### Interrater Reliability

The interrater reliability for the raters was found to be very high, $r = .99$ ($p < .001$).

### Main Analyses

No significant differences were identified in task performance between the two groups of participants (i.e., nondancers and trained dancers) in the conditions with nonsyncopated rhythm ($U = 118.50$, $p = .384$), moderately syncopated rhythm ($U = 99.50$, $p = .126$), and highly syncopated rhythm ($U = 118.00$, $p = .384$). It is noteworthy, however, that the scores from both groups appeared to exhibit greater heterogeneity as they were exposed to increased levels of syncopation; the means decreased while the *SD*s increased. Ostensibly, while the nondancers made more errors in performance accuracy than the dancers across conditions, as the task increased in difficulty, there was greater variability evident in the scores of both groups (see Figure 1 and Figure 2).

The degree of syncopation in the rhythmic accompaniment had a significant effect on dance performance in both groups of participants (nondancers: $\chi^2_2 = 14.80$, $p = .001$; trained dancers: $\chi^2_2 = 19.63$, $p < .001$). Pairwise comparisons using the Wilcoxon Signed-Rank Test showed that the performance of nondancers was significantly affected by moderately ($W$ = 12.00, $p$ = .011) and highly syncopated rhythms ($W$ = 3.00, $p$ = .001). Interestingly, performance degradation was only observed in trained dancers when this group of participants was exposed to highly syncopated rhythms ($W$ = 3.00, $p$ = .002). Moderately syncopated rhythms were not sufficiently potent to influence task performance in trained dancers ($W$ = 5.00, $p$ = .069).

***Figure 1***

***Figure 2***

**Manipulation Check**

The manipulation check showed that every participant, regardless of group membership (i.e., dancers vs. nondancers), found that the highly syncopated rhythm track had been the most difficult with which to perform the dance routine.

## Discussion

The main purpose of the present study was to examine the effects of different levels of auditory syncopation on the execution of a dance sequence by dancers and nondancers. We hypothesized that in the condition with nonsyncopated rhythm, there would be no group differences in task performance, given that nondancers and trained dancers were equally experienced in syncing their movements to music ($H_1$). However, we hypothesized that nondancers would make more errors than trained dancers when exposed to moderately ($H_2$) and highly syncopated rhythms ($H_3$). Moreover, we hypothesized that there would be differences among all rhythm conditions for the nondancers ($H_4$), but no performance degradation would be observed across conditions for the expert dancers ($H_5$). The present findings do support $H_1$ given that no differences in task performance were observed between groups in the nonsyncopated rhythm condition. Nonetheless, the results did not support $H_2$

and $H_3$ given that no significant differences were observed between nondancers and trained dancers when participants were exposed to moderately and highly syncopated rhythms. Higher levels of syncopation corresponded with higher levels of difficulty and more errors in the synchronization of dance movements were made as a consequence in both nondancers ($H_4$) and trained dancers ($H_5$). Interestingly, no degradation in task performance was observed between No Syncop and Moderately Syncop conditions in trained dancers.

The largest differences in performance accuracy lay between the No Syncop and Highly Syncop conditions. There were also large differences in performance accuracy between the Moderately Syncop and Highly Syncop conditions for both groups of participants (see Figure 1). This is consistent with the findings of tapping studies (see e.g., Okano et al., 2017; Pflug et al., 2017; Vuust et al., 2005) and thus extends previous findings to the larger-scale movement germane to whole-body dance. Along similar lines, Witek et al.'s (2017) motion capture study showed that low and medium syncopated rhythms led to superior synchronization of free body-movements to the beat when compared to highly syncopated rhythms. It is notable that in the postexperimental manipulation check, all participants verbally reported the difficulties they had experienced in attempting to coordinate their movements with the rhythm during the Highly Syncop condition. Figure 1 and Figure 2 illustrate how participants' perceived difficulties are reflected in their accuracy scores.

The fifth hypothesis ($H_5$) held that no degradation in performance would occur among the group of trained dancers. Differences related to the influences of long-term training were anticipated (Burzynska et al., 2017; Landau & D'Esposito, 2006); however, this proved not to be the case, as the dancers also experienced a gradual degradation in performance through the conditions from No Syncop to Highly Syncop, although they made fewer errors in the synchronization of dance movements than the nondancers overall (see Figure 1). Dancers and nondancers did not differ in how they coped with the difficulty of the task with increasing levels of syncopation. The pattern of difference between trained dancers and nondancers was analogous in the No Syncop, Moderately Syncop and Highly Syncop conditions; however, no performance degradation was observed between No Syncop and Moderately Syncop conditions for the group of trained dancers.

Only nonmusicians were included in the present study given that Gaser and Schlaug (2003) found that brain structures differ between musicians and nonmusicians. Furthermore, lateralization differs between expert musicians and nonmusicians (Vuust et al., 2005; Vuust & Witek, 2014) and this is supported by differences in performance on rhythmic perception tests (Wallentin et al., 2010). Moreover, Brochard et al. (2003) reported differences between musicians and nonmusicians, which suggested that musically trained listeners exhibit more efficient temporal processing. Accordingly, it has been hypothesized that a stronger and more fine-grained metric model exists in rhythmic experts than in nonexperts (cf. Vuust et al., 2009). Nonetheless, given the level of expertise that professionally trained dancers have in coordinating movements to a variety of musical rhythms and tempi, they were expected to cope with increasing syncopation with greater movement accuracy than what was observed in the present study. This proposed metric model can, however, be challenged in the case of highly syncopated rhythms, as witnessed by a larger standard deviation and strong activation of frontal brain areas when participants are tapping the main meter in a polyrhythmic context (Vuust & Witek, 2014).

Keller and Repp (2004) found greater variability in tap timing for bimanual syncopation compared to unimanual synchronization and four other conditions in expert musicians. This result could not be accounted for by movement frequency or dexterity limitations associated with use of the nonpreferred hand. Thus, the extra level of syncopated coordination using alternating hands had the most influence on instability. The authors argued that one possible explanation for this is that the requirement to alternate hands may divert the attention from the task of maintaining antiphase with a metronome.

The trained musicians in Keller and Repp's (2004) study were aware of the task they were required to perform whereas the present participants were unaware they were expected to synchronize their movements in time to the underlying simple four-beat rhythm in all three conditions. Despite this, interviews conducted with participants immediately after completion of all conditions revealed that they were actively attempting to synchronize their movements to the rhythm tracks albeit some claimed that they could not perceive the underlying four-beat rhythm in the Moderately Syncop and Highly Syncop conditions. The *detuning* required in order to reduce the frequency mismatch between musical and physical oscillations may have proven too challenging with the attendant reduction in movement accuracy (Roerdink, 2008, p. 13). In which case, the requirement to perform the task using both legs and changing direction during the dance sequence (see Supplementary File 1 and Supplementary File 2) may have diverted attention from the task of synchronizing movement with the underlying four-beat rhythm track in both groups, regardless of their level of expertise.

Furthermore, metrical patterns of greater complexity may have been engaged to synchronize the more elaborate movements in the dance performances than those used to guide bimanual finger tapping (Coey et al., 2016; Large, 2000). Alternatively, dance training is typically accompanied by piano music or a rock/pop music track that is relatively simple in rhythmic terms. It may be the case that such accompaniment during training does not adequately equip dancers to be able to cope with coordinating their movements with more complex rhythms. Pollatou et al. (2003) suggested simple rhythmic beats might be a more suitable auditory accompaniment for initial learning, with more complex musical patterns being suitable only in advanced stages of learning. The present findings indicate that even trained dancers can struggle in processing complex rhythmical structures; to the degree that there is a significant degradation in their movement accuracy (see Figure 1 and Figure 2).

There is, nonetheless, the possibility of a type of ceiling effect (i.e., the independent variable manipulation no longer has an effect on the dependent variable) permeating the present findings. Such an effect might have been caused by the trained dancers' limited ability to synchronize their movements with complex syncopated rhythms. The dance sequence was designed in chunks to be relatively simple to learn (Rhodes et al., 2004) and set at a beginner level of expertise. Nonetheless, some degree of difficulty with the dance steps was observed in both groups across the measures (see Figure 2). Specifically, the steps changed at measures 3, 5, 7, 9, 11, 13, and 15, with participants appearing to make the most errors across all conditions in measures 3, 7, and 14. Measure 7 featured a double-time step, and measure 14 featured a backward-traveling step. Both dancers and exercise class attendees are expected to successfully perform a variety of movements of varying speeds. Notwithstanding this commonality, there were observed differences in the way participants coped with the dance sequence that pervaded both groups. This suggests some steps that deviated radically from the norm, diverted attention from synchronizing movements to the beat, albeit temporarily.

Roerdink, Bank, Peper, and Beek (2011) found that participants took a number of steps to establish synchronization between footfalls and the beat from a metronome while treadmill walking. Previous studies used tasks that involved finger-tapping to a beat in a stable, continuous manner (Delevoye-Turrell et al., 2014; Falk et al., 2017; Okano et al., 2017), whereas the present task was dynamic and entailed several planes of movement. As a result, other factors may place restrictions on the temporal perception of the rhythmic structure, such as demands on short-term memory (Chen, Ding, & Kelso, 2001), the dancers' focus on style as opposed to step accuracy (Effenberg et al., 2016), and the absence of pitch-related elements of music (Karageorghis, 2016).

Repp (2005) found that although on-beat tapping variability did not change with tempo, off-beat tapping became more difficult with increases in tempo. The tempo of the rhythmic tracks used in the present study (120 bpm) was designed to represent an accompaniment to a jazz dance sequence and to maintain participants' interest. Further investigation involving performing a sequence at different tempi would be required to ascertain whether tempo affected the synchronization of dance movements, as the rhythm track became more highly syncopated. Moreover, other factors in real music can affect synchronization difficulty, such as variations in duration, pitch, and intensity (Delevoye-Turrell et al., 2014; Vuust & Witek, 2014).

Importantly, Witek et al. (2017) only found differences between musicians and nonmusicians in ratings of wanting to move for rhythmic stimuli that were enriched by different levels of harmonic complexity, but not for simple drum rhythms, similar to those used in the present study. It may be that enriched musical material would lead to a differentiation between dancers and nondancers and this should be a focus of further study. The present study represented an initial exploration with simple rhythmical stimuli and, due to this, the exploration of other musical cues that guide the performance of a dance sequence fell beyond its scope.

In theoretical terms, examining the present findings through the lens of Dynamic Attending Theory (Jones & Boltz, 1989), it is clear that the disruption of a steady beat through rhythmic syncopation resulted in skill degradation among both trained dancers and nondancers. If a single oscillator does not provide a clearly extractable meter, it appears that a breakdown in motor performance ensues, as evident in both the Moderately Syncop and Highly Syncop conditions. Trained dancers appear to depend heavily upon the auditory stimulus—in making the audible visible—without necessarily carrying a strong internal sense of meter to guide their actions (i.e., in the manner of trained musicians).

Moreover, there are many studies examining brain differences that are evident when comparing musicians vs. nonmusicians (Gaser & Schlaug, 2003; Zhang, Peng, Chen, & Hu, 2015), albeit there are relatively few that conduct similar comparisons between expert dancers and nondancers. A program of work by Kaparti and her coworkers showed through cortical thickness analyses that dancers have thicker gray matter than controls in the superior and middle temporal gyri and precentral gyrus (Karpati, Giacosa, Foster, Penhune, & Hyde, 2015). Follow-up work with performance on dance-related tasks showed a reduced correlation between cortical thickness in the left dorsolateral prefrontal cortex (DLPFC) and mean cortical thickness across the whole brain in the dancers compared to controls (Karpati, Giacosa, Foster, Penhune, & Hyde, 2018). A reduced correlation between these two cortical thickness measures was associated with superior performance in a dance-video game. This leads to the intriguing hypothesis that the left DLPFC is structurally decoupled in dancers. Nonetheless, the potential performance advantage that such a decoupling might confer did not emerge in the present findings.

## Limitations of the Present Study

Although the dance sequence used in the present study was set at a beginner level of expertise, and despite piloting of the protocol, it may have been that some steps in the sequence were too complex to enable group differences to emerge. In addition, it is possible that learning was still occurring during the testing phase. Nonetheless, if the working memory had been overburdened, one would expect to observe a degradation in performance in the middle of the sequence and not throughout the performance, as we observed. A more simple, static sequence may have reduced the attentional demands placed upon participants.

With regard to the marking procedure, the dance performances for each participant were filmed and the ability of the participant to execute the required steps in synchronization to the musical phrase was qualitatively evaluated by two independent dance teachers. Subjective ratings such as these are prone to error and individual interpretation of the performances. Previous studies have used a variety of apparatus to measure timing accuracy. In finger-tapping tasks, Repp (2005) used an electronic percussion pad. Repp, Windsor, and Desain (2002) used a digital piano, and Chen et al. (2001) asked participants to press a computer key. Clearly, these methods are not suitable for measuring the ability of the participant to perform a multi-limb task in synchronization to a beat.

It is important to note that several confounding variables could have influenced the present findings. For example, the age of participants could have influenced the degree to which dance movements were recalled/executed and so the relatively broad age range (18–49 years) represented a threat to internal validity. It is also noteworthy that nondancers were significantly older than trained dancers ($t_{32} = 2.99$, $p = .005$). Furthermore, participants were not equally distributed between dancer and nondancer groups in accord with nationality, as eight of the dancers were recruited in the US.

Another potential confound is that the group of nondancers was exposed to music on a weekly basis by dint of their attendance of aerobics classes. However, we hypothesized that the experience of trained dancers in executing dance movements using different levels of auditory syncopation would override the potentially catastrophic effects on performance of increasing levels of syncopation. Even if we were to assume that all participants had equal exposure to music and aerobic dance exercise, the group of trained dancers had a distinct advantage over exercise participants in terms of perceiving rhythm and executing complex dance movements (that are not demonstrated isochronously by an instructor). Moreover, we did not ask what type of professional dance training (e.g., salsa, jazz, and etc.) the expert dancers received. The reason we did not explore this potential confound was because former studies have been unable to find significant differences in dance performance between dance disciplines with regards to how movement is coordinated with music at the professional level (Fitch, 2016; Miura, Fujii, Okano, Kudo, & Nakazawa, 2016).

Finally, it is important to emphasize that participants always started the movement phrase from the beginning. This learning strategy was chosen primarily to prevent errors in the middle section of the routine (i.e., as a consequence working memory and chunking). Also, breaking the piece into its component parts is standard practice in both dance and aerobics. However, the learning strategy implemented in the present study could have also led to potential learning differences between the beginning and end of the phrase, due to many more repetitions of the first part when compared to the later parts (see Figure 2). For the purposes of the present experiment, we decided to explore the effects of auditory rhythm on movement accuracy in an applied context (i.e., with a leaning toward greater ecological validity). Our results should be interpreted with this in mind.

**Conclusions and Recommendations**

The present findings may have marked implications for practitioners, particularly as the tasks used were analogous to those employed in real-life dance settings. Dance training may rely too heavily on musical accompaniment with basic rhythms, hence the difficulty experienced by trained dancers in the present study who attempted to coordinate their movements with a highly syncopated rhythm. Training with jazz, latin, or other complex musical rhythms may be beneficial to dancers, as trained jazz musicians appear to be more neuronally sensitive to musical rhythm than nonmusicians as a result of their musical training (see Vuust et al., 2005; Vuust & Witek, 2014).

The effects of increasing level of syncopation on dance performance of male participants remain largely unknown given that the sample used in the present study was exclusively female. However, as this line of investigation has the potential to discriminate against males who may have little movement-to-music experience (Karageorghis, 2017), gender differences could be investigated further by using a male and female sample drawn solely from a population of dancers. Dancers in the present study were trained in ballet, jazz, or contemporary dance. Further style-specific research might reveal differences in task performance and could involve other areas of dance, such as tap or street dance. Moreover, future studies should aim for greater homogeneity in terms of participant characteristics, such as age, nationality, and cultural background. Such characteristics have the potential to moderate how perception of auditory rhythm influences movement accuracy.

The present study has advanced knowledge of the effects of increasing levels of syncopation on the execution of a dance sequence performed by trained dancers and nondancers. A gradual degradation in performance was observed through the conditions from No Syncop to Highly Syncop. The results indicate that trained dancers do not outperform nondancers when administered increasing levels of rhythmic syncopation during a simple dance task.

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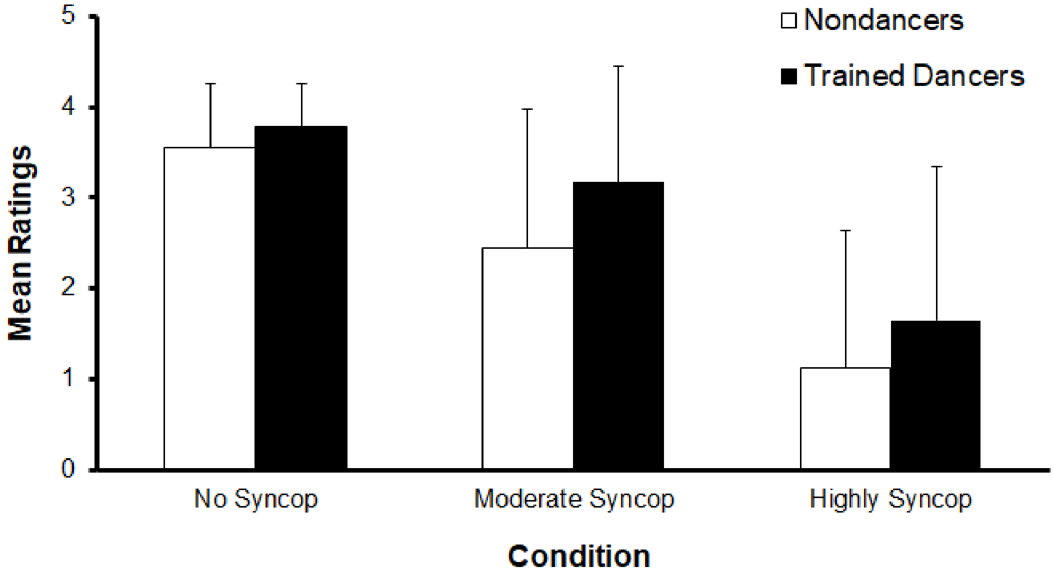


*Figure 1*. Mean ratings for nondancers and trained dancers for No Syncop, Moderate Syncop, and Highly Syncop conditions. *Note*. Error bars denote standard deviation.

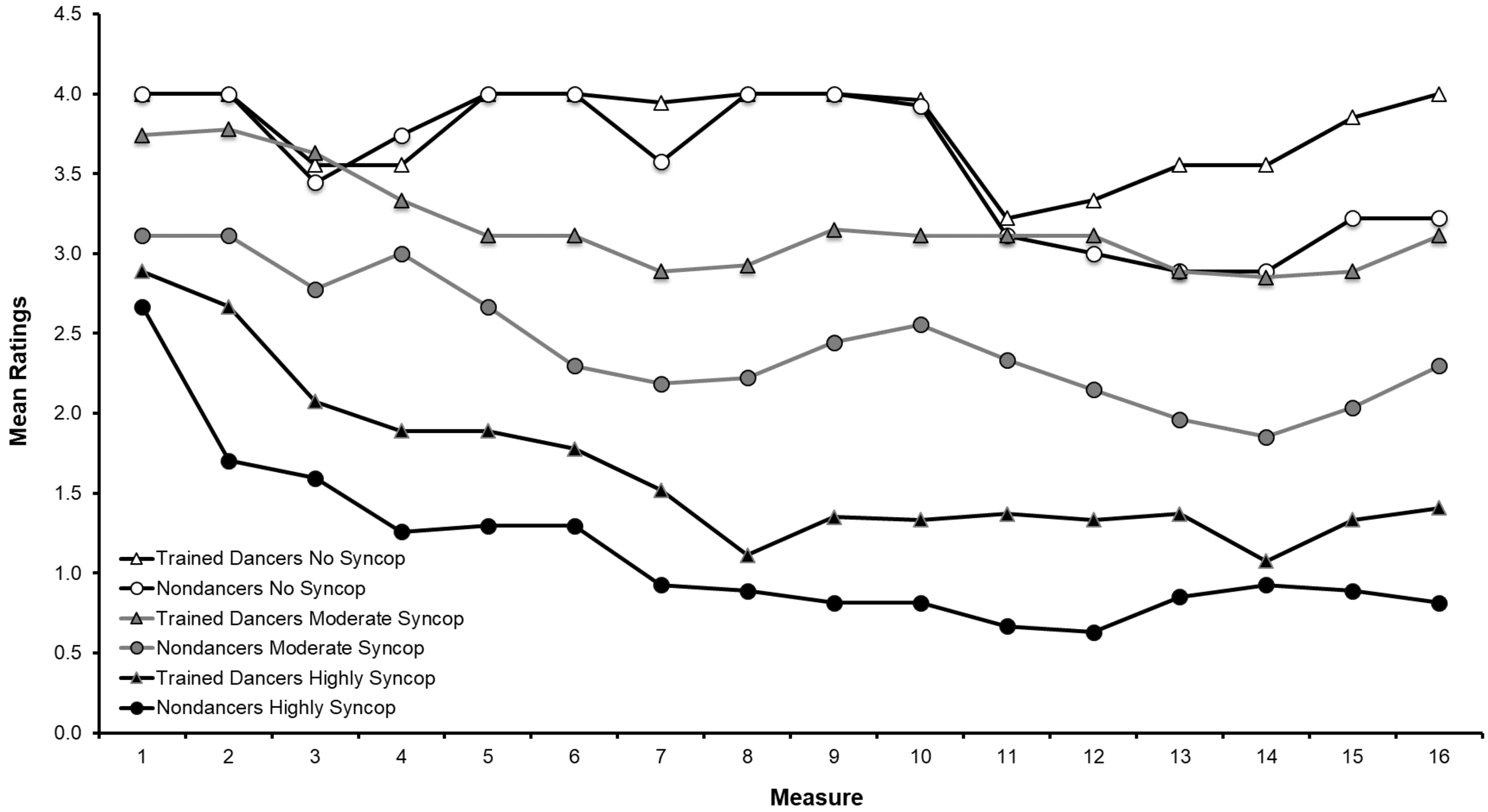


*Figure 2.* Mean ratings for nondancers and trained dancers for No Syncop, Moderate Syncop, and Highly Syncop conditions by musical measure/bar.