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RESEARCH ARTICLE

Does dance training influence beat sensorimotor synchronization? Differences in finger-tapping sensorimotor synchronization between competitive ballroom dancers and nondancers

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Abstract

Sensorimotor synchronization is the coordination of rhythmic movement with an external beat. Dancers often synchronize each beat of their motion with an external rhythm. Compared with social dancing, competitive ballroom dancing requires a higher level of sensorimotor ability. Although previous studies have found that dance experience may facilitate sensorimotor synchronization, they did not examine this in competitive ballroom dancers. Thus, the present study compared sensorimotor synchronization in 41 nondancers and 41 skilled, competitive ballroom dancers as they performed a simple beat synchronization finger-tapping task. All participants finger-tapped freely at their preferred tempo before the formal experiments. Participants were then required to synchronize their finger-tapping with auditory, visual, or combined audiovisual signals in separate experiments and at varying tempos. To assess sensorimotor plasticity, the participants then repeated the free-tapping task after completing all three finger-tapping experiments. Compared with nondancers, dancers showed more accurate and stable beat synchronization. Dancers tapped before onset of all three types of sensorimotor stimulation, indicating a significant negative mean asynchrony and had a tendency to anticipate (predict) the stimuli. Dancers tended to auditory stimulation for beat sensorimotor synchronization, whereas nondancers tended to visual stimuli. Dancers had a faster tempo preference in the initial free-tapping task; however, the preferred tapping tempo increased in all participants in the second free-tapping task, suggesting that beat induction is affected by practice. Together these findings suggest that dance experience enhances sensorimotor synchronization and sensorimotor plasticity, with ballroom dancers tending to auditory stimulation for beat induction.

Keywords Beat induction · Ballroom dancer · Auditory · Visual · Sensorimotor synchronization

Introduction

Sensorimotor synchronization (SMS) refers to "the coordination of rhythmic movement with an external rhythm" or beat, and it can range from simple finger- or toe-tapping to the complex performance of music (Repp 2005; Repp and Su 2013). According to Rajendran et al. (2017), the pulse or beat is not a physical property of the music itself but is a perceptual phenomenon that arises from the music through beat induction. Beat induction is the ability not only to extract a periodic pulse from music (Honing 2012; Ravignani et al. 2017) but also to synchronize the tempo of body itself with this pulse. Thus, beat induction is a representation of SMS, and it is involved in environmental rhythmic sensory stimuli and daily behaviors, such as walking, playing music, dancing, or clapping (Blais et al. 2015; Repp 2010), and is widely considered a cognitive skill (Honing 2012).

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Finger-tapping is the most popular paradigm used to investigate SMS, to assess an individual's SMS and the perceived beat in participants. Synchrony and asynchrony can be assessed as the difference in the mean time delay between a stimulus and participant's corresponding tap and as the variability in the mean delay over time (Blais et al. 2015; Chen et al. 2002). Participants tend to predict stimulus onset and tap before it is presented. Thus, rather than being distributed symmetrically around the stimulus onset, mean asynchrony is typically negative (Repp and Su 2013), and as such is referred to as negative mean asynchrony (NMA). The cause of NMA has been explored in numerous studies. For example, music training has been reported to reduce NMA compared with that in nonmusicians (Aschersleben 2002), and individual differences and sensory modalities can contribute to NMA (Repp 2005). But whether dance training influences NMA is still not fully understood. Moreover, the synchronization strategy of an individual can be assessed using the NMA measurement: NMA indicates that a strategy of predictive timing is being used, whereas positive asynchrony suggests the use of an event-based strategy (Dione and Delevoye-Turrell 2015; Wing and Kristofferson 1973). The mean absolute asynchrony is also an index used for examining the synchronization performance: lower absolute asynchrony scores indicate greater synchrony. The standard deviation (SD) of the asynchrony is an index of stability and precision.

One prevailing finding is that synchronized performance also depends on the sensory modality. When participants are required to tap along with an auditory (tone) or visual (flashing light) stimulus, synchronization with the auditory stimulus is more accurate (Hove et al. 2013; Iversen et al. 2015; Tierney and Kraus 2013), whereas combined auditory and visual stimuli result in the best synchronization (Hove et al. 2013; Iversen et al. 2015). Higher stability of synchronization is usually found in tapping with auditory pacing stimuli rather than with visual stimuli (Chen et al. 2002; Repp and Penel 2002).

In the terms of rhythm beats, several studies have shown that humans prefer a tempo of 1.5–2.5 Hz (with interbeat intervals between 400 and 700 ms) for musical rhythms (Parncutt 1994, Su 2016) and a frequency of 2 Hz for finger-tapping tasks (Macdougall and Moore 2005). When judging the duration of the intervals, participants tend to overestimate shorter intervals (250–400 ms), underestimate longer ones (600 ms to 2 s), and best estimate intervals between 400 and 600 ms, the latter of which corresponds to the spontaneous tap rate in humans (Rajendran et al. 2017). Various SMS studies have screened participants with little music experience (Blais et al. 2015; Delignières et al. 2004) as well as musicians (Aschersleben 2002; Baumann et al. 2007; Hove et al. 2013, Su 2014) and dancers (Miura et al. 2011; Murgia et al. 2017). Studies have consistently found that experience in music facilitates SMS performance (Krause et al. 2010; Miura et al. 2016; Repp and Su 2013; Stupacher et al. 2017). Moreover, street dancing experience also promotes SMS, with higher level skills corresponding to more accurate and stable SMS (Miura et al. 2016).

Throughout human evolution, dance has been a traditional performance consisting of purposeful sequences of movement. One of the most representative intrinsic movements of human SMS motion is the tight coupling of various kinds of music to a beat. Dancing contains structured movement patterns performed in time to music and temporally coordinated with a musical beat (Su 2016), and people usually raise their hands, swing their arms and legs, and sway their body along with the music. Hitting the beat too soon or too late may destroy such a dance rhythm. Thus, dance movement can be strongly associated with SMS. Previous studies have examined the influence of stimuli (auditory and visual) (Iversen et al. 2015; London et al. 2016), tempo (faster or slower beat) (Dahl et al. 2014; Repp 2006), and experience (Miura et al. 2016) to dance-related SMS. Researchers have found that dance training might also facilitate SMS (Karpati et al. 2016). A specific type of dancing, called dancesport or competitive ballroom dancing has evolved so much in its choreography over the years that it requires a high level of athleticism. Compared with social dancing, competitive ballroom dancing requires greater physical attributes and demands and a higher level of perception and synchronization of motion with strong beats, which may contribute to enhanced SMS among such dancers. Although ballroom dancers have motor experience as well as dance performance advantages over nondancers, the extent to which these characteristics influence SMS or the characteristics of SMS that may be unique to ballroom dancers is unknown. Whether SMS is also influenced by dance experience among ballroom dancers or whether there exists tempo range differences between dancers and nondancers remains unknown. In addition, whether the SMS characteristics of ballroom dancers are similar to those of dancers performing other types of dances is also unknown.

The purpose of the present study was to explore the characteristics of SMS and whether sensorimotor plasticity is affected by practice training in highly skilled, competitive ballroom dancers. We hypothesized that (1) dance experience would improve SMS performance in dancers compared to nondancers and those dancers would show an ability to synchronize with a larger range of tempi than nondancers would and (2) competitive ballroom dancers would perform more accurate than nondancers in all modalities, especially for audio-related modality, which may be attributable to dance experience accompanied with music.

Methods

Participants

To achieve a statistical power of 80% to conduct statistical assessments, a power analysis indicated that 82 participants were required. Candidate participants were screened at Nanjing University of Sports and Shanghai University of Sports for ballroom dance training and music experience. Ballroom dancers with at least 5 years of ballroom dance experience who had won at least a provincial dancesport competition were recruited. Individuals who reported extensive training in music were excluded. After screening, 41 skilled ballroom dancers (18 men; mean age, 20.3 ± 1.1 years) and 41 nondancer controls (16 men; mean age, 22.2 ± 1.9 years) were recruited. All participants were of Chinese nationality. The skilled dancers had 2346 ± 1777 h of accumulated dance practice time (6.4 ± 3.4 years of dancing experience). The nondancer controls had no training or experience in any kind of dance or music. Hereafter, we refer to the ballroom dancing group as dancers and the control group as nondancers. All participants were consistently right-handed. They did not have any observable cognitive, motor, or sensory disorders that could affect their ability to perform the required task.

Materials

The experiment was conducted in a dimly lit room. A computer (X64 architecture and Windows 7 Ultimate System) provided visual instructions and auditory metronome sounds using routines from Psychtoolbox 3.0 running in Matlab (The Mathworks Inc., MA, USA, R 2013a). The screen was placed 1 m in front of the participants.

The experimental program was controlled by a customized Matlab script using Psychtoolbox 3.0 routines running on a Windows 7 Ultimate environment. The visual stimuli were displayed on a 19.5-inch LED monitor (ThinkVision T2014D) with a frame frequency of 75 Hz and a spatial resolution of 1280×1024 pixels. Auditory stimuli were presented with in-ear headphones (Sennheiser, CX 3.00) at a comfortable hearing level. The reaction was tapped on a mechanical keyboard (Filco FKBN104MRL/EB2).

Task

The task involved tapping the index finger of right hand on the "M" key of a keyboard in synchronization with visual (flashes), auditory (beeps) or combined audiovisual (flashes and beeps) stimuli. The visual stimulus was a blue circle (2.5 cm in diameter) presented in the center of a gray screen for 40 ms. A low-pitched (500 Hz) "beep" tone played for 40 ms served as the auditory stimulus. For the combined audiovisual task, the flash and beep were presented simultaneously. All beat intervals ranged from 0.2 to 1.2 s, with a step of 0.1 s, which is from 50 beats per minute (BPM) to 300 BPM (i.e., 50, 54, 60, 66, 75, 88, 100, 120, 150, 200, and 300 BPM), and the beat rate increased from 0.83 to 5 Hz.

Procedures

Before the experiment, participants read and signed an informed consent form approved by the Shanghai University of Sport. All procedures were performed in accordance with the ethical standards of the Shanghai University of Sport Research Ethics Committee and with the 1964 Helsinki Declaration. During the experiment, participants sat comfortably in front of the screen with their right-hand index finger positioned on the "M" key of the keyboard, ready to perform the finger-tapping task. Participants were asked to complete a free-tapping task, which required tapping the "M" key to express the beat preferred in their daily life. Participants were then asked to practice several trials until they understood the required auditory, visual, and audiovisual stimulation tasks. The formal trials began after completion of the practice trials. During each trial, a visual instruction ("Press SPACE to start the test") appeared on the screen until the participant pressed the space bar on the keyboard. Then a black cross appeared in the middle of the screen (1000 ms) before the stimulus appeared. The cross appeared on the screen for the duration of trials with the auditory stimulus, whereas for trials with visual or audiovisual stimuli, the cross disappeared and the circle flashed at different tempos. The appearance of the stimulus was entirely predictable, and participants were never surprised. At the end of the trial, a visual stimulus ("STOP") was shown on the screen for 1000 ms. Each trial lasted approximately 22 s. The participants could trigger the next trial whenever they wanted. Participants were required to keep their eyes open during the performance of all tasks. Each of the three experimental tasks contained 11 beat intervals that were randomly repeated four times, with total numbers of 44 stimuli per condition. All participants completed the visual, auditory, and audiovisual stimulation tasks separately, and the order of the three tasks was randomized across participants. After completion of all three tasks, the participants were again asked to tap their preferred tempo using the "M" key to investigate the influence of beat-tapping practice on personal beat preference. The entire session took approximately 1.5 h. All participants were fully debriefed after the study.

Statistical analysis

Synchrony and asynchrony were analyzed by averaging the difference in the mean delay times between the presentation of each stimulus and the participant's corresponding tap. The script was set up to calculate the time only when the keyboard was pressed. When a tap fell exactly between two stimuli, it was allocated to the previous stimulus. However, if participants did not press the keyboard during presentation of stimuli, the script would reject the trial for the results output. If participants did not tap for the first beat until the second beat appeared, and then realized this and delayed their reaction, this tap was also deleted from the data analysis. These were all considered invalid taps and were rejected by the script.

The relative average asynchrony was assessed to evaluate the predictive or tracking strategies of participants for tapping synchronization. The standard deviation in the tapping delay over time was used to estimate the variability in beat synchrony (Blais et al. 2015; Chen et al. 2002). The average asynchrony for each trial was calculated by converting the asynchrony series between each tapping to absolute values to avoid the prediction (negative) or tracking (positive) strategies in the corresponding beat (Dione and Delevoye-Turrell 2015). Thus, lower absolute asynchrony scores indicated better performance (i.e., greater synchrony). In addition, the tapping beat preference was determined by comparing the initial free-tapping interval with that after the completion of the three types of stimulation.

A 2 (group: dancers and nondancers) by 3 (stimulus type: visual, auditory, and audiovisual) by 11 (beat interval: 50, 54, 60, 66, 75, 88, 100, 120, 150, 200, and 300 BPM) mixed-level analysis of variance (ANOVA) was conducted to analyze the interactions among participant group, stimulation type, and beat interval. The participant group served as the between-subjects variable, whereas stimulation type and beat interval were the within-subjects variables used to assess the mean and the SD of SMS at each beat interval. In the ANOVA, when Mauchly's test of sphericity showed heterogeneity of covariance, the more conservative Greenhouse–Geisser test was performed. Statistical significance was set at $p < 0.05$. When one of the ANOVA factors was significant, Bonferroni post hoc tests were performed.

A 2 (group: dancers and nondancers) × 3 (stimulus type: visual, auditory, and audiovisual) × 2 (free-tapping: pre-task, post-task) repeated measures ANOVA was used to assess the effect of training on free-tapping by comparing the interval before the task with that after completing tasks in three types of stimuli (auditory, visual, and audiovisual).

Results

Beat preference

The results of a repeated measures ANOVA indicated significant main effects of stimulus type ($F_{(2,160)} = 15.65$, $p < 0.0001$, $\eta_p^2 = 0.164$), free-tapping task ($F_{(1,80)} = 25.18$, $p < 0.0001$, $\eta_p^2 = 0.239$), and participant group ($F_{(1,80)} = 9.27$, $p = 0.003$, $\eta_p^2 = 0.104$). There were significant interactions between stimulation type and group ($F_{(2,160)} = 4.49$, $p = 0.024$, $\eta_p^2 = 0.053$), stimulation type and tapping task ($F_{(2,160)} = 5.04$, $p = 0.015$, $\eta_p^2 = 0.059$), and tapping task and group ($F_{(1,80)} = 4.07$, $p = 0.047$, $\eta_p^2 = 0.048$). Bonferroni post hoc pairwise comparisons revealed that (1) dancers (353 ± 43 ms) tapped faster than nondancers (536 ± 43 ms) in the three stimulation conditions ($p = 0.003$); (2) there were differences in tapping speed among the three types of stimulation in nondancers, with fastest tapping for visual stimuli (450 ± 38 ms, $p < 0.0001$) and slowest tapping for auditory stimuli (626 ± 54 ms, $p = 0.023$), but no significant difference was found in the dancer group; (3) participants tapped quicker in the post-tapping task than in the pre-tapping task in the dancer group (306 ± 36 ms and 399 ± 57 ms, respectively, $p < 0.05$) and in the nondancer group (427 ± 36 ms and 646 ± 57 ms, respectively, $p < 0.0001$).That is, after completing the whole experiment, all participants preferred tapping at a faster tempo. However, these increases in the tapping beat, calculated by post-tapping beat minus pre-tapping beat, were not significantly different between the two groups (all p values > 0.05).

A repeated measures ANOVA of the SD demonstrated that only the main effect of tapping task ($F_{(1,80)} = 26.24$, $p < 0.0001$, $\eta_p^2 = 0.247$) was significant; that is, the SD in the initial tapping task was larger (more variable) than that in the post-tapping task ($p < 0.0001$). The tempo was more stable in the free-tapping task performed after completing the whole experiment than that in the initial free-tapping task. However, there was no significant difference between the dancers and the nondancers ($p > 0.05$).

Mean asynchrony: SMS accuracy

To explore absolute asynchrony in dancers and nondancers, the mean asynchrony between tapping and stimulus presentation (beep, flash, or beep with flash) was determined (Fig. 1). The results indicated that dancers anticipated the stimuli, which was reflected as a negative reaction time. Mean asynchrony in a group of dancers is typically negative (Repp and Su 2013). Therefore, the absolute error between finger-tapping and stimuli onset (which is positive) was examined next.

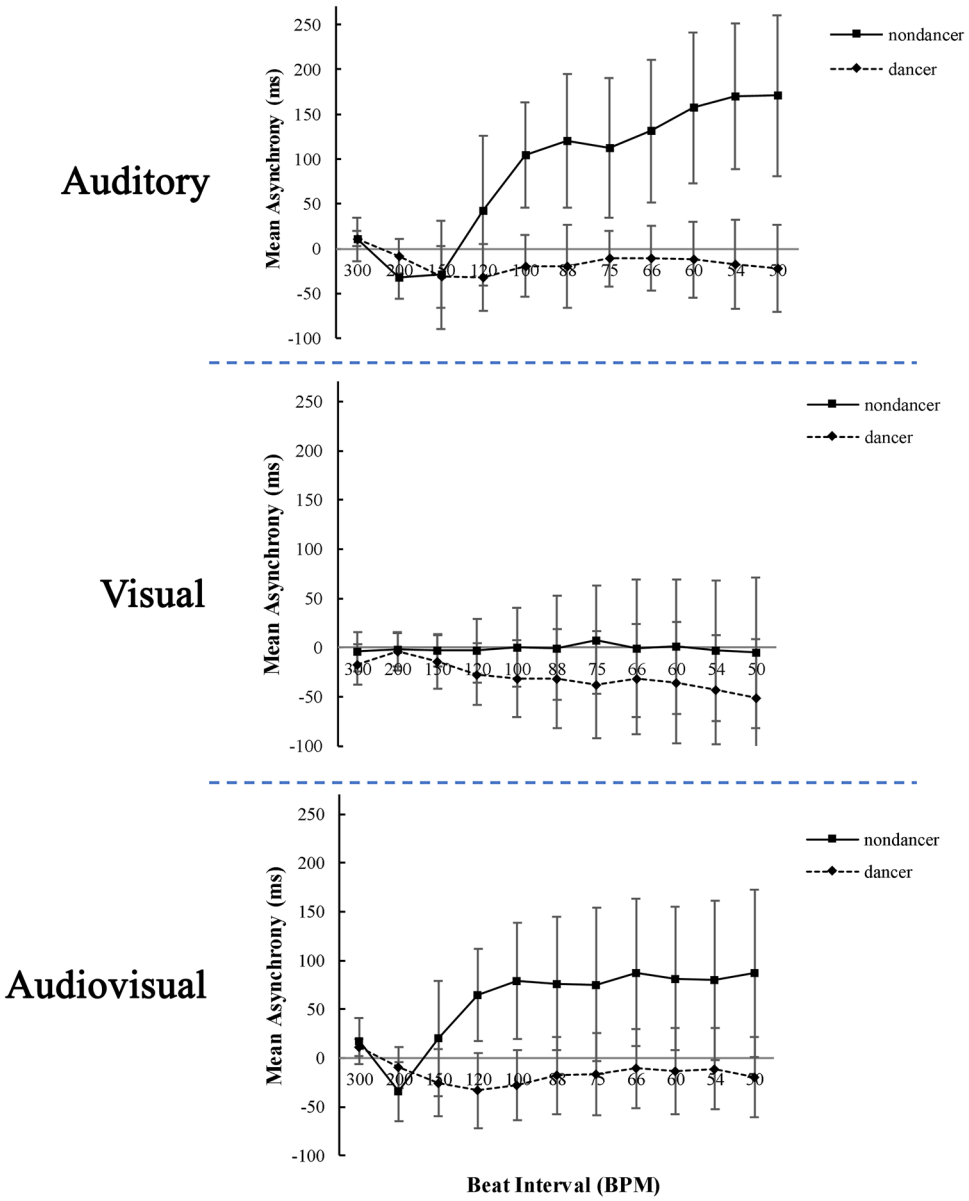

Fig. 1 Mean asynchrony of beat intervals for dancers and nondancers during the presentation of the three types of stimuli, auditory, visual, or combined audiovisual. A positive value indicates a "tracking" beat-tapping strategy, whereas a negative value indicates a "predictive" beat-tapping strategy. Error bars represent the standard deviation of the mean asynchrony corresponding to 95% confidence intervals

Absolute error of mean asynchrony

To examine the exact mean asynchrony of each tap with the stimuli, the absolute error of the mean asynchrony was determined (Fig. 2). A three-way ANOVA examining the absolute error in finger-tapping and stimulus asynchrony revealed significant main effects of stimulus type ($F_{(2,160)} = 38.93$, $p < 0.0001$, $\eta_p^2 = 0.327$), beat interval ($F_{(10,800)} = 100.20$, $p < 0.0001$, $\eta_p^2 = 0.556$), and participant group ($F_{(1,80)} = 91.84$, $p < 0.0001$, $\eta_p^2 = 0.534$). Bonferroni corrected comparison showed that, absolute error of mean asynchrony in dancer group (34.35 ± 2.95 ms) was significantly smaller than nondancer group (74.30 ± 2.95 ms), $p < 0.0001$.

In addition, there were significant interactions between stimulus type and participant group ($F_{(2,160)} = 81.94$, $p < 0.0001$, $\eta_p^2 = 0.506$); beat interval and participant group ($F_{(10,800)} = 29.63$, $p < 0.0001$, $\eta_p^2 = 0.270$) and stimulus type, beat interval, and participant group ($F_{(20,1600)} = 14.11$, $p < 0.0001$, $\eta_p^2 = 0.150$). To further explore the interactions among participant group, beat interval, and stimulus type, we conduct several mixed-level ANOVAs and simple effect analyses. The Bonferroni post hoc pairwise comparisons indicated that for auditory stimulation, (1) the nondancer control group had a larger absolute error than the dancer group at all beat intervals (all values of $p < 0.01$); (2) for dancers, there were error differences only in 150 BPM and 300 BPM, (i.e., 120–300 BPM) (all values of $p < 0.01$); (3)

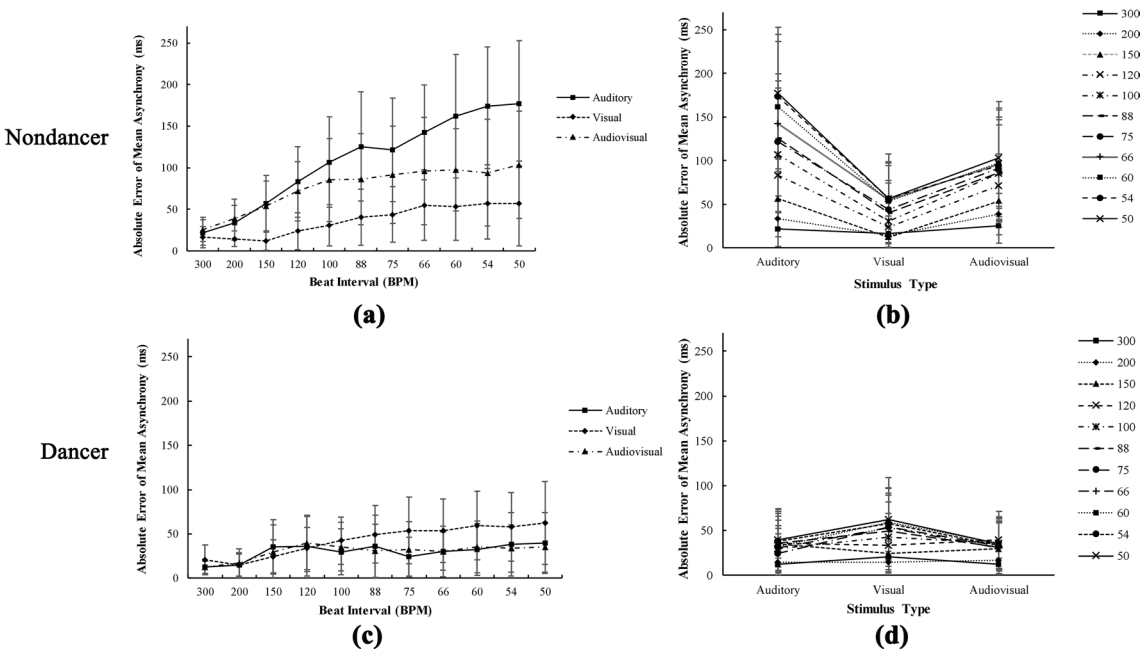

Fig. 2 Absolute error in the mean asynchrony of **a** beat intervals and **b** the three types of stimulation among nondancers, and the **c** beat intervals and **d** three stimulus types among dancers. Error bars represent the standard deviation of the absolute mean asynchrony corresponding to 95% confidence intervals

for the control group, there was a stable error mean asynchrony range of 75 BPM to 120 BPM (all values of $p > 0.05$), whereas significant differences were found at the other times (all values of $p < 0.0001$). For visual stimuli, the absolute error of mean asynchrony at 150–300 BPM was significantly smaller than that of the other beat intervals ($p < 0.0001$ for all comparisons), and there was no significant difference at beat intervals of 50–85 BPM ($p > 0.05$). For the combined audiovisual stimuli, (1) the nondancers had a larger absolute error than the dancers at all beat intervals (all values of $p < 0.01$); (2) for dancers, there were only significant error differences between 120 BPM and 200 BPM/300 BPM (all values of $p < 0.05$); (3) for the nondancers, there were significant error differences in the range from 150 BPM to 300 BPM (all values of $p < 0.001$).

In addition, for the dancer group, the absolute error for the auditory stimulation was significantly smaller than that for the visual stimulation ($p < 0.0001$) but not for the audiovisual stimulation ($p > 0.05$). For the nondancer group, the absolute error for the visual stimulation was significantly smaller than that for both the auditory ($p < 0.0001$) and the audiovisual ($p < 0.0001$) stimulation.

Standard deviation of asynchrony: sensorimotor stability

The results of an ANOVA revealed main effects of stimulation type ($F_{(2,160)} = 104.93$, $p < 0.0001$, $\eta_p^2 = 0.567$), participant group ($F_{(1,80)} = 68.91$, $p < 0.0001$, $\eta_p^2 = 0.463$), and beat interval ($F_{(10,800)} = 132.46$, $p < 0.0001$, $\eta_p^2 = 0.623$). Bonferroni corrected multiple comparisons of main effects indicated that (1) the nondancer group (125.95 ± 3.41) showed more variable SD for asynchrony than the dancer group (85.91 ± 3.41), $p < 0.0001$; (2) the audiovisual stimuli (89.01 ± 2.79) showed the smallest SD, and the SD for visual stimuli (122.38 ± 2.55) was the largest, all values of $p < 0.0001$. The differences among participant group, beat interval, and stimulation type are illustrated in Fig. 3, which compares the SD of the asynchrony in the two groups across the beat intervals for the three types of stimuli. Three-way ANOVA results indicated significant interactions between stimulation type and participant group ($F_{(2,160)} = 56.18$, $p < 0.0001$, $\eta_p^2 = 0.413$); beat interval and participant group ($F_{(10,800)} = 5.42$, $p = 0.002$, $\eta_p^2 = 0.063$); beat intervals and stimulus type ($F_{(20,1600)} = 8.75$, $p < 0.0001$, $\eta_p^2 = 0.099$); and participant group, beat interval, and stimulus type ($F_{(20,1600)} = 5.23$, $p < 0.0001$, $\eta_p^2 = 0.061$).

Significant interactions were further examined used Bonferroni post hoc pairwise comparisons, which are illustrated in Fig. 4. For auditory stimulation, the nondancers had a larger SD than the dancers across all beat intervals (all values of $p < 0.0001$); for dancers, there were no significance differences at the shortest beat intervals (200, 300 BPM), medium beat intervals (85, 100 BPM), or longest beat intervals (50–75 BPM), but there were significant differences between the three interval lengths (values of $p < 0.0001$),

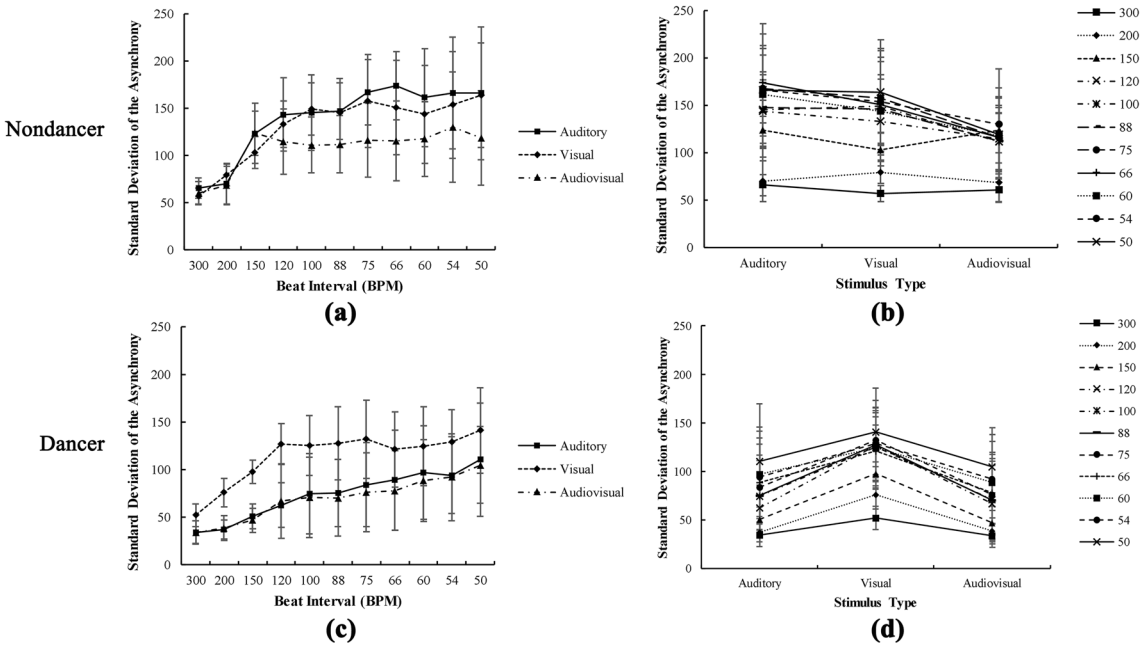

Fig. 3 Standard deviation of the asynchrony of **a** beat intervals and **b** the three types of stimulation among nondancers, and the **c** beat intervals and **d** three stimulus types among dancers. Error bars represent the standard deviation in the asynchrony corresponding to 95% confidence intervals

with longer beat intervals having a more variable tapping rate. For visual stimulation, the SDs of beat intervals 150–300 BPM were significantly smaller than those of the others ($p < 0.0001$ for all comparisons); the longer the interval, the more variable the tap. For the combined audiovisual stimulation, nondancers had a larger SD than the dancers did at 54–300 BPM beat intervals (all values of $p < 0.05$).

In addition, for the dancer group, the SD for visual stimulation (114.08 ± 3.34) was significantly larger than those for both auditory (73.72 ± 4.47, $p < 0.0001$) and audiovisual (69.93 ± 4.47, $p < 0.0001$) stimulation; the SDs for the 120–300 BPM intervals were significantly larger than those for the other intervals ($p < 0.0001$). For the nondancer group, the SD for audiovisual stimulation (108.10 ± 3.35) was significantly smaller than those for both auditory (139.07 ± 3.37, $p < 0.0001$) and visual (130.69 ± 3.85, $p < 0.0001$) stimulation.

Discussion

The present study investigated beat induction in skilled ballroom dancers, who combine choreography and athleticism, by assessing their preferred finger-tapping interval, accuracy, and stability as compared with those in nondancers. Our results indicated that beat induction in SMS varied based on dance experience. The preferred beat tempo in dancers was faster than that in nondancers for all three sensorimotor stimulation types. In addition, we found that dancers but not nondancers tapped before the onset of auditory, visual, or audiovisual stimuli. Dancers displayed less asynchrony (thus better synchrony) with auditory stimuli, whereas nondancers showed less asynchrony with visual stimuli. Dancers also showed greater synchronization, less variability, and the ability to tap over a broader tempo range in the present tapping synchrony task than nondancers. We also found that dancers preferred faster tempos than nondancers, which may due to dance experience, and for all participants, practicing sensorimotor training appeared to change beat preference.

The NMA phenomenon, which refers specifically to finger-tapping before the stimulus onset, was more marked in dancers than in nondancers. This result indicated that dancers used a prediction strategy. By contrast the nondancers tended to track the beats although beat induction among nondancers at the relatively short intervals, such as 150–300 BPM, tended to precede stimulus onset. This later finding is consistent with the results of a previous study that found that when the sequence intervals are shorter, responses turn toward anticipation (Engström et al. 1996). However, our results comparing dancers and nondancers differed from those of previous studies comparing musicians and nonmusicians, which indicated that musicians tend to show less NMA than nonmusicians (Aschersleben 2002). This difference in findings for dancers versus musicians may be caused by a general anticipation process in dancers, who are required to move the entire body when dancing to be on

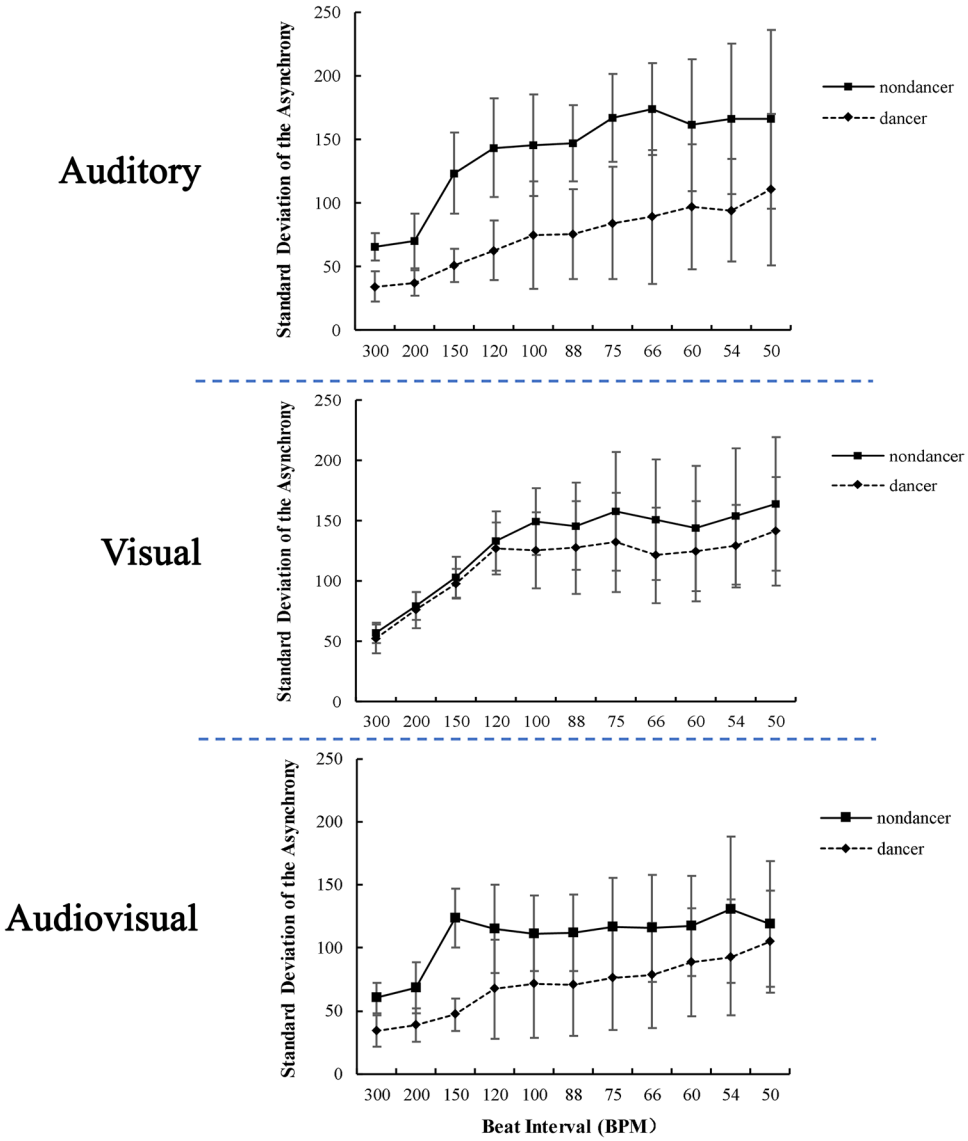

Fig. 4 Standard deviation of the asynchrony in ballroom dancers and nondancers based on the three types of stimulation. Error bars represent the standard deviation in the asynchrony corresponding to 95% confidence intervals

time, which requires more anticipation time (Di et al. 2017; Miura et al. 2016; Romeas and Faubert 2015), contributing to a greater SMS ability. The present study focused on beat induction among ballroom dancers, who were not only aesthetic dancers but also skilled competitive athletic dancers. Therefore, they are likely accustomed to anticipating the beat onset, aiming to synchronize exactly with the music tempo. A greater NMA for dancers in the visual stimulation task would be consistent with the difference they showed for greater synchronization with auditory rather than visual stimulation. However, we found a visual perception preference for nondancers, which is reflected in a lower absolute error asynchrony for visual stimulation than for auditory or audiovisual stimulation. Tranchant et al. (2017) found that the auditory advantage in synchronization was more experience- and stimulus-dependent. Our inconsistency with their results may be because the participants in the present study reported no music or dance experience and thus may have less training in the auditory modality. In addition, the presented stimuli differed between their study and ours. Our finding suggested that whereas nondancers tended to use visual stimuli to perceive a beat, trained ballroom dancers have a greater sensitivity to the pulse or beat of the music (auditory stimulation) rather than to visual information. The neural mechanism for these different results should be explored in future studies. This result offers new data on sensorimotor (Miura et al. 2011) and cognitive SMS processes in dancers (Kattenstroth et al. 2011) and especially provides new evidence of neural plasticity (Ermutlu et al. 2015) in dancers, particularly in trained ballroom dancers.

Tapping accuracy and stability were assessed, respectively, using the absolute error and SD of mean asynchrony. A greater absolute error in mean asynchrony indicates lower accuracy. Dancers have been shown to possess greater SMS

accuracy, indicating that they have more precise temporal control than nondancers (Delignieres et al. 2004; Repp 2005; Zelaznik et al. 2002). Consistent with the NMA effects observed in the present study, the absolute errors indicated an auditory advantage in dancers and a visual advantage in nondancers. Both dancers and nondancers showed markedly greater absolute errors for longer beat intervals, which correspond to slower tempi (Madison 2014). As shown in Fig. 2, absolute errors gradually increased with longer beat intervals in nondancers. This relationship was more complex in dancers. At longer beat intervals, such as 50–85 BPM, dancers demonstrated absolute error differences similar to those at short intervals. However, unlike the nondancers, who showed a modest increase in absolute errors for the mid-intervals (from 66 to 150 BPM), dancers displayed zigzag-like error differences. This finding may shed light on information processing underlying SMS in dancers.

The stability of the beat tempo synchrony was evaluated by assessing the SD in mean asynchrony. As the beat interval increased, the SD became greater in both dancers and nondancers, indicating an unstable beat perception at long intervals for all participants. However, the lower SD in mean synchrony displayed by the dancers indicated that this group had better beat induction. Moreover, as shown in Fig. 3 and especially in Fig. 4, beat induction in the two groups was markedly different. We found a substantial auditory advantage in dancers and a visual advantage in nondancers, with the auditory and audiovisual stimuli showing a greater difference between these two groups than the visual stimuli. Nevertheless, the variability of taps synchronized with audiovisual stimuli was the smallest for all participants, showing a cross-modal integration and enhancement, as has been found in previous studies (London et al. 2016; Tranchant et al. 2017). At beat intervals below 120 BPM, all participants displayed increased SD with increasing beat interval. However, above 120 BPM, the advantage for auditory stimulation became more apparent for dancers.

After performing a free-tapping task and finger-tapping synchronized to three types of stimuli (auditory, visual, and audiovisual), both dancers and nondancers showed a preference for more rapid free-tapping and a more stable beat tempo during free-tapping than during the initial free-tapping, which suggested a short-term training effect. Interestingly, in the initial preferred tapping task, dancers had a significantly faster tempo than nondancers, which may reflect a long-term effect of dance experience. Whether dance experience influenced tempo preference needs to be explored in future studies. This finding suggests that beat induction practice may alter motor output, consistent with the suggestion of enhanced neural plasticity that has been mentioned in previous studies (Ermutlu et al. 2015; Fine et al. 2017; Fujioka and Ross 2017). Our finding of no significant differences in these measures between the two groups indicated that dance experience has no additional influence on the beat induction practice effect.

Our study had some limitations that should be considered. Firstly, the mean asynchrony scores may be somewhat positively skewed due to using a keyboard in the present tapping task, though, in which any delay was averaged and similar for all participants. The effective measurement of latency from the keyboard should be found to improve this kind of design. Because we conducted a cross-sectional behavioral study to explore beat induction advantage and plasticity in ballroom dancers, causality cannot be deduced. However, although our findings could not elucidate the neural mechanisms underlying the beat induction advantage associated with dance experience, we provided new data on this aspect among ballroom dancers. Future studies will be required to determine whether beat induction advantage in humans is caused by neural oscillations.

In summary, the present study concluded (1) that dancers had a faster tempo preference due to their dance experience, and training caused a similar effect in all participants; (2) that dancers use "predictive" beat induction strategies, (3) that for beat induction, dancers tend to auditory stimulation, whereas nondancers tend to visual stimulation, and (4) that dancers have more accurate and stable beat SMS than nondancers. The present study used the same paradigm as that used in previous studies (Blais et al. 2015; Miura et al. 2016; Repp and Su 2013) to investigate SMS characteristics in dancers, providing evidence of SMS beat induction for competitive ballroom dancers. The sensorimotor plasticity found in the present study may provide novel motor training ideas. Our findings indicate that further study investigating the development of cognitive–neural mechanisms in beat induction among experienced dancers is warranted.

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Compliance with ethical standards

Ethical standards All procedures performed in studies involving human participants were in accordance with the ethical standards of the Shanghai University of Sport Research Ethics Committee and with the 1964 Helsinki Declaration and its later amendments or comparable ethical standards.

Informed consent Informed consent was obtained from all individual participants included in the study.

Conflict of interest The authors declare that they have no conflict of interest.

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