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An Investigation of Musicians' Synchronization with Traditional Conducting Beat Patterns

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ABSTRACT Previous work has identified a transfer of domain-specific corporeal skill to a related task such that musicians are more accurate when synchronizing with conductors' gestures if they themselves have some prior conducting experience. The present study built upon this work, which used rather simple conducting gestures, by examining synchronization with more complex gestures. Participants were presented with life-size point-light representations of traditional three-beat conducting gestures, and had to tap in synchrony with the beat in each case. As in previous work, participants with previous conducting experience demonstrated higher levels of synchronization accuracy compared to those with no such previous experience. In addition, a positive relationship between tempo and accuracy was identified, while the first beat of each measure received the most accurate responses overall. The transfer of domain-specific corporeal skill in this context highlights the benefit of offering conducting tuition to ensemble musicians in order to improve their synchronization with the conductor.

KEY WORDS: Gestures, sensorimotor synchronization, point-light display

Introduction

Musicians playing in a conducted ensemble can utilize both auditory and visual cues in order to synchronize their performances with each other. Auditory cues are provided solely by the other musicians, while visual cues are primarily provided by the conductor. The musicians, too, may provide some visual synchronization cues to each other, even in a conducted ensemble, but it is the conductor who is the sole visual-only cue-provider. Musicians' ability to pick up and make use of these auditory and visual synchronization cues is, therefore, a necessary skill for a polished ensemble performance (Keller, 2001). The present study investigated people's ability to synchronize with the visual cues provided by a conductor's gestures.

A typical temporal, as opposed to expressive[1], conducting gesture denotes the tempo

[1]Note that a gesture can be both temporal *and* expressive, with basic temporal gestures often being embellished so as to indicate expressive intentions of the conductor. What we refer to here, however, are the simplest beat-patterns denoted in conducting texts, the basic tools of time-keeping

or speed at which the music should be played, and may be best described as a periodic sequence of beats. These periodic sequences are combined into various patterns, dependent upon the time-signature (number of beats in the bar) of the music being played.

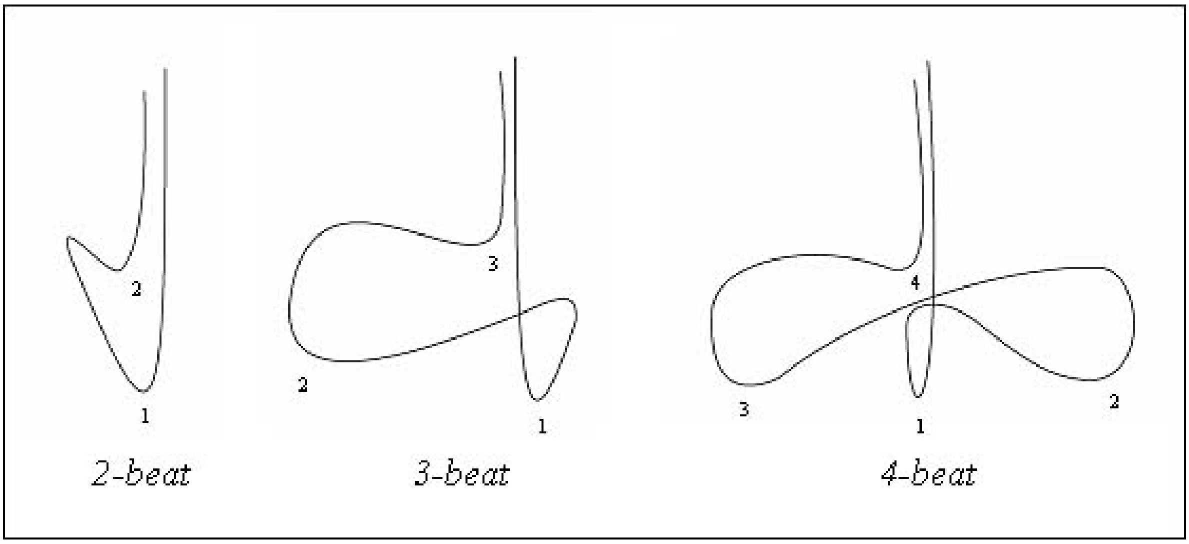

Figure 1. Examples of typical *two-*, *three-*, and *four-beat* conducting patterns, as seen from the musicians' perspective.

Examples of typical two-, three-, and four-beat patterns are shown in Figure 1.
In terms of basic visual synchronization abilities, Kolers & Brewster (1985) found that people demonstrated less consistency in synchronizing with simple visual stimuli (e.g., light flashes) compared to auditory or tactile stimuli, with visual responses tending to precede stimulus onset at fast speeds, but follow stimulus onset at slower speeds, even when accurate visual feedback was provided. Chua, Weeks, Ricker, & Poon (2001) also found speed-related differences in the variability of responses to simple visual stimuli, with faster stimulus speeds being associated with more variable and less accurate responses. These findings suggest that there may be tempo-related differences in musicians' ability to synchronize with conductors' gestures, such that faster beat patterns would be anticipated, and receive less consistent responses, while slower patterns would receive 'late' responses[2].

Contrary to this, however, Rasch (1988) reports that faster tempi tend to be associated with higher levels of synchronization between performers, while slower tempi tend to be associated with less accurate synchronizations, in studies using visual stimuli. Moreover, similar findings have been reported using auditory stimuli (e.g, Peters, 1989). Since the type of stimuli used in the studies outlined above are rather simple in nature, e.g., periodic light flashes, and thus rather far removed from the kinds of stimuli provided by a conductor, e.g., complex arm movements, it would be pertinent to examine the literature on synchronization of other, more complex, stimuli, such as biological motion.

It has been shown that both within- (Kelso, 1984, 1995; Tuller & Kelso, 1989) and be-

employed by conductors.

[2] In contrast, auditory synchronization studies have found that responses tend to precede stimulus onsets by a few tens of milliseconds, not lag behind them, regardless of the tempo (e.g., Aschersleben & Prinz, 1995; Vos, Mates & van Druysebergen, 1995).

tween-person (Schmidt, Carello & Turvey, 1990) synchronization of limb movements, and visual perception of such synchronization (Bingham, Schmidt, & Zaal, 1999), can be very accurate, providing that the phase angle of such movements is 0° (inphase) or, to a slightly lesser degree, 180° (antiphase). Movements with phase angles deviating from 0° or 180° are hard to maintain and perceive, and are generally drawn towards these 'default' phase angles (Kelso, 1984), or are difficult to distinguish perceptually from highly variable 0° and 180° phase angles (Schmidt, Carello & Turvey, 1990). A neural mechanism that simplifies human movement by allowing only certain combinations of movements to be made is believed to underlie this behaviour (Kugler & Turvey, 1987; Saltzman & Kelso, 1987).

In terms of people's ability to synchronize with conductors' temporal gestures, there is a dearth of relevant research. Most research on conductors' gestures has focused on expressive aspects of conducting, while the content of conducting manuals also tends to focus more on conveying emotional expression rather than temporal information (see Rudolf, 1995, and Prausnitz, 1983, for good examples of such manuals).

One study that did examine temporal aspects of conducting, however, was that reported by Fredrickson (1994). In Fredrickson's study, participants had to play along to a video recording of an orchestra performing Percy Grainger's "Irish Tune from County Derry", filmed in such a way that the conductor's gestures were clearly visible. Participants were divided into four groups, and each group received a different version of the recording. Group 1 were presented with both the visual (conductor's gestures) and auditory (orchestra's performance) aspects of the recording in their entirety. Group 2 lost the sound of the ensemble after the first 16 bars, while Group 3 lost the video of the conductor after the first 16 bars. Finally, Group 4 lost the entire stimulus after the first 16 bars, and thus had to complete the piece without any external timing cues. Having played along to their respective recording, each participant then rated the next participant's ability to synchronize with the recording. They did this using a continuous response digital interface (CRDI) dial, moving it to the right for "good ensemble" and to the left for "poor ensemble".

Fredrickson found that better 'ensemble' playing resulted from both being able to hear the other players and see the conductor. Moreover, the performance of the two groups who lost either the visual stimulus or the auditory stimulus did not differ significantly, suggesting that the visual and auditory timing information were equally important to the performers.

Serrano (1994), meanwhile, carried out an interesting study in which observers synchronized with point-light computer-generated simulations of conducting gestures. Results indicated that both musicians and non-musicians responded with a high degree of uniformity when the stimuli resembled the kind of motion produced by gravitational forces. Other types of motion, however, received less consistent responses.

Luck & Toiviainen (2006) also examined temporal relations between conductors and musicians, but in a non-experimental, real-world setting. The gestures of an expert conductor directing an ensemble were recorded using an optical motion-capture system, and various features of these gestures compared with the timing of the ensemble's performance. A cross-correlation analysis indicated that the ensemble's performance tended to be most highly synchronized with periods of maximal deceleration along the trajectory, followed by periods of high vertical velocity.

There is also a growing body of work on computer-based interactive conducting systems, such as those described by Ilmonen and Takala (1999) and Lee, Wolf, and Borchers

(2005). The main shortcoming of such systems is that they tend to presuppose that the beat is conveyed by the change in direction from downward to upward motion, and do not allow for the fact that other features, such as those identified by Luck & Toiviainen (2006) may be related to beat induction.

To date, the only published study to have quantified synchronization with real conducting gestures through the systematic manipulation of relevant variables is that reported by Luck & Nte (in press). In that study, participants were presented with single instances of point-light representations of simple, single beat, conducting gestures, and had to tap in synchrony with the beat in each case. Three factors were manipulated: the experience level of the conductor who produced the gesture, the 'clarity' of the gesture[3], and participants' previous experience. Of these three factors, only participants' previous experience affected the consistency with which they were able to synchronize with the gestures. Specifically, those with both previous synchronization *and* conducting experience (*conductors*) synchronized more accurately than both those with synchronization experience only (*musicians*), and those with neither types of experience (*non-musicians*).

Luck & Nte (in press) suggested that the participants with conducting experience themselves were able to make better use of the kinematic information contained in the gestures presented to them, compared to participants who had no such previous experience. Consequently, they had a deeper understanding of how the beat was communicated, and, as a result, were able to synchronize more consistently with these gestures. Such performance-facilitating effects of domain-specific experience have been found in other movement-synchronizing activities, such as in relation to tennis players' ability to return a serve (e.g., Goulet, Bard & Fleury, 1989), and in squash players' anticipation of ball trajectory and required court position (e.g., Abernethy, 1990; Abernethy, Gill, Parks, & Packer, 2001).

The present study sought to build upon Luck & Nte's (in press) study by examining synchronization with more complex conducting gestures, namely traditional beat patterns. As in Luck & Nte's study, several pertinent variables were manipulated. The first of these was participants' previous experience. As in Luck & Nte's study, participants were divided into *conductors*, *musicians*, and *non-musicians*, depending upon the type of previous experience they had. In line with previous work, it was predicted that there would be a positive relationship between the conductors' level of experience and participants' level of synchronization consistency, and that, in terms of participants' previous experience, *conductors* would synchronize more consistently than either *musicians* or *non-musicians*.

The use of extended beat patterns allowed the investigation of two further factors, namely the tempo at which the sequence of beats was conducted, and changes in synchronization consistency related to beat position in the overall sequence.

As regards the relationship between tempo and synchronization consistency, the literature reviewed above suggests contradictory hypotheses regarding the direction of this relationship with regards to visual stimuli. However, given that the auditory literature consistently indicates a positive relationship between tempo and accuracy, a similarly positive relationship between gesture tempo and synchronization consistency was predicted in the present study.

The relationship between beat position and synchronization consistency was also hard to predict, since no previous studies have examined this in relation to conducting ges-

[3] This was accomplished by varying the radius of curvature with which the beat was defined.

tures. However, anecdotal evidence from both conductors and musicians, as well as the content of conducting manuals (see, for example, McElheran, 1989; Prausnitz, 1983; Rudolf, 1995), suggests that the conductor and musicians tend to 'come together' on the first beat of each measure, while possibly maintaining a looser relationship on all other beats. This mirrors the finding that, when listening to auditory sequences, listeners synchronize more accurately with accented tones, tending to perceive them as "down beats" in the sequence (Repp, 2005). Thus, in the present study, it was predicted that the first beat of each measure would receive the most consistent synchronizations, while the second and third beats would receive somewhat less consistent synchronizations.

Method

Participants

Twenty-four university undergraduates took part in the study, and were divided into three groups – *conductor-participants*, *musicians*, and *non-musicians* – according to their responses to a questionnaire administered prior to data collection. *Conductor-participants*, who had both previous synchronization experience and previous conducting experience, comprised 2 males and 3 females (mean age 18.4 years). *Musicians*, who had previous synchronization experience only, comprised 1 male and 6 females (mean age of 20.1 years). *Non-musicians*, who had neither type of previous experience, comprised 2 males and 10 females (mean age of 19.4 years).

Stimuli

The stimuli consisted of point-light representations of traditional three-beat patterns, conducted over four measures. The gestures were produced by two different conductors, who differed in the amount of previous conducting experience they had. The *novice* conductor (a 21 year old advanced music student) was a competent performing musician, but had no prior conducting experience. The *experienced* conductor (a 28 year old advanced music student), meanwhile, was an equally competent performing musician, but had received conducting tuition, and gained regular experience directing ensembles, over a four-year period. Both conductors were familiar with the aims of the study.

A reflective marker was attached to each conductor's right index fingertip, and this marker was tracked by a three-camera Qualisys Pro Reflex motion-capture system, which recorded the position of each marker in a designated 3D space, at 60 fps.

The conductors were asked to produce four measures of a traditional three-beat pattern (see Figure 1), in which the beats were characterized by either a *small* (3.75 cm), *medium* (7.5 cm), or *large* (15 cm) radius of curvature[4], and at either a *slow* (60bpm),

[4] Note that, although this description refers to a curvature/clarity manipulation, this was not included as a factor in the present study, and all analyses collapse across this manipulation. The reason for its presence is that the multi-beat gestures were recorded in the same session as the single-beat gestures used in Luck & Nte (in press), prior to which decisions had been made as to which variable should be manipulated. Since curvature had been predicted to affect synchronization consistency, all gestures recorded were subject to this manipulation. The failure of this manipulation to significantly affect synchronization consistency in Luck &Nte (in press) led to its removal from the present study. Nonetheless, the gestures used in the present study contained different degrees of curvature. Therefore, for completeness, we describe exactly what was recorded, despite the

medium (90bpm), or *fast* (120bpm) tempo[5]. The experimenter specified the required radius of curvature and tempo before each gesture was recorded, and the conductors were allowed to listen to a metronome set at the required tempo until they indicated that they had the tempo firmly in their head. The metronome was then switched off, and the gesture was recorded. At no time did the conductor conduct in synchrony with the metronome's pulse – it was always switched off before recording began.

This resulted in a total of eighteen different gestures being recorded (2 conductors × 3 radii of curvature × 3 tempi), each of which contained twelve beats (3 beats × 4 bars). Each gesture was recorded three times in order to ensure a level of certainty in the accuracy of these gestures. Only one of each set of three was actually chosen to generate the subsequent stimuli, and this decision was based on the same correlational procedure described in Luck & Nte (in press).

The *Viewer* programme (described in detail in Luck & Nte, in press) was used to scale the stimuli so that they were life-size in relation to the figure on the default screen of *Conductor*, the programme used to present the stimuli to participants and record their responses (also described in detail in Luck & Nte, in press). This was accomplished by taking the gesture with the largest distance between its upper and lower extremities, and scaling it so that it moved between the top of the figure's head and their waist. A note was made of the amount of adjustment that was necessary to accomplish this, and the remaining gestures were scaled by the same amount. Thus, all stimuli moved within the normal vertical boundaries of conducting gestures, while retaining their relative size to each other.

Each stimulus item consisted of a point-light representation of the reflective marker's trajectory, from the moment it started to descend, to the moment it stopped after the beat. To allow participants to ready themselves, and so as to make each stimulus a little 'tidier', each stimulus remained stationary for 1500 ms at both the beginning and the end of the gesture.

Apparatus

The point-light stimuli were projected life-size onto a screen 3 m directly in front of participants, using an SVGA (800 × 600) data projector connected to a PC running Windows 98. Participants sat at a desk, and responded to the stimuli by pressing the space bar on a computer keyboard.

Design and Procedure

The present study employed a four-factor mixed design, with three related factors and one unrelated factor. The first related factor was beat number (BN), and had three levels: *1st* beat, *2nd* beat, *3rd* beat. The second related factor was the tempo at which the beat pattern was conducted (T), and had three levels: *slow*, *medium*, and *fast*. The third related factor was the experience level of the conductor (CE), and had two levels: *novice* conductor and *experienced* conductor. The unrelated factor was participants' previous experience (PE), and had three levels: *conductor*, *musician*, and *nonmusician*.

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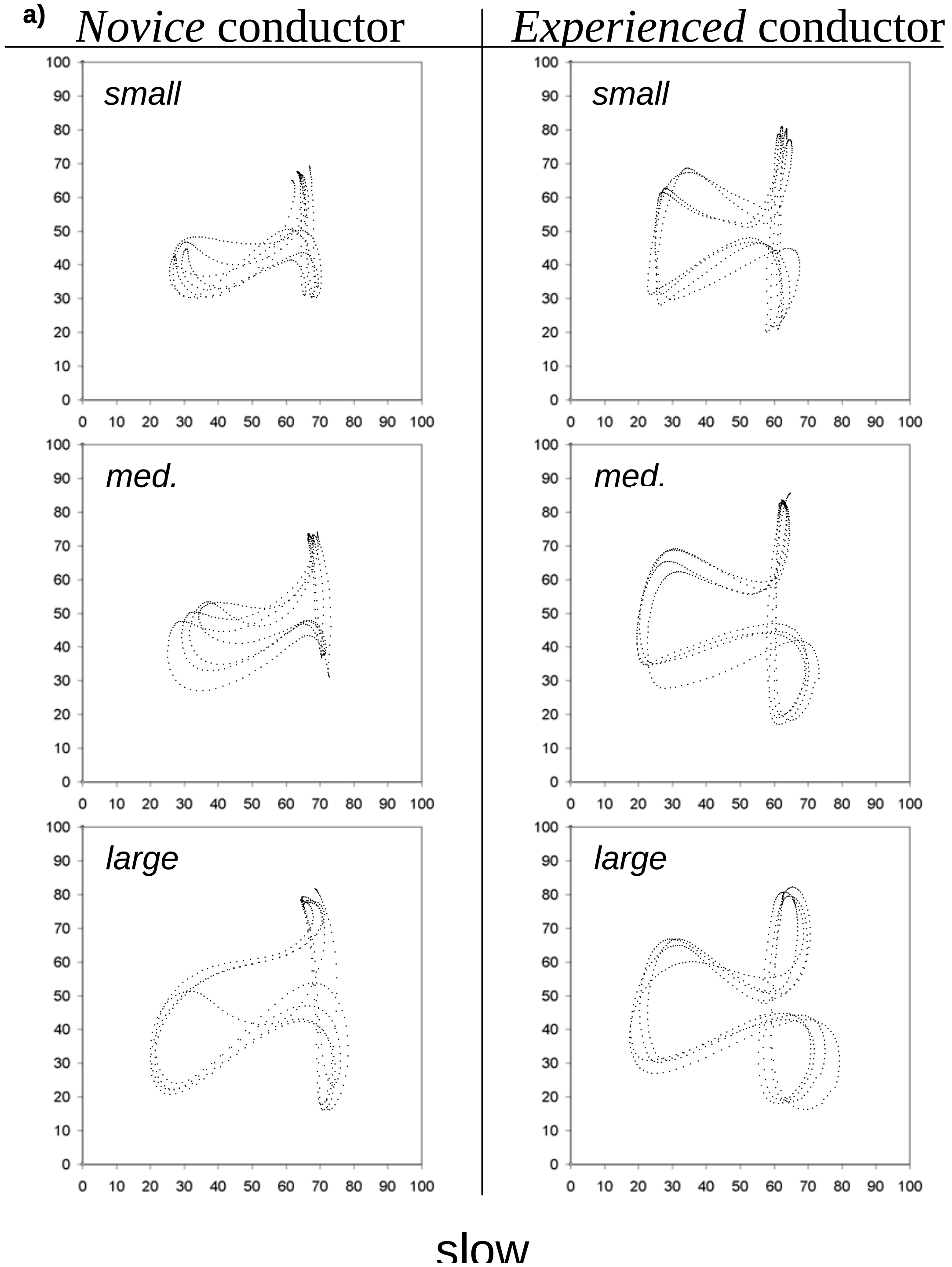
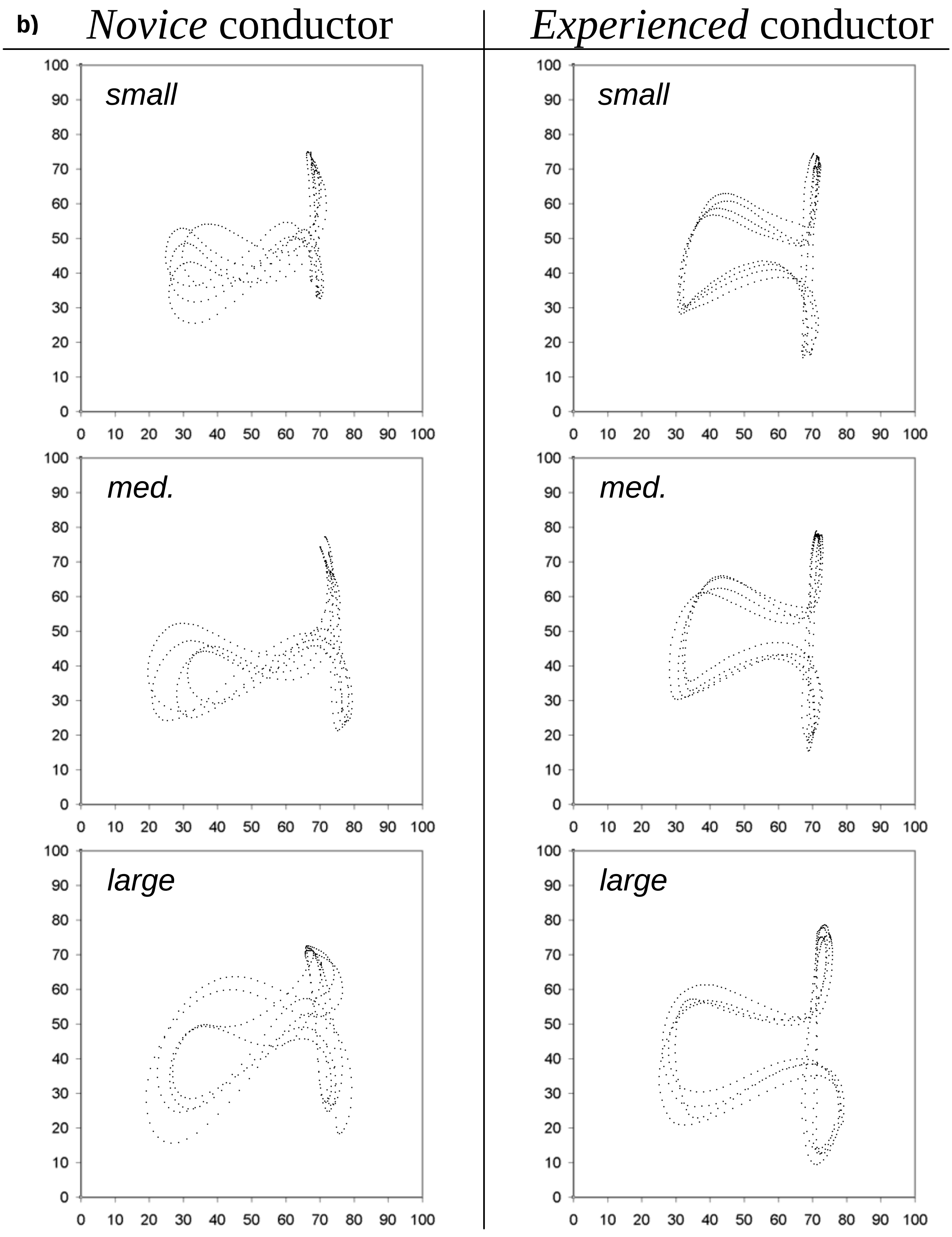
fact that subsequent analyses collapse across this manipulation.

[5] These three measurements and tempi were chosen as it was considered that they would result in the production of three clearly differentiable sizes of beat, and three clearly different tempi, none of which would require unwieldy movements from the conductors.

All experimental stimuli were presented five times, in a random order, in a single block. Prior to the experimental block, each participant was presented with a block of five practice trials to familiarize them with the experimental task. The procedure was in every other way identical to that reported in Luck & Nte (in press), except that participants were instructed to synchronize with as many points (i.e., beats) as they felt able to during each gesture (each gesture consisted of twelve beats).




b)
Novice conductor
Experienced conductor
small
small
med.
med.
large
large
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10
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90
100

medium

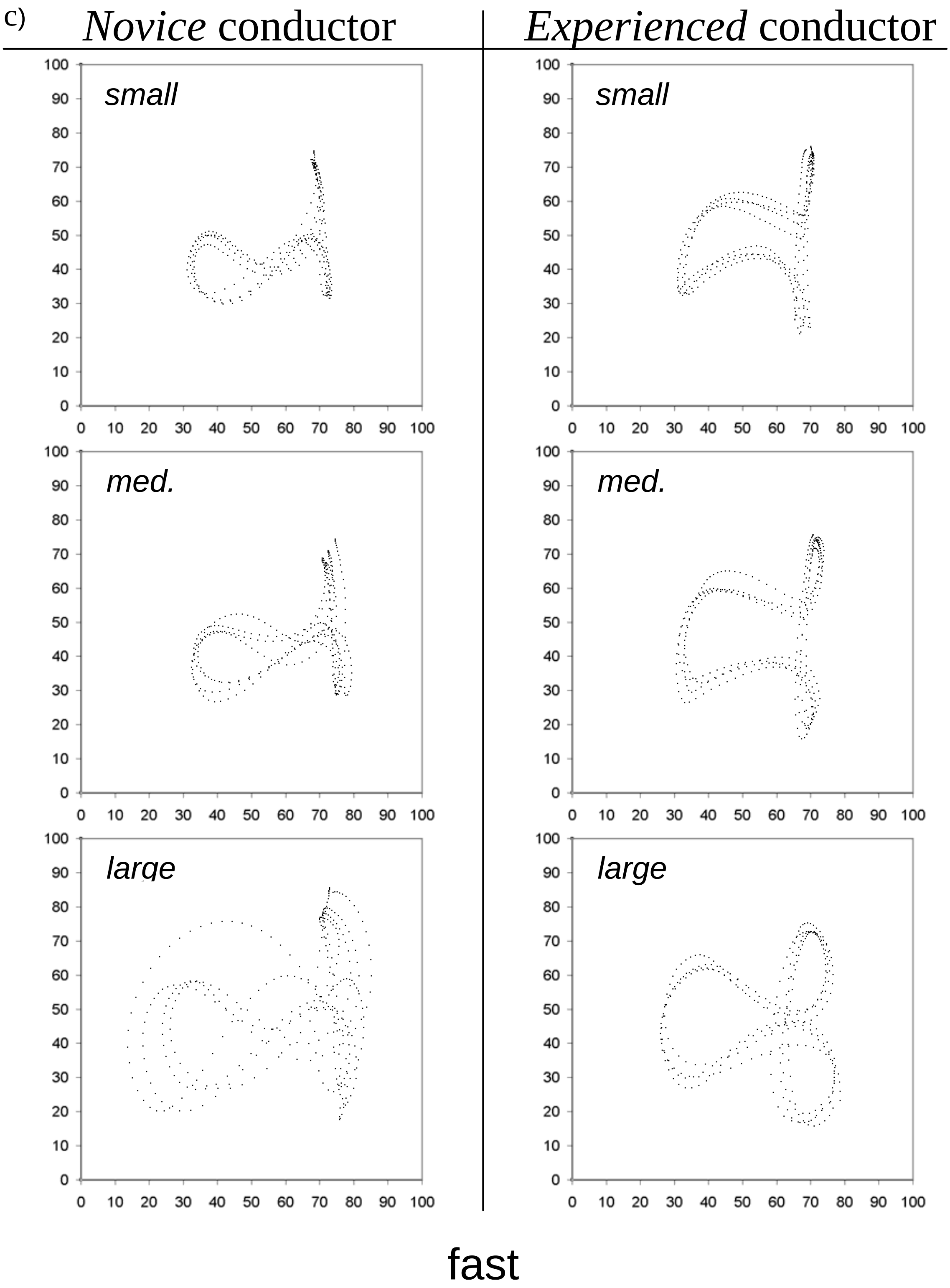

Figure 2. Plots of the six three-beat pattern gestures produced by the *novice* and *experienced* conductors at the a) slow, b) medium, and c) fast tempo, as seen from the musicians' perspective. All measurements are in cm. Although tempo was included as a factor in the present study, curvature was not – the plots, however, cannot be collapsed across curvature.

The dependent measure was the time (in milliseconds) elapsed from the start of a gesture to each time a participant responded. For each response, the elapsed time was measured from the beginning of the twelve-beat sequence (i.e., the inter-response interval was not directly recorded). This elapsed time was recorded for every response a participant made within a gesture, for every presentation of every gesture.
the *novice* conductor.

Results

The 18 three-beat pattern gestures produced by the two conductors are shown in Figure 2a· a) low and next pages). It can be seen that the consistency with which the gestures were produced over the four measures differed between the two conductors: the *experienced* conductor's gestures are clearly more consistent (i.e., follow a similar path through each measure) compared to those produced by*Analysis* was used to collate the key-press data, and generate each participant's mean response time (MRT) for each beat of every gesture presented. This resulted in MRT's being calculated for a total of 216 beats (18 gestures, each containing 12 beats) per participant. The procedure for deciding which re-

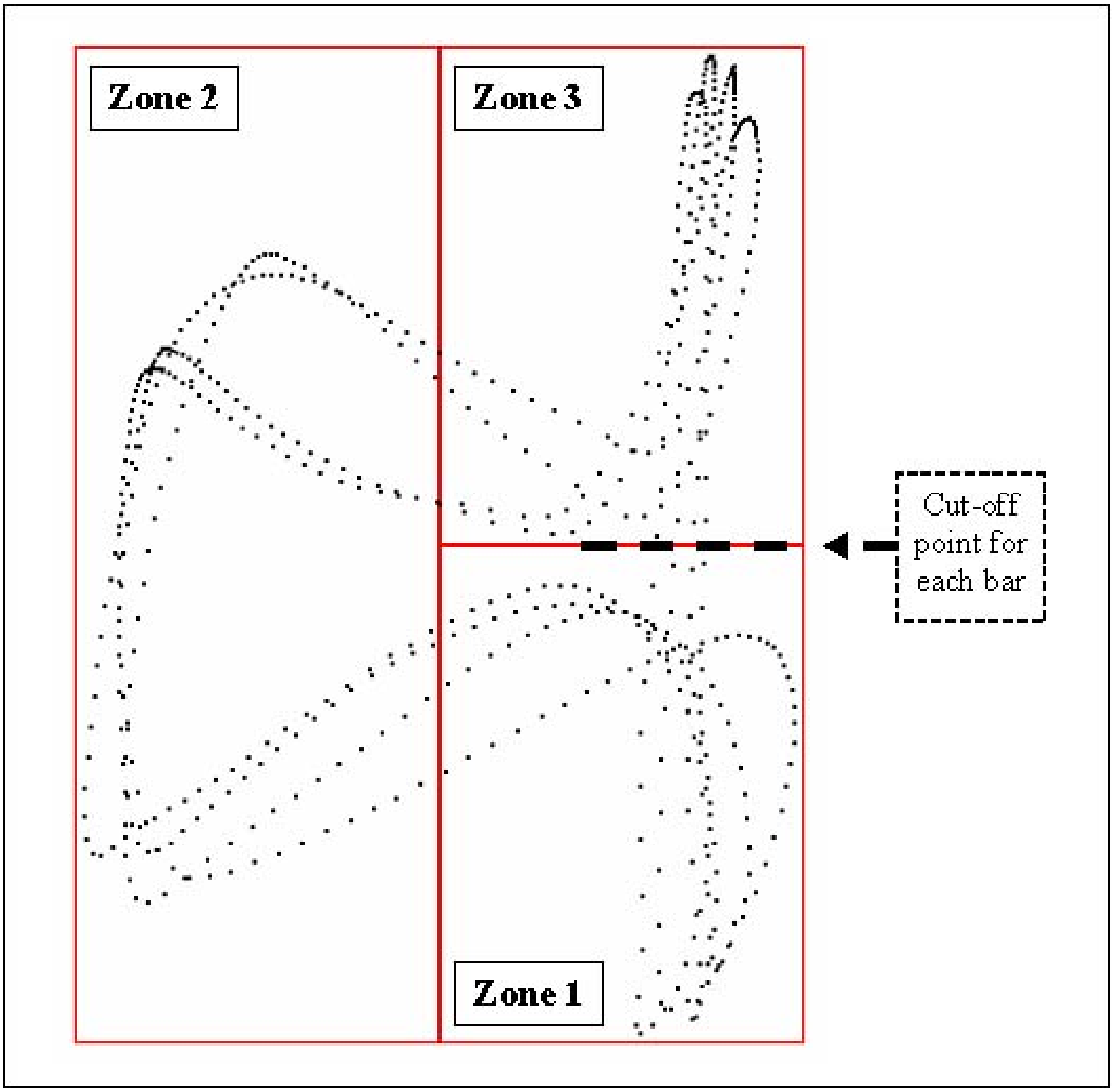

Figure 3. The procedure used to decide which responses related to which beats.

sponse related to which beat is described below, and is shown in Figure 3.

For each gesture, the highest and lowest points in the *x* and *y* axes were identified, and were used to calculate the horizontal and vertical midpoints of each gesture. Based on these midpoints, each gesture was divided into three zones, each of which was used to classify participants' responses: responses which occurred during the time the stimulus was in zone 1 were classified as being made to the 1st beat of a given measure; responses which occurred during the time the stimulus was in zone 2 were classified as being made to the 2nd beat of a given measure; and responses which occurred during the time the stimulus was in zone 3 were classified as being made to the 3rd beat of a given measure. The cut-off point for each measure was the mid-point in the *y* axis as the gesture descended again after showing the third beat.

The standard deviations associated with each MRT was also calculated, and used as an indication of participants' response consistency. A smaller standard deviation indicated greater consistency (i.e., that all responses to a particular beat were similarly placed in time), while a larger standard deviation indicated less consistency. At this point, it became apparent that responses to the last beat of the last measure (the 3rd beat in the final measure) were markedly less consistent than responses to all other beats. This may have been because this beat was qualitatively different to the previous 3rd beat of each measure: while beats three, six, and nine looped over

the top and back down again, beat 12 was effectively cut off at the upper apex. Many participants commented that they had been confused by this final beat, and had been unsure as to how to respond. Consequently, it was decided to exclude responses to beat 12 from all subsequent analyses.

Conductor	*Novice*			*Experienced*		
Tempo	*Slow*	*Med.*	*Fast*	*Slow*	*Med.*	*Fast*
MSD	69	57	46	78	59	48

Table 1. Mean standard deviations (MSD) in ms of participants responses to the traditional beat patterns, collapsed across beat number. MSD's are based on the standard deviations of individual participant's mean response times (summed and averaged in this case into 6 groups).

The consistency with which participants responded to the different gestures is shown in table 1. This shows mean standard deviations (MSD), that is, the mean of the standard deviations associated with the relevant MRT's, of participants' responses to the traditional beat patterns, collapsed across beat number, and excluding responses to beat number 12. It can be seen from this table that, as predicted, the tempo of the beat pattern app

ears to be positively related to the consistency of participants' responses, with the smallest MSD's being associated with the *fast* tempo, and the largest MSD's with the *slow* tempo. The effect of the conductor's level of experience, however, is rather less clear.

These data were then subjected to two analyses. Firstly, the effects of CE and PE were examined, after which the effects of BN and T were investigated. These two combinations of factors were selected on the basis that they a) separated the factors into those concerned with previous experience, and those concerned with experimenter-defined variables, and b) kept the analyses, and subsequent interpretations, as simple as possible.

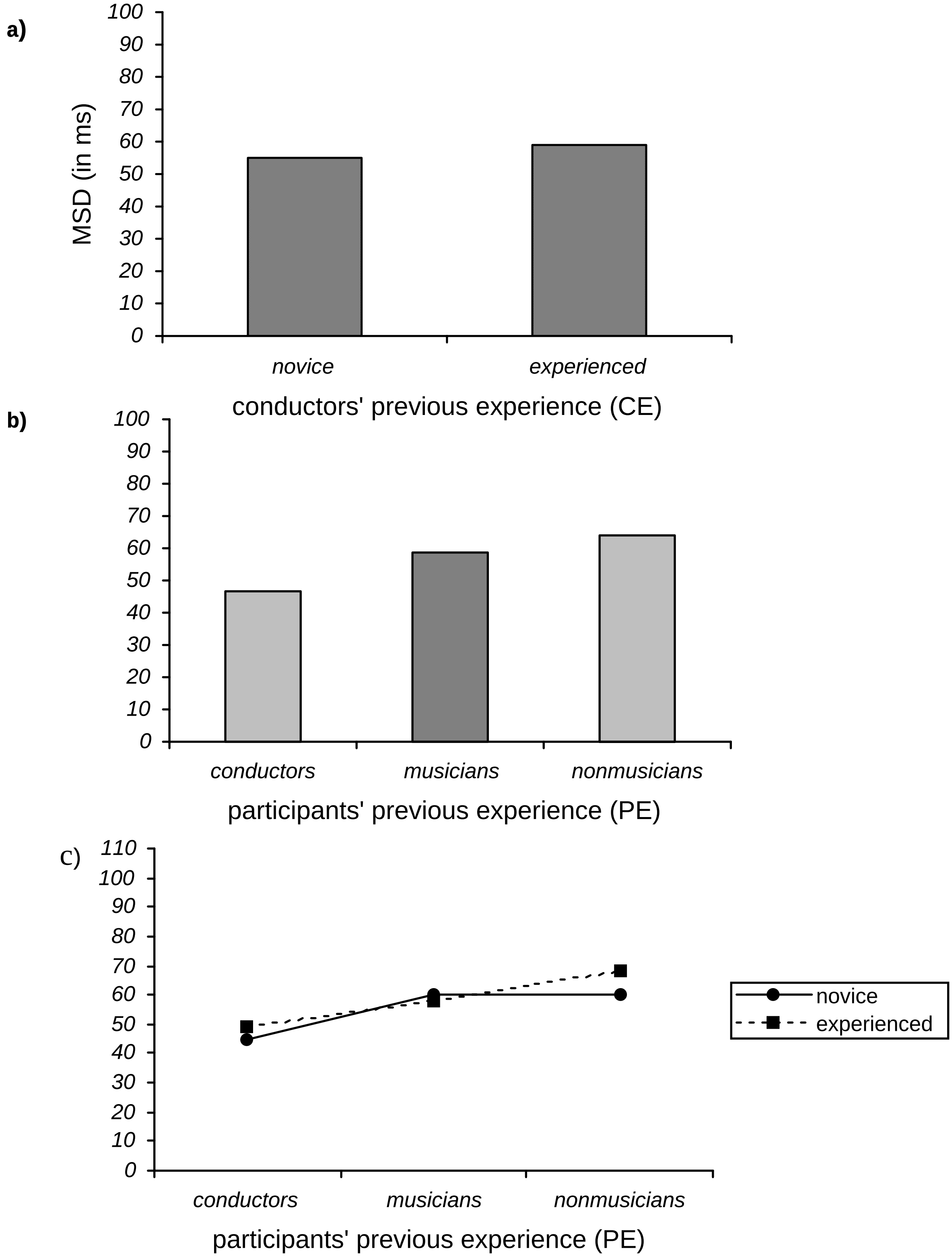

Figure 4. a) Main effect of conductors' previous experience on Mean Standard Deviation (MSD: y-axes) of participants' synchronizations; b) Main effect of participants' previous experience on MSD of synchronizations; c) Interaction effect between conductors' previous experience and participants' previous experience. Lower MSD's indicate more consistent synchronizations

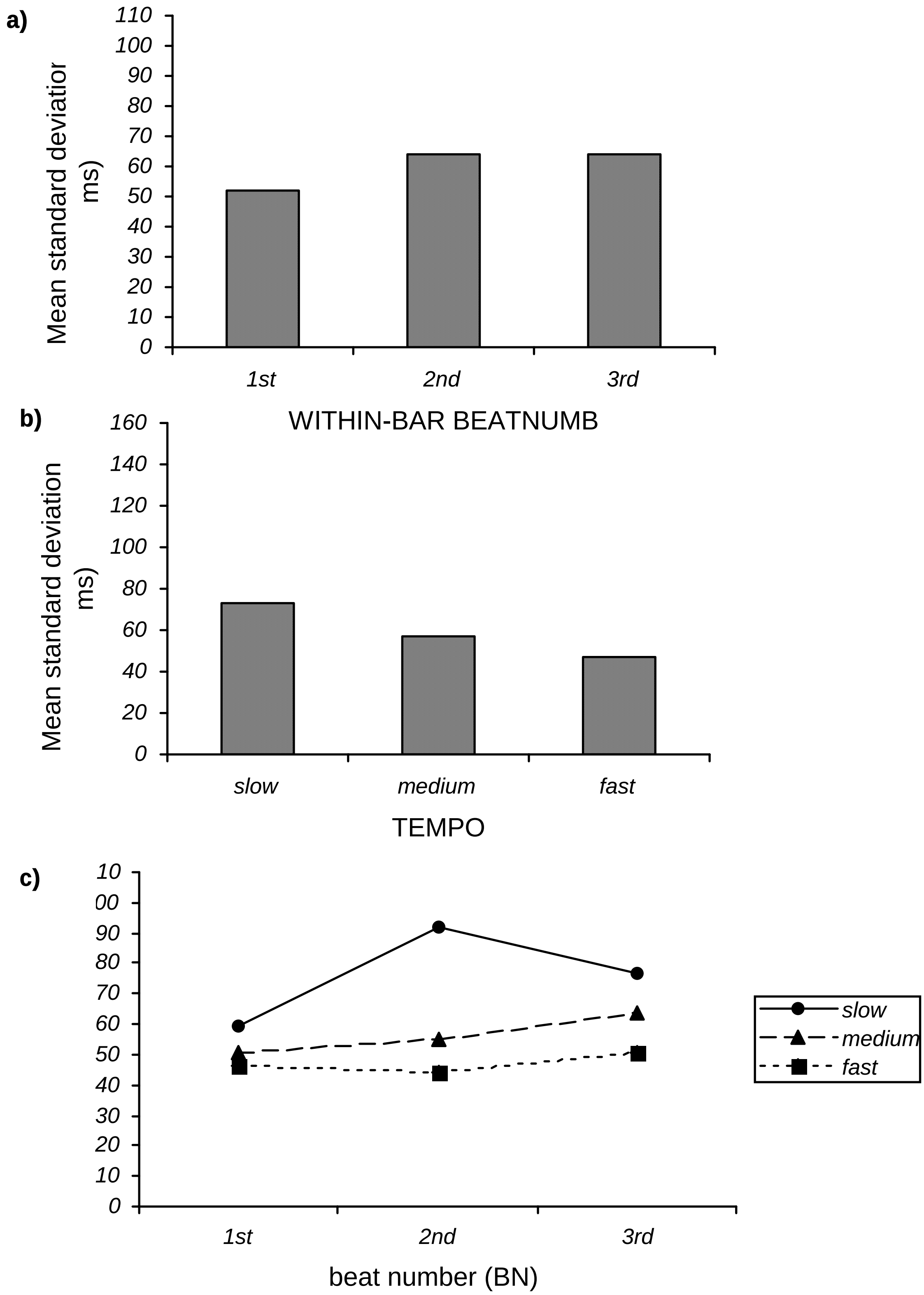

Figure 5. a) Main effect of beat number on Mean Standard Deviation (MSD: y-axes) of participants' synchronisations; b) Main effect of tempo on participants' synchronizations; c) Interaction effect between beat number and tempo. Lower MSD's indicate more consistent synchronizations.

Firstly, then, a 2-way mixed Analysis of Variance (ANOVA) was performed on CE and PE, using the standard deviation of each participant's MRT to each gesture as the dependent variable. This revealed significant main effects of both CE [$F(1, 2350) = 6.815$, $p<.01$, $\eta_p^2 = .003$] and PE [$F(2, 2350) = 29.139$, $p<.001$, $\eta_p^2 = .024$], and a significant CE $\times$ PE interaction [$F(2, 2350) = 5.094$, $p<.01$, $\eta_p^2 = .004$]. The main effects of CE and PE, and the CE $\times$ PE interaction, are shown in Figure 4.

It can be seen that, contrary to expectation, the *novice* conductor elicited slightly more consistent synchronizations from participants compared to the *experienced* conductor. Meanwhile, as predicted, *conductor-participants* synchronized more consistently than *musicians*, who in turn synchronized more consistently than *nonmusicians*. A post-hoc multiple comparison (Tamhane's T2) revealed significant differences in consistency between all three groups [for *conductor-participants* $\times$ *musicians*, $p<.001$; for *conductor-participants* $\times$ *nonmusicians*, $p<.001$; and for *musicians* $\times$ *nonmusicians*, $p<.05$]. Finally, while *conductor-participants* and *nonmusicians* responded more consistently to the *novice* conductors' gestures, the musicians responded slightly more consistently to the *experienced* conductors' gesture.

The second analysis investigated the effects of BN and T on participants' synchronization consistency. A 2-way fully-related ANOVA was performed on these two factors, using the standard deviation of each participant's MRT to each gesture as the dependent variable. This revealed significant main effects of BN [$F(2, 838) = 21.300$, $p<.001$, $\eta_p^2 = .048$] and T [$F(2, 838) = 104.069$, $p<.001$, $\eta_p^2 = .199$], and a significant BN × T interaction [$F(4, 1676) = 21.378$, $p<.001$, $\eta_p^2 = .049$]. The main effects of BN and T, and the BN × T interaction, are shown in Figure 5.

It can be seen that, as predicted, the *1st* beat of each bar received the most consistent synchronizations, while the *2nd* and *3rd* beats of each bar received somewhat less consistent synchronizations. Meanwhile, again as predicted, gestures conducted at the *fast* tempo received the most consistent synchronizations, followed by gestures conducted at the *medium* tempo, while gestures conducted at the *slow* tempo received the least consistent synchronizations. Finally, as expected, the *most* consistent synchronizations were made to the first beat of each bar when conducted at the *fast* tempo.

Discussion

The present study examined the effect of four factors on the consistency with which participants were able to synchronize with conductors' traditional three-beat patterns. It was found that synchronization consistency was positively related to participants' previous experience, with participants who had previous conducting experience being the most consistent overall. Meanwhile, synchronization consistency was negatively related to the conductor's level of experience, with the *novice* conductor eliciting slightly more consistent synchronizations overall. Furthermore, beat patterns conducted at faster tempi were responded to more consistently than those conducted at slower tempi, and the 1st beat of each measure received more consistent responses than the 2nd and 3rd beats.

The finding that *conductor-participants* achieved the highest level of synchronization, followed by the *musicians*, while the *nonmusicians* achieved the lowest level of synchronization, is in line with previous work in which participants were presented with simple conducting gestures (Luck & Nte, in press). Again, the *conductor-participants'* superior performance may be explained by their better understanding of what exactly characterized a visual beat, and an increased sensitivity to the kinematic information contained in the gestures of other conductors. Thus, it can be seen that when attempting to synchronize with both single beat gestures and traditional beat patterns, it is previous conducting experience that allows participants to achieve the highest level of consistency.

The implication here is that a higher level of conductor-musician synchronization could be achieved if all ensemble musicians received (at the very least, basic) conducting tuition. This tuition would lead to a greater understanding of how the beat is communicated, and result in higher quality ensemble playing when a conductor is present.

As regards the surprising finding that the *novice* conductor elicited more consistent synchronizations than the *experienced* conductor, there are at least two plausible explanations. Firstly, the inconsistency with which the *novice* conductor produced the gestures may have resulted in participants having to concentrate on synchronizing with every individual beat, as they could not be sure exactly where and when the next beat would be communicated. This increased attention may have resulted in more consistent synchronizations over repeated presentations.

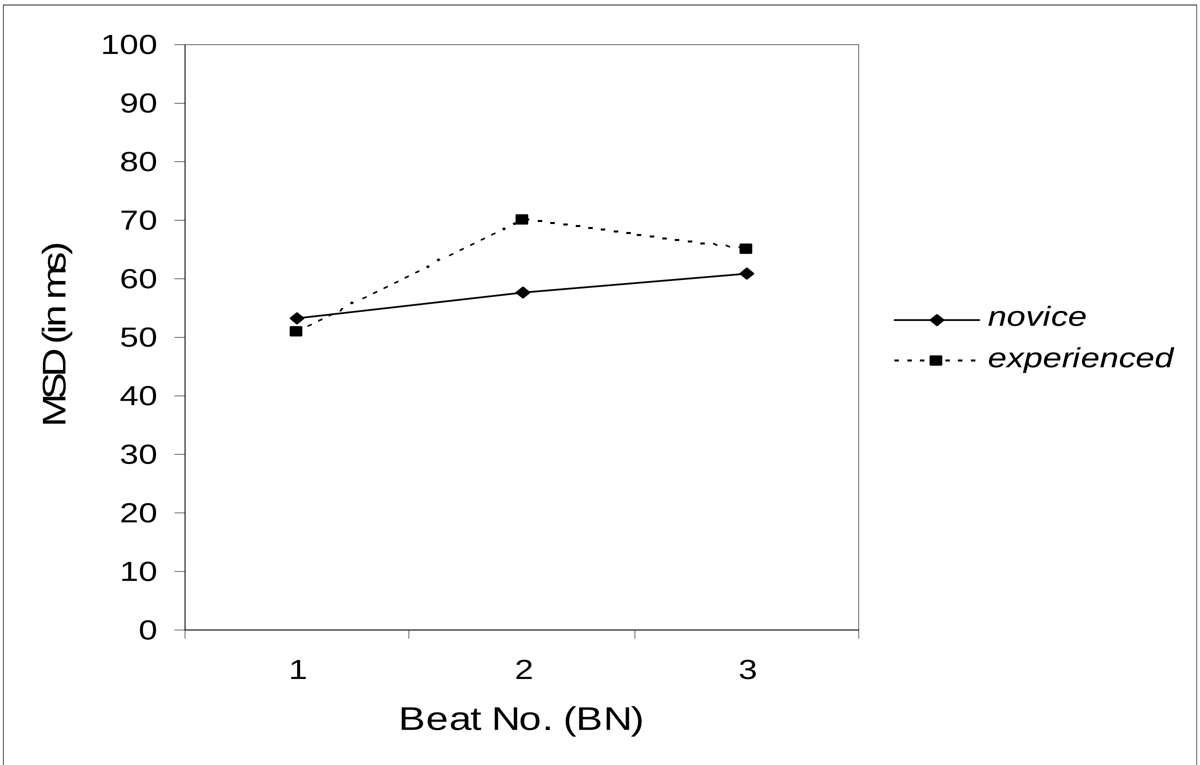

Figure 6. Interaction effect of beat number and conductors' experience on MSD of participants' synchronizations. Lower MSD's indicate more consistent synchronizations.

A second possible explanation is that the *experienced* conductor deliberately (and perhaps unconsciously) introduced some sort of structure into their beat patterns, emphasising the downbeats, and relegating the 2nd and 3rd beats to a subordinate status in terms of the accuracy of their production. Participants may thus have responded in a similar manner, maintaining good consistency to the downbeats, but being less concerned with the other two beats, the effect of which was to lower overall consistency. This latter explanation was tested by carrying out a two-way related ANOVA on BN and CE. The results supported the theory. Specifically, the significant interaction between BN and CE [F(2, 1264)

= 9.455, p<.001, η_p^2 = .015] indicated that the *experienced* conductor elicited the most consistent synchronizations on the *1st* beat, but the least consistent synchronizations on the *2nd* and *3rd* beats (Figure 6). As can be seen, however, the difference between the conductors for the *1st* beat is rather small: clearly, future studies would benefit from examining synchronization with multiple conductors at each experience level.

The fact that participants tended to synchronize most consistently with the 1st beat of each measure provides experimental evidence to support the widely accepted view that conductors and musicians tend to 'come together' on the downbeat. Moreover, downbeats naturally have greater clarity compared to all other beats because of the effect of gravity on their production. Gravity causes higher downward acceleration, necessitating a more marked deceleration as the gesture rounds the corner, due to the negative speed-curvature relationship characteristic of human movement (see Lacquaniti, Terzuolo & Viviani, 1983, and Luck & Nte, in press, for an application to conductors' gestures). This results in spatio-temporal changes of greater magnitude, and thus greater clarity, for the 1st beat of each measure compared to all other beats.

As regards the positive relationship between tempo and synchronization consistency, this is in line with Rasch's (1988) finding that faster tempi tend to be associated with higher levels of synchronization between performers, while slower tempi tend to be associated with less accurate synchronizations. Moreover, it suggests that a similarly positive relationship between speed of presentation and accuracy exists for both auditorily- and visually-presented stimuli.

Besides the results, some discussion of issues relating to the methodology employed in the present study is warranted. For example, we cannot say that a single moving point in space fully represents a conductor's gestures. By its very nature, a point-light display reduces the information available to an observer below what would be available if the conductor could be seen in a more naturalistic way. However, the advantage of using point-light displays is that the amount of information available to an observer can be precisely controlled. The movement that is deemed relevant or interesting to the research question(s) under investigation can be presented in isolation. In the present study, the available information was the same for both conductors, and all participants saw the same displays. Thus, we can be quite sure that observed differences between different groups of participants were due to differences in the movement of the conductors' fingertips, not their elbow, shoulder, head, or indeed their age or gender. What we must acknowledge, however, are the limitations in generalising from this study to the real world.

Related to this is the use of computer keyboard versus a real instrument to record participants' responses. Whilst the keyboard allowed more precise recording for all participants, it was obviously not the same as playing a real instrument. However, recording keyboard taps is considerably easier than recording tones produced on a variety of instruments given difficulties such as determining when the tone actually starts, and differences caused by different microphone techniques.

Future work in this area might consider examining a wider range of gestures, as well as a larger number of conductors. In addition, point-light displays comprised of varying numbers of points could be considered in order to see what effect additional information regarding wrist, arm, shoulder, and head movement has on observers' synchronization with the gestures. Finally, it would be interesting to examine synchronization with modulated-tempo gestures to see how different observers are able to follow tempo changes introduced by the conductor. All of these developments would help increase our understanding of musicians' ability to synchronize with conductors' gestures.

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