Spatio-Temporal Cues for Visually Mediated Synchronization

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The accuracy with which individuals are able to synchronize with each other using vision alone is well documented. Less attention, however, has been given to the spatio-temporal characteristics of human movement that offer cues for such synchronization. The present study investigated such cues in the context of conductor-musician synchronization. Twenty-four participants tapped in time with dynamic point-light representations of traditional conducting gestures, in which the clarity of the beat and overall tempo was manipulated. A series of nine linear regression analyses identified absolute acceleration along the trajectory as the main cue for synchronization, while beat clarity and tempo influenced the weights of the variables in the emergent models.

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Synchronizing our movements with those of people around us is a fundamental aspect of everyday life. Social interaction (Kendon, 1970), sport (Dawson, Lockwood, Wilson & Freeman, 1998), dance (Allard & Starkes, 1991), and music (Baer, 1987), for example, all require a high level of synchronization for their effective execution. While synchronization processes may be mediated by both visual and auditory cues, such as the way dancers synchronize their steps both by listening to the music they are dancing to as well as by observing the steps of the dancers they are performing with, there are times when an individual is required to synchronize with visual-only cues. One such example is a musician synchronizing with a conductor's gestures.

A typical temporal (as opposed to expressive) conducting gesture denotes the tempo or speed at which the music should be played, and may be best described as a movement trajectory that denotes a periodic sequence of visual events (beats[1]) with which the musicians should synchronize. Given that it is the aim of a conductor to optimize coordination between ensemble musicians using visual cues alone, the investigation of beat-inducing aspects of conductors' gestures provides an ecologically valid way in which to study visually mediated between-person coordination.

Research has shown that most people, even those with little or no previous experience with conductors' gestures, are able to tap in time with such sequences of beats (Luck, 2000), suggesting that the detection of these temporal events involves rather basic human perceptual processes. What is less clear is what physical features of a movement trajectory induce the perception of a beat. The aim of the present study was to collect some preliminary data on this question.

Basic Synchronization Abilities

The ability of people to synchronize their movements to those of a periodic external stimulus is a widely studied phenomenon. Most of this research has focused on synchronization with auditory stimuli, and has shown that people are able to achieve a high level of synchronization with stimuli presented in this modality (see Repp, 2005, for a review). Much less attention has been given to people's ability to synchronize with simple visual stimuli (e.g., light flashes), although a few such studies have been reported. Kolers and Brewster (1985), for example, compared synchronization with auditory, visual, and tactile stimuli, and found that people were least consistent in synchronizing with visual stimuli. Chua, Weeks, Ricker, and Poon (2001), meanwhile, found that faster visual stimulus speeds were associated with more variable and less accurate responses.

As regards visually mediated synchronization of human movement, it has been shown that between-person synchronization of limb movements (Schmidt, Carello, & Turvey, 1990), and visual perception of such synchronization (Bingham, Schmidt, & Zaal, 1999), can be very accurate, providing that the phase angle of

[1]The word "beat" will be used this way throughout this paper.

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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 behavior (Kugler & Turvey, 1987; Saltzman & Kelso, 1987).

Conductor-Musician Synchronization

The majority of 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, for example, Rudolf, 1995, and Prausnitz, 1983). However, Luck (2000) examined musicians' synchronization, using prerecorded, videotaped gestures with which participants had to synchronize a tapping response. Synchronization accuracy was found to be negatively related to previous synchronization experience, with the most experienced musicians tending to lag behind the beat more than less experienced musicians. Precise recording of the level of conductor-musician synchronization was not, however, possible due to the low frame rate of the recordings. Also, since the beat was defined *a priori* as the lowest point in the -axis, no analysis of the beat-inducing properties of the gestures was undertaken. A further problem was that the video recordings did not permit a detailed kinematic analysis of the gestures.

Building on this earlier study, Luck and Nte (2008) investigated conductor-musician synchronization by presenting dynamic point-light displays, derived from motion-capture data, to participants. Participants had to tap in time with the beat, and the conductors' level of experience, participants' level of experience, and the clarity with which the beat was communicated, were all systematically manipulated (beat clarity was manipulated by varying the radius of curvature with which the beat was defined, with smaller radii being related to greater clarity). Results indicated that participants with both previous synchronization *and* conducting experience (*conductor-participants*) synchronized more consistently (mean response points had lower standard deviations) than both those with synchronization experience only (*musicians*), and those with neither types of experience (*nonmusicians*). Neither the experience level of the conductor nor clarity of the gesture had any effect.

Luck and Toiviainen (2006), meanwhile, examined precise temporal relations between computationally extracted features of a conductor's gestures and musicians' performance in a nonexperimental, real world setting. The gestures of an expert conductor directing an ensemble were recorded using motion-capture, and features of these gestures compared with the timing of an audio recording of the ensemble's performance. A crosscorrelation analysis indicated that the ensemble's performance tended to be most highly synchronized with periods of maximal deceleration along the movement trajectory, followed by periods of high vertical speed (a higher correlation, but a longer delay, than deceleration).

Similar results were reported by Luck and Sloboda (2008), who examined spatio-temporal cues for synchronization in a laboratory setting. In a first experiment, participants synchronized with point-light representations of simple conducting gestures, and visual beat induction was found to be related to acceleration along the trajectory, and, to a lesser extent, high instantaneous speed. In a second experiment, the curvature component of the gestures was held constant. The results largely supported those of the first experiment. In a final experiment, the speed component of the gestures was held constant, and revealed that neither radius of curvature nor rate of change of radius of curvature alone were related to visual beat induction.

These findings suggest that a visual beat is communicated by periods of acceleration or deceleration, and, as such, supports the idea that the percept of a visual beat is created by a variable that reflects a change in the value of one of the parameters that defines a movement's trajectory. Furthermore, these results suggest that temporal features of a movement trajectory (acceleration along the trajectory and instantaneous speed) offer more reliable and stable cues for synchronization than do spatial features (radius of curvature and rate of change of radius of curvature).[2]

Other related work includes the development of computer-based conducting systems, such as those

[2]The terms "temporal" and "spatial" were used by Luck and Sloboda (2008) to refer to these two pairs of variables, respectively. While one could argue whether or not it is possible to define any particular feature of a movement trajectory as being either temporal or spatial, since, in a dynamic display, spatial change necessarily takes place over time, these terms were used due to the way that the trajectories of the original stimuli were manipulated in the three experiments reported by Luck and Sloboda. These manipulations effectively separated the temporal elements of the trajectories from the spatial ones. Since the same variables were extracted in the present study, the same terms are thus used here.