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Influence of stimulus amplitude on unintended visuomotor entrainment

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ABSTRACT

Rhythmic limb movements have been shown to spontaneously coordinate with rhythmic environmental stimuli. Previous research has demonstrated how such entrainment depends on the difference between the movement periods of the limb and the stimulus, and on the degree to which the actor visually tracks the stimulus. Here we present an experiment that investigated how stimulus amplitude influences unintended visuomotor entrainment. Participants performed rhythmic forearm movements while visually tracking an oscillating stimulus. The amplitude and period of stimulus motion were manipulated. Larger stimulus amplitudes resulted in stronger entrainment irrespective of how participants visually tracked the movements of the stimulus. Visual tracking, however, did result in increased entrainment for large, but not small, stimulus amplitudes. Collectively, the results indicate that the movement amplitude of environmental stimuli plays a significant role in the emergence of unintended visuomotor entrainment.

1. Introduction

Rhythmic human movements spontaneously coordinate with those of other individuals or environmental stimuli during visual interaction (e.g., Oullier, de Guzman, Jantzen, Lagarde, & Kelso, 2008; Schmidt & O'Brien, 1997; Schmidt, Richardson, Arsenault, & Galantucci, 2007; Varlet, Marin, Lagarde,

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& Bardy, 2011). Such entrainment can occur in everyday life when an actor is walking, dancing, or just talking with another individual (e.g., Richardson, Marsh, & Schmidt, 2005; van Ulzen, Lamoth, Daffertshofer, Semin, & Beek, 2008). Having access to visual information about the movements of an environmental rhythm, however, does not ensure that entrainment will occur (e.g., Shockley, Santana, & Fowler, 2003) and the emergence and stability of spontaneous (or, unintended) coordination can depend on the difference between the natural periods of the movements involved and the degree to which the actor attends to the relevant movement information (e.g., Richardson, Marsh, Isenhower, Goodman, & Schmidt, 2007; Schmidt et al., 2007). The aim of the current study was to investigate whether movement amplitude also influences the occurrence and stability of unintended visuomotor coordination. More specifically, the study examined whether the larger the movement amplitude of a visual stimulus, the greater the occurrence and stability of unintended visuomotor entrainment.

Inspired by the dynamical systems theory, previous research has shown that rhythmic visuomotor coordination between the movements of an individual and an environmental stimulus or rhythm is constrained by the dynamical entrainment processes of coupled oscillators (e.g., Byblow, Chua, & Goodman, 1995; Richardson et al., 2005; Schmidt et al., 2007; Wimmers, Beek, & van Wieringen, 1992). In line with the predictions of the Haken, Kelso, and Bunz (1985) coupled oscillator model that captures the dynamics of bimanual rhythmic coordination (see also, Kelso, 1995) and its derivatives for visual coordination perception (e.g., Bingham, 2004; Bingham, Schmidt, & Zaal, 1999; Zaal, Bingham, & Schmidt, 2000), visuomotor limb-to-stimulus movements are constrained (without practice) to in-phase and anti-phase patterns of coordination (relative phase values of 0° and 180°, respectively), with in-phase coordination being more stable than anti-phase coordination (e.g., Richardson et al., 2007; Schmidt & O'Brien, 1997; Wimmers et al., 1992). In addition, the stability of in-phase and anti-phase coordination decreases as movement period decreases (i.e., movement becomes faster) and the difference between the natural periods (i.e., detuning) of movement's involved increases, with anti-phase coordination becoming unstable at fast movement periods and for large magnitudes of detuning (e.g., Richardson et al., 2007; Schmidt, Carello, & Turvey, 1990; see Schmidt & Richardson (2008) for a review).

Rhythmic visuomotor coordination can occur both intentionally and unintentionally (spontaneously and without awareness). Like bimanual coordination, intended visuomotor coordination is typically *absolute*, meaning that either in-phase or anti-phase coordination are stably maintained for an extended period of time. In contrast, unintended coordination tends to be *relative* because of the weak strength of the coupling (e.g., Richardson et al., 2007; Schmidt & O'Brien, 1997; von Holst, 1973) and is characterized by an intermittent attraction toward in-phase and anti-phase patterns of coordination (e.g., Issartel, Marin, & Cadopi, 2007; Schmidt & O'Brien, 1997; Tognoli, Lagarde, de Guzman, & Kelso, 2007). Accordingly, unintended visuomotor entrainment is much more affected by differences between the period of the visual stimulus and the preferred period (i.e., comfort mode) of the actor than intended visuomotor coordination, with even small differences in period greatly reducing the chance that entrainment will occur (e.g., Richardson et al., 2007; Schmidt & O'Brien, 1997; Schmidt et al., 2007).

Lopresti-Goodman, Richardson, Silva, and Schmidt (2008) provided a clear demonstration of the significant impact period difference has on the occurrence of unintended visuomotor coordination. In this experiment, participants were instructed to oscillate a wrist pendulum at a self-selected comfort tempo while simultaneously reading letters displayed on an oscillating visual stimulus displayed on a projection screen. The period of the visual stimulus was manipulated as a function of the participant's preferred movement period as measured from a set of pre-trials. The results demonstrated that the magnitude and stability of entrainment decreased when the stimulus period was faster or slower than the participant's preferred movement period, with no visuomotor entrainment occurring for stimulus periods that were greater or less than 15% of the participant's preferred movement period.

Researchers who have investigated unintended visuomotor entrainment have also shown how the strength of the visual coupling is mediated by the degree to which an actor attends to the displacements of rhythmic stimuli. Using a similar method to the Lopresti-Goodman et al. (2008) study just described, Schmidt et al. (2007) demonstrated the role that visual tracking plays in the emergence of visuomotor entrainment. Participants were instructed to read letters that were displayed at random intervals either on an oscillating visual stimulus (i.e., tracking condition) or just above the middle of