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Effects of visual and auditory guidance on bimanual coordination complexity

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ABSTRACT

Perceptual guidance of movement with simple visual or temporal information can facilitate performance of difficult coordination patterns. Guidance may override coordination constraints that usually limit stability of bimanual coordination to only in-phase and anti-phase. Movement dynamics, however, might not have the same characteristics with and without perceptual guidance. Do visual and auditory guidance produce qualitatively different dynamical organization of movement? An anti-phase wrist flexion and extension coordination task was performed under no specific perceptual guidance, under temporal guidance with a metronome, and under visual guidance with a Lissajous plot. For the time series of amplitudes, periods and relative phases, temporal correlations were measured with Detrended Fluctuation Analysis and complexity levels were measured with multiscale entropy. Temporal correlations of amplitudes and relative phases deviated from the typical $1/f$ variation towards more random variation under visual guidance. The same was observed for the series of periods under temporal guidance. Complexity levels for all time series were lower in visual guidance, but higher for periods under temporal guidance. Perceptual simplification of the task's goal may produce enhancement of performance, but it is accompanied by changes in the details of movement organization that may be relevant to explain dependence and poor retention after practice under guidance.

1. Introduction

The existence of spontaneous movement tendencies and movements that are very difficult to perform suggests constrains to coordination. For example, oscillating both hands at the same frequency, in mirrored or opposite directions (in phase and antiphase), comes naturally and is considerably easier than oscillating the hands at different frequencies or other phase relations. Motor constraints, such muscular anatomical symmetry and activation pathways have been considered essential to explain these coordination tendencies (Carson, Riek, Smethurst, Párraga, & Byblow, 2000; Kelso, 1984; Salter, Wishart, Lee, & Simon, 2004; Temprado, Swinnen, Carson, Tourment, & Laurent, 2003). Perceptual factors, however, also play an indispensable role (Mechsner, Kerzel, Knoblich, & Prinz, 2001; Mechsner & Knoblich, 2004; Riek & Woolley, 2005). Current theory acknowledges that a variety of constraints interact to shape coordination (Kelso, Fink, DeLaplain, & Carson, 2001; Shea, Buchanan, & Kennedy, 2016; Swinnen & Wenderoth, 2004). These constraints can be manipulated to influence the stability and accuracy of coordination patterns (Park, Collins, & Turvey, 2001; Riek & Woolley, 2005; Swinnen & Wenderoth, 2004;

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Temprado, Salesse, & Summers, 2007; Temprado et al., 2003) with a dramatic impact on performance (Mechsner et al., 2001). For example, perceptual constraints can be manipulated with feedback. Concurrent feedback of interlimb coordination by means of an angle-angle plot (i.e., a Lissajous figure) translates motion into a simple visual pattern and makes normally unstable bimanual coordination patterns achievable after little training (Kovacs, Buchanan, & Shea, 2010). Use of these plots can improve error detection and correction while also reducing attentional demands necessary to 'tune-in' the desired coordination pattern (Kennedy, Wang, Panzer, & Shea, 2016). Several phase relations other than the spontaneously stable inphase and antiphase can be consistently produced with reduced variability and error (Kennedy, Wang, Panzer, & Shea, 2016; Kovacs, Buchanan, & Shea, 2009a,b).

The evidence suggests that simplification of perceptual goals can overrule basic coordination tendencies such that days of practice can be sidestepped. If the primary challenge in motor learning is the overcoming of basic coordination tendencies (Temprado & Swinnen, 2005; Zanone & Kelso, 1992), adequate task manipulations could become a formidable tool to aid learning in fields such as rehabilitation, sports and music. However, being able to execute movements under appropriately manipulated perceptual conditions does not imply that learning to execute the task in usual conditions will be facilitated (Kovacs & Shea, 2011). Movement coordination under guidance of simplified feedback and under usual perceptual circumstances involve different neural pathways (Debaere, Wenderoth, Sunaert, Van Hecke, & Swinnen, 2003) and might have different dynamical requirements. These differences may lie behind the poor retention observed after practice with guidance (Kovacs & Shea, 2011; Maslovat, Brunke, Chua, & Franks, 2009; Ronsse et al., 2011; Salmoni, Schmidt, & Walter, 1984). Do visual and auditory guidance produce synergies with qualitatively different dynamical organization?

The structure of variability of a movement time series is informative about the dynamical processes of coordination that underlie performance (Riley & Turvey, 2002). Specifically, the nature of the coupling between degrees of freedom of a system can be assessed with measures of complexity. Although complexity has proved to be a slippery concept, recent explanatory proposals recognize that behavioral complexity derives from the activity of numerous substructures and subfunctions distributed over multiple spatiotemporal scales (Ihlen & Vereijken, 2010; Turvey, 2007). The tying together these numerous time scales in nested loops allows for the stable and adaptable control which is characteristic of coordinated movement (Turvey, 2007; West & Griffin, 1998). Multiscale entropy measures can capture such structural richness. Multiscale entropy measures are based on calculation of entropy values for several time scales of a time series. Contrary to usual single scale entropy measures, multiscale measures consistently yield higher complexity values for simulated long-range correlated stochastic series compared to uncorrelated, unstructured random stochastic series (Costa, Goldberger, & Peng, 2002). Multiscale entropy should be able to capture differences in structural richness of motor synergies assembled under distinct perceptual constraints.

What changes should be expected under guidance of simplified perceptual patterns? Studies comparing independent and guided movement suggest hypotheses. In self-paced movement the time series of relative phase in 0° and 180° bimanual coordination (Torre, Delignières, & Lemoine, 2007) show an inverse relationship between power and frequency ($1/f$ or pink noise). Pink noise, a kind of correlated, structurally rich noise, is indicative of a long-range memory process: a typical dependence in the series, for example a positive trend between successive values, appears nested with statistically similar trends expressed at larger scales (Diniz et al., 2011). Pink noise has been interpreted as a signature of interdependent interactions among the numerous components of a system, self-organization (the spontaneous organization that coordinates system behavior in the absence of a central controller) and emergence (the appearance of features that are not implicit in the parts of the system) (Turvey, 2007; Van Orden, Holden, & Turvey, 2003). Under metronome pacing, the typical $1/f$ observed in independent, self-controlled performance disappears. In its place, anti-persistent temporal correlations are observed (Chen, Ding, & Kelso, 1997; Torre & Delignières, 2008).

These findings have generated interesting theoretical speculations: $1/f$ structure is likely to appear when the coordination is weakly constrained by external requirements. In contrast, enhanced sources of external constraint would reduce voluntary control (Kloos & Van Orden, 2010; Van Orden, Kloos, & Wallot, 2011; Van Orden et al., 2003). Given the dramatic effects of Lissajous guidance on performance, it appears to function as more global constraint on performance than metronomes. If reliance on a Lissajous plot can in fact substitute for mechanisms of voluntary control and interfere with the intrinsic pink noise dynamics of purposeful coordination, it should produce time series with fluctuations that change away from $1/f$ towards "whiter" variation. The washing away of temporal correlations would indicate less integration of components of the underlying synergy, with lessening of structural richness and acquisition of degrees of freedom that begin to vary with greater independence (Kiefer, Riley, Shockley, Villard, & Van Orden, 2009). These changes should be evidenced as reduced levels of complexity.

The aforementioned bimanual coordination task performed under three different perceptual conditions was used to test these expectations. Specifically, an anti-phase wrist flexion and extension coordination task was performed under no specific perceptual guidance, under temporal guidance with a metronome, and under visual guidance with a Lissajous plot. The temporal correlations and the complexity of time series produced under each condition were compared. Results might be relevant to explaining why little retention is observed after practice with some kinds of perceptual guidance.