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Manual asymmetries in bimanual isochronous tapping tasks in children

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ABSTRACT

Tapping tasks have been investigated throughout the years, with variations in features such as the complexity of the task, the use of one or both hands, the employ of auditory or visual stimuli, and the characteristics of the subjects. The evaluation of lateral asymmetries in tapping tasks in children offers an insight into the structure of rhythmic movements and handedness at early stages of development. The current study aims to investigate the ability of children (aged six and seven years-old) to maintain a rhythm, in a bimanual tapping task at two different target frequencies, as well as the manual asymmetries displayed while doing so. The analyzed data in this work are the series of the time intervals between successive taps. We suggest several profiles of behavior, regarding the overall performance of children in both tempo conditions. We also propose a new method of quantifying the variability of the performance and the asymmetry of the hands, based on ellipses placed on scatter plots of the non-dominant–dominant series versus the dominant–non-dominant series. We then use running correlations to identify changes of coordination tendencies over time. The main results show that variability is larger in the task with the longer target interval. Furthermore, most children evidence lateral asymmetries, but in general they show the capacity to maintain the mean of consecutive intertap intervals of both hands close to the target interval. Finally, we try to interpret our findings in the light of existing models and timing modes.

1. Introduction

Daily actions may require the use of one hand, usually the preferred hand, or the use of both hands in cooperation. The two hands can be used simultaneously to achieve the same goal by performing similar or different movements, as seen in the production of rhythmic patterns, such as clapping or playing a drum. In other circumstances, the nature of the task may require the two hands to perform complex coordination patterns, by moving independently to fulfill the same or different goals (Fagard, 1991; Otte & van Mier, 2006).

Some authors claimed that handedness is expressed in different ways across the lifespan and shifts in lateral preference follow other developmental milestones (Corbetta & Thelen, 2002). Yet, during infancy and childhood the use of a dominant hand is progressively observed, and by the time a child learns how to use writing tools, the option for a preferred hand becomes clearer (Greenwood, Greenwood, McCullagh, Beggs, & Murphy, 2007). Until the fifth year of life, the child displays superiority in terms of speed and coordination of the preferred hand, which becomes less evident after this age, probably as a result of a rapid neurological development (Barnea-Goraly et al., 2005; Denckla, 1973; in Roeder et al., 2008).

Over the last decades, many studies have focused on hand preference, as well as movement asymmetries between both hands. One particular task that is well adjusted to the research of this question is the tapping task. This experimental procedure was introduced by Stevens (1886) as a way of studying the maintenance of a rhythm initially set by an external auditory signal. The task required that the participants tapped their fingers simultaneously with a sequence of signals generated by a metronome and maintained the same rhythm after the external signal was removed. The author called the first stage *synchronization* and the second one *continuation*, and the variable of interest was the duration of the intervals between taps of the continuation phase. With these data the author meant to verify the fluctuations on the motor behavior of the participants, and the main conclusions were that there are fluctuations around the correct value, and the variability of the intertap intervals increases with the increasing length of the target intervals. He also proposed two factors to explain this variability – long-term fluctuations as a consequence of cognitive processes, and short-term fluctuations related to motor limitations (Stevens, 1886).

Later, Wing and Kristofferson (1973), proposed a stochastic two-level model for the fluctuations of the intertap intervals that has been deeply discussed and challenged in recent decades. The two main elements of this model are the central clock or cognitive component, responsible for the perception of timekeeping, and the motor component, which refers to the motor execution of the tap. Just like Stevens' work, this model allowed the authors to conclude that the variability of the intervals between taps, or interresponse intervals, grows

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as the length of the target interval increases. In the original approach, based on experiments with short continuation phases (namely 20–50 taps), the cognitive and the motor components were regarded as independent white noise sources (i.e., uncorrelated in time) (e.g., Vorberg & Wing, 1996; Wing & Kristofferson, 1973). This implies that the autocorrelations between adjacent intervals are negative, while the autocorrelations for lags higher than one are close to zero. More recently, other experiments with longer continuation phases (namely around 1000 taps) reported long nonperiodic oscillations typical of long-memory processes (i.e., long-range correlated in time) (e.g., Delignières, Lemoine, & Torre, 2004; Diniz et al., 2011; Diniz, Barreiros, & Crato, 2010; Diniz, Barreiros, & Crato, 2012; Madison, 2004).

The first studies related to tapping tasks involved unilateral movements, but tapping tasks with two hands have also been investigated. Peters (1980) carried out three tapping experiments with the purpose of observing the differences between the performances of both preferred and non-preferred hands. He found that the preferred hand is faster and more regular on its performance, but the complexity of the task, as well as many other factors, may contribute to the hand asymmetries in tapping tasks (Peters, 1980). Peters' experiments revealed a strong influence of the reversal portion of the tapping movement on the between-hand performance differences, as well as the kind of tapping movement, the smaller movements being more prone to generate larger differences.

Yamanishi, Kawatu, and Suzuki (1980) introduced the Coupled Oscillator Model, which suggests that rhythmic movements performed by any body part are controlled by neural structures, named neural oscillators. According to this model, finger tapping with both hands is controlled by two neural oscillators that produce periodic outputs endogenously, each one controlling one hand, but interacting with each other at the same time. Semjen and Ivry (2001) claimed that an act performed by the two hands is interdependent, as the spatial, temporal, and intensive characteristics of each hand's movement are constrained by the movement of the other hand. The authors referred to a timing control hypothesis, according to which the rhythmic patterns are not related to the two-hand collective, but instead each time interval is controlled individually, regardless of the effector involved.

Although most studies on bimanual coordination and handedness have focused on adults, some have children as subjects of research (e.g., Dellatolas et al., 2003; Pellegrini, Andrade, & Teixeira, 2004; Fagard, 2006; Otte & van Mier, 2006; Roeder et al., 2008). A bilateral tapping task demands the use of two limbs in a complex coordinated task, implying the integration and sequencing of actions between limbs. The development of bimanual tapping follows unimanual spontaneous tapping, becoming preferred over unimanual tapping by 2 years of age (Brakke, Fragaszy, Simpson, Hoy, & Cummins-Sebree, 2007), and children between 4 and 10 years continuously improve their capacity to coordinate two limbs with respect to kinematic and rhythmic features of movement. However, children persistently exhibit higher variability in performing bimanual coordinated tasks (Bobbio, Gabbard, & Caçola, 2009; Otte & van Mier, 2006).

Drake and colleagues showed that children improve rhythmic skills between 4 and 10 years of age, namely the capacity to synchronize to an external beat (Drake, 1993; Drake, Jones, & Baruch, 2000). Particularly, there is a clear distinction between 5 and 7 years-old children in what concerns rhythm reproduction, with 7 years-old children exhibiting similar performance to untrained adults (Drake, 1993). Interestingly, Baruch and Drake (1997) showed that 2 months-old infants exhibit a good tempo discrimination around 600 ms, an interval that falls among the optimal range for tempo discrimination in adults.

Pellegrini et al. (2004) carried out a study with children between the ages of 5 and 12 years-old, to determine the effect of attentional focus on bimanual coordination. They found that focusing the attention on the non-preferred hand, when compared to the preferred hand, contributes to a higher accuracy in the task. They also observed that left-handed children show a lower error rate when using the non-preferred hand (Provins, 1997, in Pellegrini et al., 2004). Njiokiktjien et al. (1997) focused on age related effects and asymmetries in bimanual tasks with children also from 5 to 12 years-old, having found that the more right-handed children are, the more the right hand is ahead of the left hand during a finger tapping task. In many activities of everyday living, humans find the need to perform coordinated movements, and to do so it is fundamental to control temporal and spatial activity patterns of the movement.

The goal of this study is to identify and explore the nature of manual asymmetries in the bimanual behavior of children in an alternate tapping task with two different target intervals. Bilateral “drumming” can be enjoyable, understood, and also performed reasonably well by 6–7 years-old children. We propose a new method of quantifying the variability of the performance and the asymmetry of the hands, based on ellipses placed on scatter plots of both hands' movements. This provides a clear visual queue of the general performance and the types of behaviors displayed by the participants, as well as numerical values that precisely quantify the variability and the asymmetry of each subject in each tempo condition. We also use running correlations to capture changes of coordination tendencies over time. Finally, we try to incorporate our findings into existing models and timing modes.

2. Methods

2.1. Participants

Twenty-three children participated in the experiment. The participants were students of the first year of a public school, ten males and 13 females, aged 6 and 7 years-old (mean age = 6.82; *SD* = 0.25). None had known sensory or motor impairments or any expertise or extensive practice in music. Nineteen children were categorized as right-handed and four as left-handed based on the information about the writing hand.

The children's guardians signed an informed consent form and none of the subjects was paid for their participation.

2.2. Experimental device

The experiment was performed individually in a quiet room, where each child sat on a chair in front of a table with two Gretsch 6-inch practice drum pads that produced a very smooth and low sound. The free audio editor software Audacity generated midi metronome beep stimuli. The sound of the taps was captured in WAV format to Audacity with a Shure SM57 microphone and a Behringer preamplifier connected to a laptop. The duration of the time intervals between successive taps was measured, in milliseconds, using Sonic Visualiser.

2.3. Procedure

The children sat on a chair with no armrest in front of the table with the arms flexed about 90°. The participants were asked to tap on the two practice pads with their hands alternately, starting with the right hand. The task consisted of a synchronization-continuation bimanual tapping task, and the subjects were asked to synchronize their taps with the signals emitted by a digital metronome. After 20 signals, the metronome was muted and the participants tried to continue tapping regularly, maintaining the initial tempo. The continuation phase lasted until 150 successive time intervals were recorded.

The subjects were asked to perform two trials at two different frequencies: one trial at 200 beats per minute, i.e., a beat every 300 milliseconds and another trial at 100 beats per minute, i.e., a beat every 600 milliseconds. The 300 ms and 600 ms target intervals were chosen taking into account the children's age. Longer intervals would make the task too extensive and shorter intervals could become too rapid to follow. Repp (2005) explains that for intertap intervals shorter than 120 ms, it is difficult to tap at the correct tempo and it becomes unclear