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Short Communication

The ability to tap to a beat relates to cognitive, linguistic, and perceptual skills

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ABSTRACT

Reading-impaired children have difficulty tapping to a beat. Here we tested whether this relationship between reading ability and synchronized tapping holds in typically-developing adolescents. We also hypothesized that tapping relates to two other abilities. First, since auditory-motor synchronization requires monitoring of the relationship between motor output and auditory input, we predicted that subjects better able to tap to the beat would perform better on attention tests. Second, since auditory-motor synchronization requires fine temporal precision within the auditory system for the extraction of a sound's onset time, we predicted that subjects better able to tap to the beat would be less affected by backward masking, a measure of temporal precision within the auditory system. As predicted, tapping performance related to reading, attention, and backward masking. These results motivate future research investigating whether beat synchronization training can improve not only reading ability, but potentially executive function and auditory processing as well.

1. Introduction

Tapping to a beat is a seemingly simple task. In reality, though, it is a specialized, complex process that calls upon a wide-ranging network of auditory, motor, and prefrontal areas (Chen, Penhune, & Zatorre, 2008; Chen, Zatorre, & Penhune, 2006; Penhune, Zatorre, & Evans, 1998; Pollok, Gross, Muller, Aschersleben, & Schnitzler, 2005) and may be an ability limited to species capable of vocal learning (Patel, Iversen, Bregman, & Schulz, 2009). Although synchronized tapping requires fine motor control, it also places stringent demands on auditory processing, as listeners must accurately track the rhythm of the beat in order to reproduce it. This rhythmic tracking may rely on processes shared with language processing, as it has been proposed that temporal sampling of slow information within auditory signals is vital for syllable segmentation and, therefore, for the successful acquisition of reading skill (Goswami, 2011). Supporting this hypothesis, children and adults with reading disorders show greater variability when asked to tap along to a steady beat (Corriveau & Goswami, 2009; Thomson, Fryer, Maltby, & Goswami, 2006; Thomson & Goswami, 2008). This impairment may be related to their difficulty in tracking changes in the amplitude of the sound envelope, which is a cue to the onset time of speech sounds (Goswami et al., 2002, 2010; Hamalainen, Leppanen, Torppa, Muller, & Lyytinen, 2005; Leong, Hamalainen, Soltzész, & Goswami, 2011; Muneaux, Ziegler, Truc, Thomson, & Goswami, 2004; Surányi et al., 2009).

If reading and rhythm tracking do share neural resources, one would expect tapping ability to relate to reading skill not only in reading-impaired populations, but in typically-developing subjects as well. We tested this hypothesis by measuring the ability of typically-developing adolescents to tap along to a metronomic beat. We hypothesized that tapping variability relates to reading ability.

It is known that auditory-motor synchronization relies heavily on the motor system (Chen et al., 2006, 2008; Penhune et al., 1998; Pollok et al., 2005), and that individual differences in tapping performance are linked to structural characteristics of motor areas such as white matter volume within frontal cortex (Ullén, Forsman, Blom, Karabanov, & Madison, 2008) and gray matter volume within the cerebellum (Steele, 2012), as well as brain activity within the basal ganglia and cerebellum (Steele & Penhune, 2010). However, the extent to which auditory-motor synchronization also relies upon the fidelity with which sound is represented in the auditory system is unknown. Synchronization to an auditory beat is more accurate than synchronization to a visual beat (Patel, Iversen, & Chen, 2005; Semjen & Ivry, 2001) and the basal ganglia are involved in synchronization to auditory but not visual stimuli (Witt, Meyerand, & Laird, 2008); the fine temporal precision of the auditory system, therefore, may be vital for the production of accurate, consistent responses during auditory-motor synchronization. It is

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possible, therefore, that auditory-motor synchronization is affected by individual differences in the auditory system's ability to extract the exact time of onset of a sound. If so, then less variable tapping performance should be linked to fine temporal precision within the auditory system. Thus, we predicted that tapping variability would also relate to backward masking thresholds, a measure of auditory temporal processing. To measure backward masking thresholds, a tone is presented, followed by a noise burst. The ability to detect soft tones despite the presence of the noise is an indication of fine temporal precision within the auditory system. Furthermore, backward masking thresholds may relate to speech processing, as it is thought that backward masking of consonants by the louder, longer subsequent vowel affects the perception of initial consonants in consonant–vowel syllables. We predicted that less variable tapping would be linked to easier detection of a target sound masked by a subsequent noise burst.

However, auditory-motor synchronization does not solely rely on accurate tracking of temporal rhythms by the auditory system and consistent motor responses. No matter how accurate the brain's representation of the auditory rhythm and no matter how finely the motor system is able to control the output, slight discrepancies between the target rate and response rate will quickly lead to large asynchronies between tap and auditory stimulus. Successful tapping, therefore, also requires constant attending to the relationship between motor output and auditory input, as well as the appropriate adjustment of motor commands to bring the two in line. We predicted, therefore, that tapping variability would also be linked to attention, particularly sustained attention. To ensure that any relationships between tapping and perceptual and cognitive abilities found were not driven by general intelligence, we also gave participants an IQ test.

Backward masking thresholds (and, generally, temporal precision within the auditory system) have been linked to reading skill (Griffiths, Hill, Bailey, & Snowling, 2003; McArthur & Hogben, 2001; Montgomery, Morris, Sevcik, & Clarkson, 2005). Executive function and attention have also been linked to reading ability (Asbjørnsen & Brynden, 1998; Booth, Boyle, & Steve, 2010; Foy & Mann, 2012). A relationship between tapping performance and measures of backward masking and attention would, therefore, provide a further basis for the link between tapping performance and reading ability, as it would suggest that auditory-motor synchronization calls upon a wide range of skills also known to be involved in reading.

2. Results

Pearson's r-values for correlations between tapping performance and all behavioral measures are listed in Table 1. (p-values for all correlations are listed in Tables S1, S2, S4, and S6 within Supplementary Information.) The composite tapping measure consisting of tapping variability in 2 Hz and 1.5 Hz paced conditions correlated with three of the four measures of reading: untimed nonword reading (Word Attack, $r = -0.38$, $p = 0.0036$), untimed word reading (Letter-Word ID, $r = -0.35$, $p = 0.0067$), and timed nonword reading (TOWRE Phonetic Decoding, $r = -0.27$, $p = 0.038$). Timed word reading showed only a weak trends towards being related to tapping performance (TOWRE Sight Reading, $r = -0.18$, $p = 0.18$). Composite paced tapping also related to backward masking threshold in both conditions (no-gap: $r = 0.51$, $p = 0.00016$, gap: $r = 0.39$, $p = 0.0059$). Composite paced tapping related to sustained attention in both the visual (-0.51, $p = 0.00017$) and auditory ($r = -0.47$, $p = 0.00060$) modalities but related to cued attention in only the auditory modality ($r = 0.30$, $p = 0.038$). For each significant relationship found, less variable tapping was linked to better performance. Scatterplots displaying selected relationships between tapping variability and attention, backward masking threshold, and reading ability are shown in Fig. 1.

There was no relationship between tapping performance and uncued attention in either modality. No tapping measure related to two-scale WASI IQ, confirming that relationships between tapping performance and linguistic, cognitive, and perceptual skills were not driven by differences in general intelligence. The composite measure for the unpaced condition related only to performance on the test of sustained visual attention; thus, it is specifically the ability to synchronize to a concurrently presented beat, rather than simply motor coordination, or the ability to imagine a beat, that relates to reading, attention, and auditory temporal processing.

Performance on attention and backward masking tasks was related to reading ability (Table 2). Untimed nonword reading was correlated with sustained attention in both the auditory ($r = 0.28$, $p = 0.046$) and visual ($r = 0.35$, $p = 0.013$) modalities. Timed reading also correlated with auditory ($r = 0.33$, $p = 0.019$) and visual ($r = 0.38$, $p = 0.0069$) sustained attention. However, cued and uncued attention tests from the IMAP battery did not significantly correlate with any reading measure. Backward masking threshold in the no-gap condition correlated with untimed nonword reading ($r = -0.43$, $p = 0.0019$), untimed word reading ($r = -0.39$, $p = 0.0048$), and timed reading ($r = -0.46$, $p = 0.00082$), but the less perceptually demanding 50-ms-gap condition was not significantly correlated with any reading measure.

To determine whether the relationships between tapping and backward masking and between tapping and reading ability were entirely driven by an influence of attention on all three abilities, these relationships were re-assessed via partial correlations controlling for variance in sustained auditory attention. This procedure preserved the relationships between tapping and the WJIII composite untimed reading score ($r = -0.30$, $p = 0.041$) and between tapping and backward masking threshold in the no-gap condition ($r = 0.34$, $p = 0.019$), but rendered insignificant relationships between tapping and the TOWRE composite reading score ($r = -0.10$, $p = 0.49$) and between tapping and backward masking threshold in the 50-ms gap condition ($r = 0.25$, $p = 0.093$). Similarly, after partialling out variance in sustained auditory attention, the relationship between backward masking threshold in the no-gap condition and both reading measures remained significant (WJIII, $r = -0.38$, $p = 0.0089$; TOWRE, $r = -0.38$, $p = 0.0077$), but the relationship between backward masking threshold in the 50-ms gap condition and both reading measures did not reach significance (WJIII, $r = -0.06$, $p = 0.71$; TOWRE, $r = 0.08$, $p = 0.62$).

3. Discussion

We asked adolescent subjects to synchronize to a metronomic beat. We found that variability in tapping to a beat correlated with performance on tests of reading, attention, and auditory temporal precision. Their ability to tap to a remembered beat, however, did not correlate with these measures. Moreover, IQ did not correlate with tapping variability. These relationships between tapping variability and reading, attention, and perception, therefore, reflect not general intelligence or purely motor skills but the variety of perceptual and cognitive processes on which auditory-motor synchronization draws.

The finding that auditory-motor synchronization ability correlates with reading skill in a normal-developing population lends support to the idea that reading and the perception of rhythm rely on shared processes. Synchronized tapping may rely heavily on rhythmic tracking within the auditory system, such that successful fine temporal representation of rhythmic patterns is a necessary precursor for reproduction of and synchronization to these patterns. Supporting this idea is the finding that auditory-motor synchronization ability is linked to the ability to perceive the rate of increase in amplitude marking the onsets of sounds, or "rise time"