DEVELOPMENTAL CHANGES IN AUDITORY TEMPO SENSITIVITY AND PREFERRED TEMPO

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The study examined the relationship between developmental changes in preferred motor tempo and tempo sensitivity to test two hypotheses about aging and timing proposed by McAuley, Jones, Holub, Johnston, & Miller (2006): a preferred period hypothesis and an entrainment region hypothesis. Four groups of listeners (4 - 5, 6 - 7, 8 - 9, and 18+ years) were asked to tap at their preferred rate and make judgments about the relative tempo of standard-comparison isochronous tone sequence pairs. For the tempo discrimination task, three standard tempi (300, 600, and 900 ms inter-onset intervals) were crossed with three different length comparison sequences (1, 3, or 5 intervals) which were yoked to the standard using comparison rates of ± 6 %, ± 12 %, and ± 18 %. Findings related to the preferred period hypothesis were mixed; age-related changes consistent with the hypothesis were observed in preferred motor tempo but there was no age-related shift in tempo sensitivity. Preferred motor tempo slowed with increased age but best performance in tempo sensitivity occurred at the intermediate 600 ms standard tempo for all age groups. Tempo sensitivity findings were consistent with the entrainment region hypothesis. Overall, tempo sensitivity improved with age except in the youngest age group. The greatest age-related improvements in tempo sensitivity were observed at the slowest 900 ms tempo, consistent with a widening of the entrainment region with age. Improvements in tempo sensitivity associated with increasing the number of comparison intervals were generally consistent with Miller and McAuley (2005) but the amount of improvement varied with both age and tempo. Benefits were most prevalent at the fastest 300 ms tempo, with the least benefits obtained at the slowest 900 ms tempo. However, the youngest age group only showed improvement at the intermediate tempo (600 ms) when increasing from one
intervals. In conclusion, developmental changes seen in preferred motor tempo are not reflected in optimal tempo sensitivity. Developmental improvements in tempo sensitivity appear to result mainly from two factors: (1) a greater capacity to track a wider range of tempi in the environment, especially at slower rates, and (2) increasing the amount of temporal information in the comparison sequence especially at faster rates. Overall, the general findings of this study provide support for an entrainment theory of timing and event-tracking.
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DEVELOPMENTAL CHANGES IN AUDITORY TEMPO SENSITIVITY AND PREFERRED TEMPO

INTRODUCTION

Our perception of the world is shaped by the temporal patterning of events. The environment is constantly providing us with temporal cues about the occurrence of events. This is particularly true for auditory events which would be non-existent without their temporal dimension. The ability to detect these cues and the rate at which events occur is vital for fluid interaction with our environment and for language. It allows us to adapt our movements, adjust the ebb and flow of our conversation, and segment words. Many events, such as music and speech, are rhythmic. One characteristic of rhythmic events is that they convey a general sense of rate (or tempo) that potentially helps us monitor events as they unfold in time.

With respect to rhythmic events, it has been suggested by a number of researchers that each individual has his or her own preferred rate (tempo) of perceiving (Jones, 1976; McAuley, 1996). This personal affinity for a particular tempo has historically been referred to by various names such as ‘referent period’ (Drake, Jones, & Baruch, 2000; Jones & Boltz, 1989), ‘personal tempo’, ‘psychic tempo’, and ‘mental tempo’ (Fraisse, 1982; Rimoldi, 1951; Mishima, 1952), depending on whether this preference refers to a preferred rate of listening, a preferred rate of spontaneous motor activity, or more general cognitive preference. This thesis examined the relationship between developmental changes in preferred motor tempo and auditory perceptual tempo sensitivity. The introduction begins by exploring the relationship between preferred perceptual tempo (PPT) and spontaneous motor tempo (SMT), followed by an examination of the literature on developmental changes in PPT and SMT. Investigation of literature related to
the correspondence between preferred tempo and tempo sensitivity, with an overview of
developmental changes in tempo sensitivity, concludes this section.

For the purposes of this study, I refer to preferred rate of listening as ‘preferred perceptual tempo’ (PPT) and preferred rate of spontaneous motor activity as ‘spontaneous motor tempo’ (SMT). Fraisse (1982) defined PPT as “… the speed of a succession of sounds or of lights that appears to be most natural … a regular succession judged as being neither too slow nor too fast” (p. 153). SMT has been typically assessed by measuring an individual’s most comfortable rate for finger or hand tapping at regular intervals.

Fraisse’s (1982) review of research on rhythm and tempo noted that spontaneous motor tempo and preferred perceptual tempo have comparable frequencies. The range of spontaneous motor tempi in these studies extended from a produced inter-tap-interval (ITI) of 380 ms to an ITI around 880 ms (Frischeisen-Köhler, 1933; Mishima, 1951), but the most frequently produced interval for adults was 600 ms (Fraisse, 1982). Collyer, Broadbent, & Church (1994) found a bimodal distribution of SMT with modes at 272 and 450 ms. Similarly, the results of preferred perceptual tempo studies have found that the most frequent tempo is around 500 ms (Frischeisen-Köhler, 1933; Mishima, 1956). Fraisse cautioned that though PPT and SMT have comparable frequencies, the correlation between the two was moderate; no higher than 0.40 (Fraisse, 1982; Mishima, 1965).

**Developmental changes in PPT and SMT**

Recent developmental work on preferred perceptual tempo and spontaneous motor tempo has suggested that both PPT and SMT may slow across the lifespan (McAuley, Jones, Holub, Johnston, & Miller, 2006; Drake, Jones, & Baruch, 2000; Vanneste, Pouthas, & Wearden, 2001). McAuley et al. proposed two hypotheses about life span development of timing and event-
tracking: a preferred period hypothesis and an entrainment region hypothesis. The preferred period hypothesis proposes that a person’s detection of environmental events which are rhythmically structured in time is related to their preferred motor tempo. Since preferred motor tempo is associated with an intrinsic ‘ideal’ oscillator period that becomes increasingly longer as one ages, there should be a slowing of preferred listening tempo, and its related preferred motor tempo. McAuley et al. also predicted that, during childhood, there is an age-related widening of the range of associated temporal environmental events which children can accurately follow (entrainment region hypothesis). In the latter hypothesis, there is a curvilinear function to the temporal range of associated temporal environmental events with widest range occurring in young-to-mid adulthood and the narrowest range occurring at the extreme ends of the lifespan.

The results of the study confirmed these hypotheses. Consistent with the preferred period hypothesis, the authors found a systematic age-related shift in the rate of SMT which paralleled age-related changes in preferred listening tempo. SMT slowed from 300 ms IOI in children to 700 ms IOI for older adults. There was a distinct shift in the rate of spontaneous tapping and in PPT between the ages of 6 to 9 years, with the most distinct break in performance levels around the age of 8 years. SMT was also found to be highly correlated with PPT. Tapping data provided additional support for the entrainment region hypothesis. When dividing the difference of fast motor and slow motor tempo with SMT, it was found that the youngest children (ages 4 - 5 years) had the narrowest range of stable motor tapping, which was approximately half the size of the range of older children and young adults.

Drake et al. had previously investigated the relationship between detection of structured temporal events in the environment and preferred tempo in a series of experiments aimed at investigating the development of attention to rhythm in auditory sequences, primarily during
childhood. Consistent with the preferred period hypothesis, the authors also predicted an age-related slowing of preferred tempo. Preferred tempi, measured by the mean rate of spontaneous tapping, were found to slow as a function of age while variability increased incrementally with increases in mean SMT rates.

Vanneste et al. provided additional support for the preferred period hypothesis. Young adults (20 - 30 years old) and older adults (60 - 76 years old) were tested on rhythmic performance over five sessions using repetitive tapping to gauge both preferred tempo and entrainment to external tempo. Preferred tempo was measured in a free motor task where participants tapped at a comfortable rate. Results of the study revealed that, on average, SMT slowed for older adults despite increased preferred tapping rates over time for both groups on the continuation task. Variability in mean SMT did not differ significantly between the groups.

Correspondence between preferred tempo and tempo sensitivity

One question that emerges from this work is whether listeners are best able to detect changes in the tempo (rate) of auditory events for rates that are near their preferred tempo. That is, in what sense is preferred tempo optimal? Data relevant to this question are mixed. In a seminal study of tempo discrimination, Drake and Botte (1993) found that auditory tempo sensitivity was optimal for isochronous tone sequences presented at an intermediate rate ranging from 300 ms IOI to 800 ms IOI. The range of optimal tempo rates was found to be dependent on the number of intervals in the sequence. Similarly, McAuley and Kidd (1998) using two- and four-tone isochronous sequences with fixed standard IOIs of 100, 400, 700, and 1,000 ms obtained lowest mean thresholds for 400 and 700 ms IOIs. The number of sequence intervals

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1 The authors reported that the increase in preferred tapping rates was probably due to training effects.
showed an effect on tempo sensitivity with thresholds decreasing as the number of intervals increased.

The results of the two previous studies conflicted to some degree with Michon (1964) who found that maximal tempo sensitivity was closer to 100 ms IOI for sequences that were sufficiently long. The author suggested that this result was probably the consequence of the repetition of stimulus intervals, supporting the view that there might be an optimal tempo shift that is dependent on the number of sequence intervals. Grondin (2001) also failed to find optimal sensitivity at 600 ms in his study of time interval discrimination using visual stimuli. Using standard intervals of 150, 300, 600, 900, and 1,200 ms with either a continuous presentation (single sequence) or a discontinuous presentation (standard sequence-pause-comparison sequence), the overall results obtained suggested that there is a range of optimal tempo sensitivity that ends at 1,200 ms. He did not specify what was the lower limit of this range. Grondin cautioned that the absence of optimal sensitivity at 600 ms may have been due to the use of visual signals, signifying that there may be differences in optimal tempo in the auditory and visual modalities. Overall, the results of the majority of studies on tempo sensitivity using auditory sequences tend to converge on a tempo range for greatest sensitivity that is centered on a mean IOI near 600 ms. The latter corresponds to the average adult PPT and SMT found by Fraisse (1982) in his review of the literature.

*Developmental changes in tempo sensitivity*

Fewer studies have examined tempo sensitivity in infancy and childhood. Morrongiello and Trehub (1987) tested infants, preschool children and adults on their ability to detect interval duration changes in a sequence of noise bursts, and found general age-related improvements in auditory tempo sensitivity. However, they did not consider the question of whether there were
shifts in an optimal zone of temporal processing. Baruch and Drake (1997) tested fine tempo discrimination judgments in two- and four-month old infants to determine whether the zone of optimal tempi for infants was the same as adults. Using a head-turn paradigm, stimulus isochronous tone sequences of 100, 300, 600, and 1500 ms IOI with a ±15% tempo change were presented to the infants. The authors observed that significant tempo discrimination between sequences occurred only at the intermediate tempo of 600 ms IOI in both infant age groups. They concluded from these findings that there was support for a hypothesis of a similar optimal tempo sensitivity zone for both infants and adults situated around 600 ms.

However, the findings in the Baruch and Drake study conflict with the results of Drake et al. (2000) who provided evidence of a shift in optimal tempo sensitivity with increased age, which is consistent with the preferred period hypothesis. Specifically, the range of discriminable tempi increased with age, particularly towards slower rates. Children were asked to make discrimination judgments of five tempi (100, 300, 600, 1000, and 1500 ms) compared to three IOI changes of either ±10, 15 or 20% change in tempo. Tones sequences consisted of ten isochronous tones and the tempo changes were applied randomly to the pre- or post-pause sequence. Four-year-old children were shown to be the most restricted in their ability to discriminate tempi, achieving tempo discrimination only at 300 ms IOI. The 300 ms IOI maximal tempo sensitivity in younger children was the preferred motor tempo for this age group (McAuley et al., 2006).
OVERVIEW

The general aim of this thesis was to extend previous research by more thoroughly examining developmental changes in tempo sensitivity than has been undertaken in the past. Previous studies have provided mixed results about the range of optimal tempo sensitivity for infants and children. Some of these studies claimed that infants’ optimal tempo is the same as adults which is 600 ms (Baruch & Drake, 1997). Others argued for the preferred period hypothesis stating that optimal tempo is age-dependent, paralleling age-related changes in preferred tempo as measured by SMT; fast optimal tempo for young children (around 300 ms), which slows as they reach maturity, centers around 600 ms (Drake et al., 2000; McAuley et al., 2006). In the latter case, children showed the greatest improvements in tempo sensitivity at the slowest tempi, consistent with the entrainment region hypothesis. This hypothesis predicted that precision in an individual’s ability to track events in the environment has a curvilinear function and will improve from children to young adulthood as the temporal region centered on their preferred tempo widens to incorporate slower rates in the environment.

This study also builds on developmental changes reported by Drake et al. and McAuley et al. by examining the effect of number of comparison intervals on tempo sensitivity in children. Recently, Miller and McAuley (2005) reported that improvements in tempo sensitivity occur when the number of intervals in the comparison sequence is increased. It is an open question whether similar improvements might be observed with children and whether this would be the same at all tempi.

To address these issues, four age groups of participants (4 - 5 years, 6 - 7 years, 8 - 9 years, and 18+ years) completed spontaneous motor tempo and tempo discrimination tasks. For the spontaneous motor tempo task, participants were asked to tap at their preferred rate for 30
taps in two consecutive trials. SMT was then used as a measure of preferred tempo. For the
tempo discrimination task, participants were asked to judge whether the tempo of an isochronous
comparison sequence was faster or slower than the tempo of an isochronous standard sequence
that was presented at a fixed rate. Tempo judgments were made for three different standard tempi
(300, 600, and 900 ms) for comparison sequences consisting of one, three, and five intervals.

According to the preferred period hypothesis, there should be an age-related slowing of
preferred motor tempo. If this is the case, then it was predicted that there would be age-related
changes in tempo sensitivity that reflect a shift in preferred tempo; young children (4 - 7 years)
who typically have a preferred motor tempo around 300 ms should produce the lowest thresholds
at the fastest tempo (standard IOI = 300 ms) with worse performance in the two slower tempo
conditions. In conformity with the entrainment region hypothesis, tempo sensitivity should also
improve with age, with the greatest improvements found at the slower tempi (standard IOIs =
600 and 900 ms) as the entrainment region widens. Moreover, if young children have a narrow
range of entrainment centered on their preferred motor tempo, then improvements associated
with the number of intervals in the comparison sequence should be restricted to the fastest tempo
(standard IOI = 300 ms), but extend to the two slower rates (standard IOIs = 600 and 900 ms)
with increased age.
METHOD

Participants

Sixty-eight children and twenty-one college-age adults were recruited for the study. Children were recruited from the city of Bowling Green and the surrounding townships. Families of children received $10-$15 and child participants received small gifts as compensation. Adult participants were undergraduate students at Bowling Green State University who participated in return for extra credit in an introductory psychology course. All participants had normal hearing as measured by parental report for the children and self report for the adults. Twelve children with a parent-reported developmental disorder and one adult participant taking psychotropic medication were not included in the final sample. The final sample consisted of seventy-five individuals in four age groups (4 - 5 years, n = 15; 6 - 7 years, n = 21; 8 - 9 years, n = 20; 18+, n = 20)².

Design

Participants completed a spontaneous motor tempo task and a tempo discrimination task. The spontaneous motor tempo task was presented first in order to minimize the possibility that the tempo discrimination task would alter the assessment of SMT.

The tempo discrimination task employed a 4 x 3 x 3 mixed factorial design. Four age groups (4 - 5 years, 6 - 7 years, 8 - 9 years, and 18+ years) were crossed with three standard IOIs (300, 600, and 900 ms) and three different length comparison sequences (n = 1, 3, or 5 intervals; see Figure 1). Both standard IOI and number of comparison intervals were within-subject variables. Standard sequences consisted of five equal IOIs. Standard IOI was held constant within a block of trials, while number of comparison intervals varied randomly from trial to trial.

² The 4 - 5 year old age group contained only one child in the 5-year-old range.
Stimuli and Equipment

Spontaneous tapping responses were recorded on an IBM PC compatible computer using touch-sensitive copper response plates. Tapping responses were recorded using a custom-made DOS software program that measured response time to the nearest millisecond.

For the tempo discrimination task, tone sequences and supporting instruction images were presented on an IBM PC compatible computer. All stimulus tones were 50 ms in duration and had a fundamental frequency of 440 Hz played at a comfortable listening level through Grado Prestige Series model SR80 headphones attached to the computer. The experiment was controlled by E-Prime 1.1 (SP 3) software package (Psychology Software Tools © 1996, 2003) with tones generated by a Creative Labs SoundBlaster Live Sound Card (Creative Technology Limited © 1998 - 2005). Initially, tone sequences were created using Midilab software package (Todd, Boltz, & Jones, 1989) and then transferred to a laptop computer using a Radio Shack® audio patch cable with an adaptor which allowed the transfer of sound from the Yamaha PSR-270 electronic keyboard (Yamaha Corporation of America © 2005) to the computer. The files were converted into .wav files during recording using Windows XP sound recorder accessory (Microsoft Corporation © 2005). The recorded .wav files were then transferred onto the experiment computer. Responses were made on a Psychology Software Tools serial response box Model #200A (Psychology Software Tools © 1996, 2003).

Procedure

The experimenter met participants (and the parents in the case of child participants) to explain the purpose and general task of the experiment. Upon completion of the consent/assent requirements, adult participants completed a background survey to gather information about individual participant characteristics which could possibly influence timing performance, such as
number of years of music and dance training, amount of weekly music listening, history of hearing problems or ear infections, and medications or stimulants consumed during the day. Parents of child participants completed a similar background survey for their child along with the adaptive parent version of the *Barratt Impulsiveness Scale Version 11, BIS-11* (Patton, Standford, & Barratt, 1995). The *BIS-11* and the adaptive version for children (McAuley et al., 2006) were used to assess attentional impulsiveness, motor impulsiveness, and non-planning impulsiveness; see Appendixes A & B (Barratt, 1965; Barratt, Patton, Olsson, & Zuker, 1981).

The experiment began with participants completing the SMT task twice. For the SMT task, participants rested their left hand on one touch-sensitive copper plate and were then asked to tap smoothly at a comfortable, even rate (or favorite speed) using an open right hand on the other plate, while resting their wrists on a wrist pad. ‘Comfortable’ rate was defined as the rate (tempo) that was neither too fast, nor too slow, but felt ‘just right’. Tapping began when a green ‘go’ sign was shown and ended when a red ‘stop’ sign appeared. Data collection continued for thirty intervals (31 taps) during two consecutive trials at the start of the experiment.

The SMT task was followed by a hearing screening test. Participants then completed the tempo discrimination task. Child participants were administered an in-house timing/animal relationship questionnaire prior to the tempo discrimination task to determine the child’s association between two animals used for response labels (rabbit, turtle) and the rate at which these animals move (fast, slow), as well as the timing relationship between the animals (faster, slower). Figure 1 shows a diagram of the task. The experimenter read the instructions while the participant, seated in front of the computer, followed them on the computer screen. In order to make the task easier for children to understand, the instructions described the story of a walking cat that pauses, then resumes walking at a different tempo (faster or slower) with a variable
number of steps (tones). A cat puppet was used to illustrate the tempo changes and the number of steps. Participants were asked to listen to the entire sequence and then decide whether the cat goes ‘faster’ or ‘slower’ following the pause. Responses were made by pressing one of two buttons on the response box labeled as follows: 1- Faster - image of rabbit, 5-Slower- image of turtle. Small toy representations of these animals were also placed above each button to reinforce the image labeling. For children, the associated animal representations were determined prior to the task with the use of a homemade timing/animal relationship questionnaire. If a child consistently related each animal to the opposite speed, then that child’s conceptual relationship was used (i.e. turtle for faster and rabbit for slower).

Auditory and visual examples of the task (without tempo changes) were presented before the practice trials. Practice trials consisted of a training block of 12 randomized trials (two trials per condition) of the comparison sequences with IOI duration equal to ± 30% of the standard IOI. Participants were told that a tempo change would occur after the pause. Visual feedback about performance was presented after each trial. The youngest children (4 – 5 years) received verbal feedback from the experimenter in addition to visual feedback during the training block. Participants repeated the training block if overall correct performance was below 66 percent. If participants did not reach this training criterion after a second training block, then testing for that standard IOI did not proceed to the experimental task.

Following training, participants then completed a test block. The task was similar to that of the training session. A total of three blocks (one block per standard sequence) each containing 18 trials (6 comparison IOIs [±6%, ±12%, and ±18% of standard IOI] x 3 comparison intervals [1, 3, and 5]) were presented. Standard sequences were blocked to reduce the possibility of interference from other tempi which could result in gravitation towards the mean tempo, thus
eliminating the possibility of determining an optimal tempo for discrimination. Participants were tested on all three standard tempi with the order of presentation counterbalanced across participants within each age group. Data collected consisted of faster/slower response and reaction time.

A short break was given between each of the three blocks of trials (one for each standard IOI). During the first break, participants’ body measurements were taken and the handedness questionnaire was administered. The second break consisted of completing the BIS-11 (or adaptive child version) impulsiveness questionnaire. If requested, participants were allowed to engage in a brief relaxing activity not related to the study before returning to the task. Child participants were allowed to take as many additional breaks between blocks of trials as they desired during the experiment.

Finally, participants completed a response-strategy questionnaire which asked questions about the tasks in the study and any strategies that might have been used to help them perform the tasks. They (as well as the parents of child participants) received a short age-appropriate debriefing about the experiment (accompanied by an information/contact sheet) and the appropriate compensation before leaving.

Data Analysis

SMT was measured by calculating the median of inter-tap intervals (ITIs) for each participant on each of the two SMT trials. These median estimates were then averaged to produce a mean composite measure for each subject. A one-way between-subjects ANOVA was used to determine the effects of age on SMT. Levels of the independent variable consisted of the four age groups: 4 - 5 years, 6 - 7 years, 8 - 9 years, and 18+ years.
For the tempo task, overall proportion of correct responses (PC) was measured for each participant for each of the nine conditions (3 standard IOIs crossed with 1, 3, and 5 comparison intervals). A three-way mixed-factorial ANOVA was used to assess effects of age (4 - 5 years, 6 - 7 years, 8 - 9 years, 18+ years), standard IOI (300 ms, 600 ms, 900 ms), and number of comparison intervals ($n = 1, 3, 5$) on tempo sensitivity, as well as possible interactions. Because not enough data per participant was available to obtain reliable individual estimates of the relative just-noticeable difference in tempo (JND) and the point of subjective equality (PSE), tempo data were collapsed over participants to obtain single composite estimates of these measures for each age group in each of the nine conditions.

In order to measure JND and PSE for the aggregate data, proportion of faster responses for each comparison IOI was plotted in each of the nine conditions after collapsing overall subjects’ raw scores for each condition. This produced nine psychometric curves. Scores for proportion of faster responses were then transformed into $z$-scores to normalize the data. Linear regression was then used to determine a line of best fit from which both slope and intercept were extracted in order to calculate JND and PSE. Relative JND, which is equivalent to half the distance between the 25th and 75th percentiles ($d' = 0.675$) of the psychometric curve, was used to determine tempo sensitivity for each age group (Macmillan & Creelman, 1991). Relative JND corresponded to the smallest detectable change between the standard sequence and the comparison sequence. PSE, which is the point at which the comparison sequence is judged to be 50 percent “faster” than the standard sequence, was used to determine participant’s relative constant error (CE) in each condition. PSE was established by setting $z$ to zero. Relative CE was then calculated using the following formula: $CE = (PSE – \text{standard IOI})/\text{standard IOI}$. A positive
CE indicated that participants tend to overestimate the tempo of the standard IOI. A negative CE indicated that participants tend to underestimate the tempo of the standard IOI.

Finally, correlation analyses were used to examine the relationship between SMT, tempo sensitivity, and various individual characteristics (body mass index, music experience, dance experience, and impulsivity).
RESULTS

Developmental changes in SMT

Consistency of SMT across the two measurements was analyzed to determine the stability of the measurement across trials. SMT consistency was assessed by calculating the standard deviation of the two measures, then dividing by the mean SMT. This produced a normalized consistency score. Based on a 15% criterion, only two participants produced inconsistent SMTs (4 - 5 years old: \( n = 1 \), 6 - 7 years old: \( n = 1 \)).

Figure 2 shows mean SMT for the four age groups. Fifteen children in the youngest group (4 - 5 years) and 21 children in the 6 - 7 year old group who were able to complete at least one of the tempo discrimination tasks were included in the analysis. All other age groups had twenty participants. Overall, there was a significant effect of age on SMT, \( F(3, 72) = 5.771, \) \( MSE = 44919.906, p < .01 \). Consistent with the preferred period hypothesis, SMT slowed with increased age. The youngest age group (4 - 5 years old) had a mean rate of 366 ms. Mean SMT continued to increase with 6 - 7 year olds tapping at a mean rate of 534 ms, 8 - 9 year olds at 554 ms, and young adults at 666 ms. The greatest variability in SMT rates was seen in 8 - 9 year olds.

Developmental changes in tempo sensitivity

The tempo discrimination task was especially difficult for the 4 - 5 year olds, despite the fact that almost all children were able to correctly associate notions of faster and slower with the corresponding response button animal\(^3\). Only 8 out of 15 of the participants in this age group were able or willing to complete all three standard tempo conditions. More children did not complete the 900 ms standard IOI condition \( (n = 6) \) than the other two tempo conditions (300 ms

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\(^3\) Only one child systemically associated faster with the turtle and slower with the rabbit. For this child, the animal associated with the response button was the same as his response association in the timing/animal relationship questionnaire.
standard IOI: \( n = 4 \), 600 ms standard IOI: \( n = 4 \). However, most children were able to complete at least two of the three conditions. One child in the 6 - 7 year old age group was also unable to complete all three conditions.

The following analysis includes only children that could complete all three tempo conditions. Figure 3 illustrates the changes observed for tempo sensitivity in terms of mean PC (4 - 5 years: \( n = 8 \), 6 - 7 years: \( n = 20 \), 8 - 9 years: \( n = 20 \), 18+ years: \( n = 20 \)). Overall, participants showed improved tempo sensitivity with increased age, \( F (3, 64) = 38.25, MSE = .052, p < .01 \). Tempo also had a significant effect on participants’ ability to correctly detect relative tempo changes, \( F (2, 128) = 10.07, MSE = .022, p < 0.01 \). For all age groups, the 600 ms standard condition resulted in the greatest number of correct tempo discrimination responses, while the 300 ms standard condition proved to be the most difficult. This finding was inconsistent with the preferred period hypothesis which predicted that optimal tempo would shift from a fast rate to slower rates with increased age, analogous to the SMT shift. The youngest age group (4-5 years old) performed very poorly on the tempo discrimination task, with overall PC close to chance. Mean PCs (with standard deviations in parentheses) for the 300, 600, and 900 ms conditions were 0.62 (0.20), 0.65 (0.20), and 0.57 (0.17), respectively. One sample t tests on the means for this age group revealed that the 4-5 year olds were not performing significantly above chance (0.5); see Table 1.

When the youngest age group was removed from the analyses, there was a marginal interaction between tempo and age, \( F (4, 114) = 2.42, MSE = 0.018, p = 0.053 \).

The greatest age-related improvements in tempo sensitivity were found at the slowest and fastest rates. This would be consistent with the entrainment region hypothesis which predicted greatest improvements at the slowest rates.
Figure 4 shows the effect of the number of comparison intervals on tempo discrimination performance for each of the three standard tempi for each of the four age groups. Consistent with Miller and McAuley (2005), increasing the number of comparison intervals improved tempo sensitivity, with an ANOVA value of $F(2, 128) = 15.73$, $MSE = 0.022$, $p < 0.01$. Moreover, there was a significant tempo x number of comparison interval interaction, $F(3.49, 223.60) = 3.20$, $MSE = 0.02$, $p < 0.05^4$. This improvement was especially pronounced in the fastest tempo condition (300 ms standard IOI). However, this was not the case for children ages 4-5 years. For this age group, improved performance associated with increased number of comparison intervals was only significant for the intermediate condition (600 ms standard IOI) when increasing from one to three comparison intervals, $t(7) = -3.989$, $p < 0.01$ (two-tailed); and from one to five comparison intervals, $t(7) = -2.762$, $p < 0.05$ (two-tailed).

Figure 5 and Figure 6 show relative JND and relative CE organized according to age group. Relative JND and relative CE could not be reliably obtained for the youngest age group because overall PC in the tempo discrimination task was close to chance. In general, relative JND and relative CE results were consistent with the PC results. Relative JND was lowest for the 600 ms standard IOI for each age group and relative CEs were all close to zero. As would be expected, there was an inverse relationship between relative JND and the number of comparison intervals. All age groups showed lower tempo thresholds with increasing number of comparison intervals. This was particularly evident for the fastest tempo condition (300 ms standard IOI). However, adults showed very little threshold difference between comparison interval conditions at intermediate (600 ms standard IOI) and slow (900 ms standard IOI) tempi. This may have been due to the fact that the tempo discrimination task was very easy for adults.

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4 Greenhouse-Geisser correction was used because of a violation of sphericity as indicated by a significant Mauchley’s W value for this within-subjects effect.
Individual difference predictors of SMT and tempo sensitivity

Finally, predictors of individual differences in SMT and tempo sensitivity were taken into consideration. Both years of musical training and years of dance training were used to examine the relationship with SMT. Music and dance training were found not to be significantly correlated with SMT, $r = 0.155, p = 0.180$ (two-tailed); and $r = -0.048, p = 0.684$ (two-tailed), respectively.

Mean SMT was found to be marginally correlated with body mass index, $r = 0.224, p = 0.052$ (two-tailed); SMT slowed as body mass increased. However, when age was controlled for, the correlation was no longer significant, $r = -0.079, p = 0.499$ (two-tailed). SMT was not correlated with impulsivity in children but adults displayed a negative correlation, $r = -0.625, p < 0.01$ (two-tailed); the more impulsive an adult rated himself or herself, the faster the rate of SMT.

SMT did not correlate with impulsivity in children. However, tempo sensitivity did correlate with child impulsivity in one tempo condition. Analysis of the data revealed a significant correlation between tempo sensitivity and parental ratings of impulsivity only for the slowest tempo condition (900 ms), $r = -0.290, p < 0.05$ (two-tailed). In this condition, the more the child was rated impulsive, the less accurate was the discrimination response. No other correlation between tempo sensitivity and impulsivity was found either at the fastest tempo condition (300 ms), $r = -0.150, p = 0.307$ (two-tailed); or at the intermediate tempo condition (600 ms), $r = -0.146, p = 0.323$ (two-tailed).
DISCUSSION

The goal of this study was to examine developmental changes in tempo sensitivity and the relationship between tempo sensitivity and preferred tempo. Of particular interest were two developmental hypotheses proposed by McAuley et al. (2006): the preferred period hypothesis and the entrainment region hypothesis. To address these hypotheses, children ages 4 - 9 years and young undergraduate adults were asked to tap at a comfortable rate (SMT) and discriminate tempo changes in three separate isochronous standard sequences (300, 600, and 900 ms) when presented with isochronous comparison sequences of variable lengths (1, 3, or 5 intervals).

**Developmental changes in SMT and tempo sensitivity**

Consistent with the preferred period hypothesis, SMT slowed with increased age. Mean SMT for the 4 - 5 year old age group was 366 ms, which slowed to approximately 666 ms for the 18+ age group. This finding is similar to the results found by other authors examining developmental changes in SMT (Drake et al., 2000; McAuley et al., 2006; Vanneste et al., 2001). Drake et al. found a mean spontaneous tapping rate of 400 ms for 4 - 5 year olds while the mean rate for this age group in the McAuley et al. study was 312 ms. The young adults in both of these studies had mean spontaneous tapping rates around 600 ms (Drake et al., 2000, McAuley et al., 2006) while the Vanneste et al. study found a mean rate of 536 ms. In the case of the latter study, the results were averaged for data across five sessions with an observed increase in SMT across sessions. The experimenters concluded that this increase in SMT was due to training.

Curiously, the predicted parallel shift in tempo sensitivity was not found. Based on a preferred period hypothesis, it was also expected that the younger children (ages 4 - 7 years) would show the best tempo discrimination performance for the 300 ms standard IOI, which was the tempo condition closest to the average SMT for children in this age range. However, the
results indicated that best performance was obtained at the intermediate tempo (600 ms
standard IOI). This was also the tempo condition where older children (8 - 9 years old) and
adults had the lowest thresholds. The small sample of five-year-olds participating in this study ($n$
= 1; see Footnote 2) makes generalization to this age quite difficult. It would be important to
sample a greater number of children from kindergarten age (five-year-olds) in order to confirm
the results of this study for the 4 - 5 year old age group.

The results concerning tempo sensitivity did support the general entrainment region
hypothesis which proposed that age-related improvements would be greatest at the slowest rates.
Overall, the greatest age improvement in tempo sensitivity occurred at the 900 ms standard IOI
condition, followed by the 300 ms standard IOI condition and the 600 ms standard IOI condition
respectively.

These tempo discrimination findings for the younger children were inconsistent with
recent findings by Drake et al. which showed an age-related shift in optimal tempo sensitivity
with best discrimination performance in four-year-olds in the 300 ms standard IOI condition. A
possible reason for the divergence between this study’s results and those of Drake et al. is the use
of a shorter standard isochronous tone sequence. In the case of the Drake et al. study, the
standard sequence consisted of nine IOIs while our study had a standard sequence of five IOIs.
Drake et al. obtained best discrimination performance for four- and six-year-olds at the 300 ms
tempo condition while this study found best performance for six-year-olds at the 600 ms
tempo condition and no performance above chance for 4 - 5 year olds (see Table 2). Michon (1964),
using a longer pulse train stimulus, found that maximal tempo sensitivity was attained around
100 ms standard IOI. The increased length of the standard sequence in the Drake et al. study
might have allowed sufficient time for the younger children to entrain to the faster rates, thus resulting in better performance in the 300 ms condition.

Improvements in tempo sensitivity were also predicted to be impacted by the length of the comparison sequence. It was predicted that children would have a narrow range of entrainment centered on their preferred motor tempo and that improvements associated with the number of comparison intervals would be restricted to the fastest tempo (300 ms standard IOI) for the younger children, and extend to the slower tempi with increased age. This study’s findings were consistent with this prediction except for the 4 - 5 year olds. The lack of this result in the 4 - 5 year olds again may be due to their near-chance performance in the fastest tempo condition (300 ms standard IOI). For this age group, increasing the number of comparison intervals from one to three intervals did significantly improve performance in tempo discrimination at the intermediate tempo condition (600 ms standard IOI). Findings from an electrophysiological brain study by Pfeuty, Ragot, and Pouthas (2003) are consistent with findings from the current study. They noted that adult participants in a tempo discrimination task with a sequence IOI of 600 ms had better behavioral performance when both standard and comparison sequences consisted of six intervals instead of three intervals. The observed decrease in the participants’ slow negative wave (called contingent negative variation) in the comparison phase of the six-interval condition suggested that a beat-based process was involved. These findings are consistent with the entrainment hypothesis proposed by McAuley et al. in which increases in the number of intervals extend to slower tempi with age.

In order to address the questions raised for both the preferred period hypothesis and the entrainment region hypothesis in the youngest age group, it would be important to replicate this
study using the fastest tempo condition (300 ms) with a standard IOI sequence length similar to that of the Drake et al. study.

**Individual difference predictors of SMT and tempo sensitivity**

Drake et al. also found individual differences in SMT related to level of musical training. SMT was found to be slower in musicians than in non-musicians. The current study did not find a significant correlation between years of musical experience and SMT. This divergence in the findings can possibly be accounted for by the intensity of musical training for the classification of “musician”. In the Drake et al. study, musicians were defined as participants who were receiving formal musical training and were playing an instrument almost every day while in the current study, most participants with musical experience were not playing an instrument on a daily basis and only a minority who had received musical training in the past were receiving training at the time of participation. If the intensity of musical training and practice was shown to be the key factor for explaining the divergence of the results, then it could imply that (1) preferred motor tempo can be influenced motor control training, and/or (2) preferred motor tempo can be influenced by musical enculturation. More research is needed to assess these hypotheses.

One possibility for individual differences in SMT is that SMT manifests a natural resonant frequency or eigenfrequency. The eigenfrequency of a system is influenced by properties of mass, length, and force. As mass and length increase, frequency of oscillation decreases. Kugler and Turvey (1987) applied these basic principles of physics to human limb motion and hypothesized a scaling law of a wrist-pendulum system which accounts for the influence of mass on rhythmic oscillatory movements. This hypothesized scaling law states that “…for all biological systems there is a single scaling relation or law among the dimensions of
time \( (T) \), mass \( (M) \), and length \( (L) \)” (p. 206). The experiments conducted by Kugler and Turvey using varying lengths and mass of hand-held pendulums demonstrated that the preferred frequency of oscillation corresponded to the resonant frequency of the wrist-pendulum system (cited in Hatsopoulos & Warren, 1996, p. 4). Hatsopoulos and Warren found the same correspondence between the preferred rate of rhythmic arm movements and the resonant frequency of the muscle-limb complex of their participants. Since SMT involves rhythmic movement of the wrist and hand, it is plausible to assume that Kugler and Turvey’s hypothesized scaling law of a wrist-pendulum system could apply to SMT data.

In the present study, there was an observed marginal slowing of the preferred frequency of oscillation (SMT) which was eliminated by factoring out age. The current study also revealed a positive correlation of body mass \( (\text{kg/m}^2) \) with age \( (r = 0.224, p = 0.052; \text{two-tailed}) \). Since normal body development is represented by an increase in limb length and body mass during childhood, and both length and mass influence natural resonant oscillatory movements, then it is possible that natural body changes which occur across the age range of the study’s participants could Therefore explain the marginal SMT slowing associated with an age-related difference in body mass between adult and child participants. However, the absence of a correlation between SMT and body mass when only adults are analyzed, \( r = -0.132, p = .579 \) (two-tailed), argues against a developmental body mass explanation of SMT.

Individual differences in auditory perceptual sensitivity have also been found to be related to both pathological and non-pathological forms of impulsivity in children and adolescents (Margolis, 1977; Toplack, Rucklidge, Hetherington, John, & Tannock, 2003). Margolis found that impulsive children had poorer performance in discrimination tasks, especially in tasks where uncertainty was high, while Toplack et al. confirmed that children and
adolescents with attention deficit/hyperactivity disorder were less accurate in both duration discrimination and duration estimation tasks. The current study found that children rated impulsive by their parent performed more poorly on tempo discrimination at the slowest rate (900 ms) than children whose parents’ rating of their impulsivity was low. This finding is supported by the conclusions drawn from a meta-analysis of developmental changes in human duration judgments conducted by Block, Zakay, and Hancock (1999). They concluded that one contributing factor for the age-related differences found in duration judgment ratio and coefficient of variation could be children’s impatience or inability to delay their response when faced with a duration task which consists of relatively empty durations. The authors offered the attentional-gate model as a post-hoc explanation for the hypothetical mediator variable of impatience. Zakay and Block’s (1996, 1997) attentional-gate model proposes that duration judgments rely on a combination of physiological elements and cognitive elements (as cited in Block, Zakay, & Hancock, 1999). Arousal level and attentional gate are the key elements with the former influencing the pacemaker rate and the latter impacting the amount of temporal information transmitted to memory store (Block et al., 1999, p. 186). Block et al.’s post-hoc explanation for children’s impulsive response in empty-duration reproduction tasks posits that as target time elapses, children’s impatience may lead them to focus their attention on the moment when the duration will end, thus increasing the amount of attention allocated to time which would result in longer prospective duration judgments (p. 206). The present study did not use individual measures of CE, thus rendering an analysis of impulsive children’s overestimation/underestimation of tempo impossible. However, if the attentional-gate model is correct in handling a mediatory variable such as impatience, then it would be expected that children rated impulsive in the present study would overestimate the longest standard tempo (900
ms standard IOI), and respond ‘faster’ to the comparison sequence more frequently than children who were not rated impulsive. Correlation analysis of ‘faster’ responses in the 900 ms standard IOI condition with parental ratings of impulsivity (e.g., BIS-C scores) did not support this prediction, $r = -0.055, p = 0.700.$

Relation to other developmental studies of timing

Much of the past developmental research concerning auditory temporal perception in children has focused on time estimation based on single interval duration judgments, production, and reproduction (Block et al., 1999; McCormack, Brown, Maylor, Darby, & Green, 1999; McCormack, Brown, Smith, & Brock, 2004). Experiments such as those conducted by McCormack and colleagues have advanced the understanding of developmental variations in prospective time estimation (Block et al., 1999; McCormack et al., 1999, 2004). McCormack et al. (1999, 2004) found that there is an overall developmental improvement in time estimation, as well as a developmental shift from underestimation of short durations in children, which is more pronounced in young children, to an overestimation of long durations in adults. Consistent with McCormack et al. findings, the current study also revealed an overall developmental improvement in tempo judgments with a slight tendency for children to underestimate the faster tempo and for adults to overestimate the slower tempo as seen in overall CE results (see Figure 6). Block et al.’s meta-analysis of human duration judgment revealed that cognitive hypotheses related to duration units (learned duration labels), impatience, and response delay were key to explaining the greater inter-individual variability in children than in adolescents and adults. They suggested that this increased inter-individual variability was indicative of diverse developmental changes in the rate or age of time-related abilities. It is equally plausible to suggest that there was a wide developmental range of time-related abilities in the children who participated in the
current study. Impatience also played a key role for certain children in the slowest tempo condition of this study. It would be beneficial to do a more detailed analysis of the reaction times of the youngest children to see if impatience, in the form of responding before the end of the comparison sequence, contributed to overall poor discrimination performance in this age group. This could be included in broader future research emphasizing the examination of inter-individual variability in timing research not only in children but in special populations as well.

Developmental research in auditory temporal perception has extended to infancy, demonstrating that infants can not only perceive temporal groupings, but they can also differentiate rhythmic patterns and infer an underlying pattern of strong and weak isochronous beats from groupings of slower and faster isochronous patterns (Hannon & Johnson, 2005; Trehub & Hannon, 2006). Despite the progress in understanding infancy temporal event perception, there remains much work to be done in developmental research into temporal perception. Children of toddler age (2 - 3 years old) have not been studied adequately, most probably due to the difficulties of adapting timing research paradigms to this age group. Even the study of four-year-olds remains a challenge, as evidenced by the high rate of non-completion of the tempo discrimination task in this study. It would be of interest that future research focus on developing age-related modifications of current auditory timing paradigms in order to increase task completion rates and reliability of responses.

Implications for other aspects of cognitive development

This study did not find support aspects of the preferred tempo hypothesis which predicted temporal shift of preferred tempo with age that would parallel the shift in with SMT. Optimal tempo sensitivity for children ages 6 – 8 years and young adults remained constant at tempo of 600 ms IOI. This would suggest that the stable optimal tempo of 600 ms for tempo
discrimination has some innate or learned quality that allows us to attune, from a young age, to this tempo which falls within a very common range of tempi in the environment. Research conducted on the resonance frequency of Western music pulse perception and of human locomotion in adults indicates that the most predominant tempi for both these human activities falls within an approximate range of 450 to 650 ms (Van Noorden & Moelants, 1999; Todd, 1999). In the case of music or auditory events, temporal pattern complexity appears to accelerate the resonance frequency of pulse perception from 550 ms for simple auditory pulse trains to a frequency of 456 ms for music (Van Noorden & Moelants, 1999).

Optimal tempo is not the only factor that influences tempo discrimination. Fraisse (1963) referred to the ‘psychological or perceived present’ to describe the duration of the perception of time in which organization of a succession of stimuli into meaningful units emerges as a consequence of our attention being fixed on these stimuli during that moment. The duration of the ‘psychological present’ has both upper and lower limits where perceptual organization outside of these limits breaks down. The upper limit is dependant upon three interdependent factors according to Fraisse: “… (1) the temporal interval between stimuli; (2) the number of stimuli; and (3) their organization.” (p. 88). The current study directly addressed the first two factors but the support found for the entrainment hypothesis has implications for the third factor, organization. The entrainment hypothesis predicted an age-related improvement in tempo discrimination, especially at the slowest tempi, as the temporal event-tracking region centered on preferred tempo widens to incorporate slower rates in the environment. This prediction corresponds to observed age-related improvements in the organization of the perception of succession described by Fraisse (1963). Since the ‘psychological present’ is the moment where fluctuations of attention cease and perceptual organization of stimuli is created, we can infer that
maturational improvements in perceptual organization correspond to decreases in the periodicity of fluctuations of attention. The finding of greatest age-related improvements in tempo discrimination at the slowest tempo in the current study would imply, as proposed by McAuley et al. (2005), that there is a decrease in the periodicity of fluctuations of attention over longer periods of time as children mature. Thus, meaningful organization of perceptual units is facilitated in children as the duration of the ‘psychological present’ increases with age.
CONCLUSIONS

Findings from this study were generally consistent with the proposed hypotheses. A slowing of SMT was observed with increased age. One exception was the findings related to the preferred period hypothesis. The age-related changes observed in SMT were consistent with the hypothesis. However, the predicted age-related shift in tempo sensitivity did not occur. Best performance in tempo sensitivity occurred at the intermediate 600 ms standard tempo for all age groups, which was inconsistent with the predicted optimal performance at the fastest tempo (300 ms) for the younger children.

Tempo sensitivity findings were consistent with the entrainment region hypothesis. Generally, improvement in tempo sensitivity increased for all age groups except for the youngest group. Age-related improvements in tempo sensitivity were greatest at the slowest 900 ms tempo, which is consistent with a widening of the entrainment region with age.

Tempo sensitivity was also enhanced by increasing the number of comparison intervals. These improvements were generally consistent with Miller and McAuley (2005). However, the amount of improvement varied with both age and tempo. Children ages 7 – 9 years old and young adults benefited the most from the increased number of comparison intervals at the fastest 300 ms tempo, while the slowest 900 ms tempo produced the least benefits in these age groups. Improvement in tempo sensitivity for the youngest age group was restricted to an increase from one to three comparison intervals at the intermediate tempo (600 ms).

These findings contribute to the growing body of knowledge on children’s perception of temporal properties of events by increasing knowledge about younger children’s ability to discriminate tempo changes with IOIs less than 1000 ms. Young children ages 4 – 5 years old were particularly poor at discriminating tempi in the range of 300 – 900 ms. Age-related
improvements in tempo sensitivity began with school-aged children ages 6-7 years old and extended to the young adults. The improvements were particularly prevalent at the slowest tempo (900 ms).

The present study also augmented the body of knowledge related to overall contribution of increased temporal information to children’s tempo discrimination abilities. School-aged children displayed increased tempo sensitivity when provided with additional comparison intervals. However, tempo sensitivity improvements for younger children were restricted for both tempo (intermediate 600 ms tempo) and maximum number of beneficial comparison intervals (three comparison intervals).
REFERENCES


APPENDIXES

Appendix A: BIS-C (for parents)

Subject ID:__________    Date:_________________________

We would like to find out more about your child. Some children do these things; others do not. We want to know how often your child does these things. Please read the following statements and then indicate the extent to which that statement applies to your child.

<table>
<thead>
<tr>
<th>Statement</th>
<th>Never</th>
<th>Almost Never</th>
<th>Sometimes</th>
<th>Almost Always</th>
<th>Always</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. My child plans tasks carefully.</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>2. My child does things without thinking.</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>3. My child makes up his or her mind quickly.</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>4. My child is happy-go-lucky.</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>5. My child doesn’t pay attention.</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>6. My child has “racing” thoughts.</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>7. My child thinks about or plans for outings ahead of time.</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>8. My child is self-controlled.</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>9. My child concentrates easily.</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>10. My child saves the money that he or she is given by his/her own choice.</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>11. My child “squirms” during movies or plays.</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>12. My child is a careful thinker.</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>13. My child likes his/her activities to be planned ahead of time.</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>14. My child says things without thinking.</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>15. My child likes to think about complex problems.</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>16. My child is easily frustrated.</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>17. My child acts “on impulse”.</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>18. My child gets easily bored when playing quietly (e.g. coloring, doing activity books or homework).</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>19. My child acts on the spur of the moment.</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>20. My child is a steady thinker.</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>21. My child gives up when problems are too difficult for him or her.</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>22. My child buys things on impulse (e.g. buys something just because he/she wants it now).</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>23. My child can only think about one problem at a time.</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>24. My child changes what he or she calls his/her “favorite” activity.</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>25. My child often asks me or my spouse to borrow money to buy things, even if he/she can’t pay us back.</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>26. My child daydreams.</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>27. My child is more interested in the present than the future.</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>28. My child is restless in places where he/she has to sit still.</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>29. My child likes puzzles.</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>30. My child is future oriented (e.g. thinks about the future).</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
</tbody>
</table>
Appendix B: Child Impulsiveness Questionnaire

Subject ID ____________  Date: ____________

I want to know about some things that you may or may not do. I am going to read a sentence to you and I want you to tell me if that sounds like something you do by saying like me or not like me. Please be as honest as possible in your answers. After I read each sentence you can say “like me” or “not like me” depending on the best answer for you.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th>Like me</th>
<th>Not like me</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>I squirm at plays or movies, when I am supposed to be sitting still.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2.</td>
<td>I act on impulse.</td>
<td>Like me</td>
<td>Not like me</td>
</tr>
<tr>
<td>3.</td>
<td>I plan tasks (things I do) carefully.</td>
<td>Like me</td>
<td>Not like me</td>
</tr>
<tr>
<td>4.</td>
<td>I like puzzles.</td>
<td>Like me</td>
<td>Not like me</td>
</tr>
<tr>
<td>5.</td>
<td>I act without thinking too much about it.</td>
<td>Like me</td>
<td>Not like me</td>
</tr>
<tr>
<td>6.</td>
<td>I daydream.</td>
<td>Like me</td>
<td>Not like me</td>
</tr>
<tr>
<td>7.</td>
<td>I have racing thoughts.</td>
<td>Like me</td>
<td>Not like me</td>
</tr>
<tr>
<td>8.</td>
<td>I like to think about hard problems.</td>
<td>Like me</td>
<td>Not like me</td>
</tr>
<tr>
<td>9.</td>
<td>I am a careful thinker.</td>
<td>Like me</td>
<td>Not like me</td>
</tr>
<tr>
<td>10.</td>
<td>I have a hard time sitting still.</td>
<td>Like me</td>
<td>Not like me</td>
</tr>
<tr>
<td>11.</td>
<td>I make up my mind quickly.</td>
<td>Like me</td>
<td>Not like me</td>
</tr>
<tr>
<td>12.</td>
<td>I like to walk fast or run whenever I go anywhere.</td>
<td>Like me</td>
<td>Not like me</td>
</tr>
</tbody>
</table>

Younger children (< 8 years old)

<table>
<thead>
<tr>
<th></th>
<th></th>
<th>Like me</th>
<th>Not like me</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>I squirm at plays or movies, when I am supposed to be sitting still.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2.</td>
<td>I plan tasks (things I do) carefully.</td>
<td>Like me</td>
<td>Not like me</td>
</tr>
<tr>
<td>3.</td>
<td>I like puzzles.</td>
<td>Like me</td>
<td>Not like me</td>
</tr>
<tr>
<td>4.</td>
<td>I am a careful thinker.</td>
<td>Like me</td>
<td>Not like me</td>
</tr>
<tr>
<td>5.</td>
<td>I have a hard time sitting still.</td>
<td>Like me</td>
<td>Not like me</td>
</tr>
<tr>
<td>6.</td>
<td>I like to walk fast or run whenever I go anywhere.</td>
<td>Like me</td>
<td>Not like me</td>
</tr>
</tbody>
</table>
Table 1

One Sample t Tests on Tempo Sensitivity PC Means for Age Group 4-5 Year Olds

<table>
<thead>
<tr>
<th>Standard IOI</th>
<th>t</th>
<th>df</th>
<th>Sig. (2-tailed)</th>
<th>Mean Difference</th>
<th>95% Confidence Interval of the Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Lower</td>
</tr>
<tr>
<td>300 ms</td>
<td>1.687</td>
<td>7</td>
<td>.136</td>
<td>.118055750</td>
<td>-.04743933</td>
</tr>
<tr>
<td>600 ms</td>
<td>2.027</td>
<td>7</td>
<td>.082</td>
<td>.145833250</td>
<td>-.02425367</td>
</tr>
<tr>
<td>900 ms</td>
<td>1.139</td>
<td>7</td>
<td>.292</td>
<td>.069444500</td>
<td>-.07478281</td>
</tr>
</tbody>
</table>

Note. Test value = 0.5

Table 2

Overall PC as a Function of Age Group and Standard Tempo

<table>
<thead>
<tr>
<th>Age group (years)</th>
<th>300 ms</th>
<th>600 ms</th>
<th>900 ms</th>
<th>1000 ms</th>
</tr>
</thead>
<tbody>
<tr>
<td>4-5 (4)a</td>
<td>.62 (.79*)</td>
<td>.65 (.61)</td>
<td>.57</td>
<td>(.53)</td>
</tr>
<tr>
<td>6-7 (6)</td>
<td>.75** (.79*)</td>
<td>.89** (.75*)</td>
<td>.76**</td>
<td>(.65)</td>
</tr>
<tr>
<td>8-9 (8)</td>
<td>.87** (.84*)</td>
<td>.92** (.85*)</td>
<td>.89**</td>
<td>(.75*)</td>
</tr>
<tr>
<td>18+</td>
<td>.91* (1.00*)</td>
<td>.95* (1.00*)</td>
<td>.94*</td>
<td>(.94*)</td>
</tr>
</tbody>
</table>

Note. The data in parentheses are from Drake et al. (2006) and reproduced for purposes of comparison.

a Parentheses indicate values from the Drake et al. (2000) study.

*p < .05, two-tailed. **p < .01, two-tailed.
Figure 1. Diagrams of auditory sequence stimuli as a function of number of comparison intervals.
Figure 2. Mean spontaneous motor tempo for age groups 4-5 years, 6-7 years, 8-9 years, and 18+ years.
Figure 3. Mean proportion correct responses as a function of standard tempo sequence for age groups 4-5 years, 6-7 years, 8-9 years, and 18+ years.
Figure 4. Mean proportion correct responses for comparison interval sequences 1 interval, 3 intervals, and 5 intervals as a function of standard tempo (300 ms, 600 ms, and 900 ms) for age groups 4-5 years, 6-7 years, 8-9 years, and 18+ years.
Figure 5. Relative JND as a function of standard tempo and number of comparison intervals for age groups 6 – 7 years, 8 – 9 years, and 18+ years. The results for children ages 4 – 5 years are absent because of the impossibility of calculating relative JND due to near-chance performance of this age group.
Figure 6. Constant error (CE) scores as a function of standard tempo for age groups 6 - 7 years, 8 – 9 years, and 18+ years. The results for children ages 4 – 5 years are not included because it was not possible to obtain reliable estimates of relative CE due to the near-chance performance of this age group.