Evidence of Temporal Sensitivity for Short Durations in Persons with Down Syndrome

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Abstract

Individuals with Down syndrome are impaired in motor control, working memory and attention (Brown, et al., 2003; Jarrold & Baddeley, 2001; Lanfranchi, Jerman, Dal Pont, Alberti, & Vianello, 2010). These impairments may be related to a deficit in time perception as time perception is considered to be an important adaptive skill that contributes to many everyday tasks from motor control to language processing (Meck, 2005). Furthermore attention and working memory are hypothesized by the Scalar Expectancy Theory to influence time perception (Allan, 1998). Time perception of short durations (under one second) was examined in individuals with Down syndrome and typically developing (TD) children matched on mental age of approximately 5 years old. Temporal bisection and generalization tasks were used to examine basic perceptual timing mechanisms. For both tasks, the participants with Down syndrome demonstrated similar responding to making temporal judgment as the TD children. There was some indication that the persons with Down syndrome responded with lower temporal sensitivity than the TD children as the results from the repeated measure ANOVA indicated a marginally significant group by duration interaction ($F(6, 168) = 2.15$, $p = .08$) and the Weber Fraction for the individuals with Down syndrome was marginally significantly higher ($t(28) = 4.75$, $p = .06$). These findings may inform the current understanding of cognitive and motor impairment in Down syndrome and contribute to the current literature on time perception.

Résumé

La trisomie 21 affecte notamment la motricité, la mémoire et la concentration des personnes qui en sont atteintes (Brown, et al., 2003; Jarrold & Baddeley, 2001; Lanfranchi, Jerman, Dal Pont, Alberti, et Vianello, 2010). Ces troubles peuvent être liés à un déficit en ce qui a trait à la perception temporelle, qui est considérée comme étant lié entre autre à la motricité et à la communication (Meck, 2005). Ainsi, la « Scalar Expectancy Theory (SET) » pose comme hypothèse que la perception temporelle pourrait influencer la mémoire et la concentration (Allan, 1998). La perception du temps de courtes durées (moins d'une seconde) a été examinée chez des personnes atteintes de trisomie 21 ainsi que des personnes a développement normale dont, dans les 2 cas, l'âge mental était d'environ 5 ans. Afin d'examiner les mécanismes de base concernant la perception temporelle, des tâches de calcul d'intervalles et des tâches générales ont été utilisées. Dans les deux cas, les participants atteints de trisomie 21 ont eu des résultats similaires aux enfants ayant un développement normal. Il y avait une indication que les participants atteints de trisomie 21 ont répondu avec une sensibilité temporelle inférieure à celle des enfants a développement normale dans les résultats de la mesure répétée ANOVA, indiquant un groupe légèrement significatif entre la durée ($F (6, 168) = 2,15$, $p = 0,08$) et la fraction de Weber pour les participants atteints de trisomie 21 a été légèrement significativement plus élevé ($t (28) = 4,75$, $p = 0,06$).Ces résultats peuvent contribuer à la compréhension de la déficience motrice et cognitive des personnes atteintes de trisomie 21 ainsi qu'à leur perception temporelle.

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Evidence of Temporal Sensitivity for Short Durations in Individuals with Down Syndrome

Of the many forms of intellectual disability, specific interests lay in the profile of Down syndrome as it is the most common non-inherited genetic cause of intellectual impairment affecting 1 in 600-800 live births (Hutaff-Lee, Cordeiro, & Tartaglia, 2012). Among the many areas of strengths and weakness that have been identified in individuals with Down syndrome notable are specific strengths in long term memory and visuo-spatial skills, and deficits in attention, working memory and motor skills (Brown et al., 2003; Costanzo et al., 2013; Jarrold & Baddeley, 2001; Kay-Raining Bird & Chapman, 1994; Lanfranchi, Jerman, Dal Pont, Alberti, & Vianello, 2010; Rowe, Lavender, & Turk, 2006). Just as this pattern of abilities is unique to persons with Down syndrome, the underlying mechanisms that contribute to it are also likely unique. In assessing possible underlying mechanisms that contribute to the strengths and weakness in Down syndrome, the unique pattern of deficits in attention, working memory and motor control indicate that such impairment may be linked to problems in time perception as these areas are reported to be related in typical and other atypically developing populations (Allman & Meck, 2012; Ivry & Richardson, 2002; Meck & Benson, 2002; Smith, Taylor, Rogers, Newman, & Rubia, 2002). Time perception is the subjective experience of the amount of time that has passed since a particular event or the subjective experience of the speed of time passage (Meck, 2005) and it is thought to be important to abstract thinking as it contributes to formulating plans, estimating the duration of future tasks, and judging the chronology of past events (Grondin, 2012). Time perception is also considered to be an important adaptive skill that, along with other cognitive processes, contributes to many everyday tasks from motor control to language processing (Meck, 2005). Extending time perception research to include individuals with Down syndrome may provide important information on the mechanisms involved in their reported impairments in attention, working memory and motor control.

Relating Motor Control and Time Perception in Down Syndrome

Individuals with Down syndrome are reported to have slower reaction times (Anson & Mawston, 2000) and longer movement times than typically developing (TD) individuals (Henderson, Morris, & Firth, 1981; Lam, Hodges, Virji-Babul, & Latash, 2009). For example, in a study by Lam et al. (2009), participants with Down syndrome and TD participants completed a tapping task in which they were asked to alternate tapping movements as many times as possible between two targets. The participant groups were matched on Chronological Age (CA) (23 years) rather than Mental Age (MA), so that they were exposed to the same amount of movement experiences (Lam et al., 2009). Not surprisingly, the participants with Down syndrome were slower on this task than the TD participants and their total movement time increased further to twice as long as the TD participants when the task difficulty increased (Lam et al., 2009).

The movement required for reaction time tasks and other motor skills is reported to be impacted by limb mechanics and muscle organization (Lawrence, Reilly, Mottram, Kahn, & Elliott, 2013), as well as partly impacted by perceptual processes that interact with motor processes (Wilson & Knoblich, 2005). As such, perceptual motor impairment is hypothesized to be one possible explanation for the slower motor movement and other motor deficits in Down syndrome (Chiarenza, 1993; Henderson, et al., 1981; Lam, et al., 2009; Lawrence, et al., 2013; Virji-Babil, Kerns, Zhou, Kapur, & Shiffrar, 2006). Within the research examining the impact of perceptual processes on motor functioning in Down syndrome, there has been some evidence of the involvement of a temporal component (Chiarenza, 1993; Henderson et al., 1981). For example, the involvement of timing in motor impairments in Down syndrome was demonstrated in an early study by Henderson et al. (1981) who examined longer movement times in persons with Down syndrome and TD children using a drawing task. Not surprisingly the participants with Down syndrome took longer to complete the movement of tracing a curved line and found the task more difficult than the TD children. Henderson et al. suggested that the results may be related to impaired timing since the participants with Down syndrome did not have difficulty with the task when demands were strictly spatial (tracing the curved line when it was stationary), but experienced difficulty when the task demands included a timing component (tracing the curved line when it was moving).

The involvement of timing in motor impairments in Down syndrome are further exemplified in a study by Chiarenza (1993) who investigated motor skills and related cognitive processes in persons with Down syndrome. In this study the participants with Down syndrome and a group of TD children matched on a mental age of approximately 10 years completed a motor task involving the calculation of a short time interval. The author reported that the participants with Down syndrome had greater difficulty preparing and timing the necessary movement sequences needed to complete the motor task than the TD children, and hypothesized that this impairment may be related to a central timing mechanism (Chiarenza, 1993).

Evidence that time perception is related to motor impairments among persons with Down syndrome is consistent with evidence from studies reporting a link between motor impairments and deficits in time perception in other populations. For example, children with ADHD who have been reported to have deficits in time perception across multiple studies (see Toplak, Dockstader, & Tannock, 2006 for review) also are reported to have slow reactions times (Leth-Steensen, King-Elbaz, & Douglas, 2000; Van der Meere, Shalev, Boerger, & Gross-Tsur, 1995). Further, evidence of specific impairments of temporal perception in the millisecond range in

ADHD, which is important in motor control (Buhusi & Meck, 2006; Mauk & Buonomano, 2004) have led to speculation that time perception is primary to a deficit in motor control in this population (Smith et al., 2002). Other research has linked slow reaction times and slower motor movements to deficits in time perception in persons with Parkinson's disease (Pastor, Artieda, Jananshahi, & Obeso, 1992). Pastor et al. (1992) examined temporal perceptual abilities in Parkinson's patients and found them to be significantly related to tapping speed, simple reaction time, and movement time. These results highlight the possibility that the difficulty that persons with Down syndrome have with the timing component of the motor tasks that measure slower reaction times and slow motor movements could be related to a deficit in time perception.

Relating Attention and Memory and Time Perception in Down Syndrome

Just as time perception is reported to influence motor control, it may also influence cognitive processes such as attention and memory. The Oscillator-Based Associative Recall Model (OSCAR) is a computational model of human memory that demonstrates one way in which time perception might influence working memory (Brown, Preece, & Hulme, 2000). OSCAR states that responses on serial recall tasks are influenced by the temporal proximity of the list items recalled during such tasks (Brown et al., 2000). Specifically it is predicted that the closer two items are together temporally the more they will be confused with each other in working memory and thus recalled incorrectly on serial recall tasks (Brown et al., 2000).

Some evidence in support of the OSCAR model comes from studies that report that time perception and working memory are influenced by the same neurological mechanisms (Bunge & Wright, 2007; Radua, Pozo, Gomez, Guillen-Grima, & Ortuno, 2014; Smith, Taylor, Brammer, & Rubia, 2004; Smith et al., 2011). For example, both the basal ganglia and frontal cortex are involved in time perception and working memory (Matell, Meck, & Lustig, 2003) and Radua et al. (2014) reported that brain regions associated with time perception were activated when participants completed difficult cognitive tasks of executive function, and working memory. The authors suggested that these findings may indicate that time perception influences working memory and executive function when the level of difficulty on a working memory task is high (Radua et al., 2014).

Similar to working memory, the association between time perception and attention can be demonstrated from the results of neuroimaging studies which show that both attention and time perception activate the same brain regions, namely the frontal cortex and basal ganglionic areas (Meck & Benson, 2002). The importance of these regions in attention and time perception is exemplified in evidence of the abnormalities of children with ADHD who have pervasive deficits in attention and deficits in time perception (e.g., Toplak et al., 2006) and who have abnormal brain volumes and reduced white matter in the frontal, temporal, and parietal lobes (Cubillo, Halari, Smith, Tayler, & Rubia, 2012).

If time perception influences attention and working memory, deficits in time perception in Down syndrome may influence their impairment in these abilities. Individuals with Down syndrome have been reported to be impaired in sustained attention, inhibition and working memory (e.g., Brown, et al., 2003; Jarrold & Baddeley, 2001; Kay-Raining Bird & Chapman, 1994). In a study of working memory and attention among persons with Down syndrome with a mental age of 7 years old, Costanzo et al. (2013) found impairments in auditory sustained attention as compared to typically developing children matched on mental age (MA). Furthermore, the persons with Down syndrome showed greater impairments in visual sustained attention and verbal inhibition as compared to persons with Williams Syndrome matched on MA. In another study of working memory among persons with Down syndrome, Kay-Raining Bird and Chapman (1994) used a digit span and narrative recall task to assess working memory among individuals with Down syndrome and found that they recalled significantly fewer items then TD children matched on MA (4 years).

Possible Mechanisms Involved in Time Perception

There is an assumption that the relationship between time perception and cognition is bi-directional whereby perception and cognition influence each other (Cronin-Golomb, 2010; Droit-Volet, 2013). Therefore, the disturbances in attention and working memory among persons with Down syndrome (Brown, et al., 2003; Costanzo et al., 2013; Jarrold & Baddeley, 2001; Kay-Raining Bird & Chapman, 1994; Lanfranchi, et al., 2010; Rowe, et al., 2006) may also contribute to a deficit in time perception. This is reflected in the Scalar Expectancy Theory (SET), the main model of timing in the study of typical development, which predicts that accurate temporal processing is influenced by attention, working memory and long term memory, all of which involve an internal clock mechanism and decision processes that interact in a particular way to allow for the accurate perception of time (Allan, 1998; Allman & Meck, 2012; Wearden, 2003). A review of the stages of time perception hypothesized by the SET exemplifies how attention, memory and an internal clock are thought to influence time perception.

Predictions of the SET. During the initial stage of time perception, the onset of a to-be-timed event triggers the internal clock mechanism that transmits clock ticks or pulses (Allan, 1998; Allman & Meck, 2012; Wearden, 2003). For the duration of the event, these clock ticks are sent to an accumulator where they are stored (Allan, 1998; Allman & Meck, 2012; Wearden, 2003). Throughout this process, attention acts as a gatekeeper controlling the transfer of pulses such that appropriately applied attention allows for a steady accumulation of pulses, whereas clock pulses are stopped from transferring to the accumulator when attention is diverted (Allan, 1998; Allman & Meck, 2012; Wearden, 2003). As a result, variability in attention during the presentation of a to-be-timed event is thought to lead to variability in the number of pulses accumulated and therefore the stored representation of the event duration. After the duration is recorded, it is temporarily stored in working memory and ultimately transferred into reference memory to be stored long term (Allan, 1998; Allman & Meck, 2012; Wearden, 2003). Temporal variably may also occur if working memory is impaired and is unable to accurately store recorded durations. Reference memory is theorized to hold Gaussian (normal) distributions of many different durations (e.g., standard durations) in which new temporal stimuli can be compared (e.g., comparison durations) (Allan, 1998; Allman & Meck, 2012; Wearden, 2003). Experiencing a new temporal duration marks the third and final stage of time perception. Here, the new comparison duration is compared to the durations stored in reference memory and a decision is made as to whether the duration of the comparison stimulus is similar to the stored standard duration (Allan, 1998; Allman & Meck, 2012; Wearden, 2003).

Evidence supporting the SET. Evidence from studies investigating time perception in typical development is in line with these predictions. For example, studies of the age related differences in temporal variability have also confirmed the predictions that attention and working memory is involved in time perception. The propensity of young children to display lower temporal sensitivity than older children and adults is reported to be related to their poorer inhibition, selective attention and sustained attention (Droit-Volet, Delgado, & Rattat, 2006; Gautier & Droit-Volet, 2002). Delgado and Droit-Volet (2007) found that sensitivity to duration was lower among 5 year old children as compared to 8 year old children and adults and statistical modeling indicated that this was due to greater variation in attention (Delgado & Droit-Volet, 2007). The role of attention in predicting temporal sensitivity has also been reported in studies of time perception in adults. For example, Enns, Brehaut, and Shore (1999) used a paradigm with a timed flash of light to assess the role of attention in temporal sensitivity among university students. They reported that the perceived duration of a flash of light in an attended location (i.e. when the participant was cued) was longer than a flash of light of the same duration in an unattended location (i.e. when the participant was not cued) indicating that differences in attention play a role in an individual's interpretation of the length of a duration. Empirical evidence also supports the SET prediction that working memory influences temporal variability (Delgado & Driot-Volet, 2007; Zelanti, & Droit-Volet, 2011; 2012). For example, in a series of studies of time perception in young children, Zelanti, and Droit-Volet (2011; 2012) found that better working memory predicted more temporal sensitivity for durations less than 1 second, rather than for durations between 1.25 and 8 seconds or durations between 15-30 seconds.

The internal clock as a contributor to time perception. In addition to being influenced by deficits in attention and memory, deficits in time perception in Down syndrome might also be explained by disturbances in the internal clock mechanism. The internal clock has been described conceptually as an internal organ or system that functions to count time (Treisman, Faulkner, & Naish, 1992). In the SET model, the internal clock accumulates pulses that "count" the length of a particular duration of time that is eventually stored in long-term memory (Allan, 1998; Allman & Meck, 2012; Wearden, 2003). The rate of the internal clock may be influenced by information processing speed (Droit-Volet, 2013). For example, Droit-Volet (2013) found a correlation between processing speed and temporal sensitivity among TD children, where faster processing speeds showed greater time sensitivity (Droit-Volet, 2013). Since, persons with Down syndrome have slower information processing speeds (Silverman, 2007) impairments in time perception in Down syndrome may be related to a slower rate of their internal clock. The notion that a slower clock rate in Down syndrome might lead to more temporal variability is consistent with evidence from the animal and adult literature, in which explanations of individual variability in timing have focused on differences in the rate of the internal clock as the source of performance variability in time perception (Gibbon, Church, & Meck, 1984).

The present study

The goal of this study was to examine time perception of short durations in persons with Down syndrome. Time perception has been studied using multiple methods (Droit-Volet & Rattat, 2006; McCormack, Brown, Smith, & Brock, 2004; Wallace & Happe, 2008) including psychophysical approaches that quantify the relationship between the duration of events and the subjective experience of those durations. Most commonly, the psychophysical temporal bisection and generalization tasks have been used to assess time perception across the life span (Droit-Volet, Clement, & Wearden, 2001; Droit-Volet & Wearden, 2001; McCormack, Brown, Maylor, Darby, & Green, 1999). Since these two tasks provide systematic and well-established psychophysical measures of timing mechanisms they were used in the present study. Furthermore, since relatively little motor movement is required for both the temporal bisection and the temporal generalization tasks, relative to other methods of assessing time perception such as temporal production or reproduction tasks, they are ideal for assessing time perception in persons with Down syndrome. This will help rule out non perceptual aspects of motor impairments, such as resistance in limb mechanics and muscle organization, as possible confounds in the results.

Methodological considerations were related to the length of the duration to be perceived in the psychophysical tasks (temporal bisection or temporal generalization tasks). As the perception of durations of different lengths are reported to be related to different behaviours

(Buhusi & Meck, 2006) and depend on different neural networks (Gibbon, Malapani, Dale, & Gallistel, 1997; Ivry & Spencer, 2004), short and longer durations are reported to be perceived differently. For example, cognitive skills (e.g. counting) are more likely involved in perceiving longer durations, whereas shorter durations are likely unaffected by such skills and measure pure deficits in time perception (Smith et al., 2002). Thus, in order to gain a better understanding of pure temporal perceptual abilities not confounded by other cognitive abilities, the focus of this study was on time perception with durations in the millisecond range. In this study, the persons with Down syndrome were matched to the TD children on MA instead of CA to rule out possible differences detected between the TD children and the persons with Down syndrome related to differences in cognitive and related developmental abilities. This is an important consideration for all studies making comparisons across groups of individuals with different abilities (Burack, Iarocci, Flanagan, & Bowler, 2004), and has been a limitation of other investigations examining time perception in individuals from special populations and TD individuals (e.g., Allman, Deleon, & Wearden, 2011). A temporal bisection task and a temporal generalization task with short durations were administered to a group of children and adolescents with Down syndrome with a mental age of approximately 5 years old and to a group of TD children matched on mental age. Based on evidence that abilities impaired in Down syndrome are fundamental to accurate time perception, the hypothesis of this study was that the individuals with Down syndrome would be less accurate at perceiving short durations of time on both the temporal bisection and temporal generalization tasks than the TD children.

Method

Participants

The participants were 22 children and adolescents with a diagnosis of Down syndrome and 20 TD children. The participants with Down syndrome were recruited from a summer program for persons with Down syndrome, and the TD children were recruited through advertisements in a local newspaper. The participants in each group varied somewhat across the two tasks as some were unavailable to complete both tasks (Down syndrome: n = 2; TD: n = 2). In addition, since the temporal bisection task involves a log-linear modeling technique that only allows data that can be modeled to be used in the analyses, the data of some of the participants whose data were included in the analyses of the temporal generalization task were not included in the analyses of the temporal bisection task (Down syndrome: n = 1; TD: n = 3). For this reason, the sample sizes for the two groups are different for each task. The temporal bisection task included data from 15 participants with Down syndrome and 15 TD children, whereas the temporal generalization task included data from 12 participants with Down syndrome and 13 TD children (Table 1). Overall, the data of 11 participants with Down syndrome was used in the analyses for both tasks, and the data of 10 children from the TD group was used in the analyses for both tasks. These sample sizes are similar to those in studies of perceptual timing abilities among children with ASD (Allman, DeLean, &Wearden, 2011; Brodeur, Gordon Green, Flores, & Burack, 2013; Maister, & Plaisted-Grant, 2011).

The inclusion criteria for the participants with Down syndrome was a prior diagnosis only of full trisomy-21 (full inheritance of an extra chromosome 21), and not another related disorder such as translocation or mosaic Down syndrome (Brown et al., 2003). Participants were excluded from the study if their level of functioning was too low to be able to complete or understand the time task or if they had a secondary diagnosis of another disorder. As the time estimation task involved auditory tones to assess temporal functioning, exclusion criteria included a diagnosis of hearing impairment in either group.

For the temporal bisection task, the participants with Down syndrome were older than the TD children. Specifically, independent samples t-tests revealed a significant difference in chronological age (CA) age between the two groups ($t(28) = 7.77$, $p < .001$). There was no difference on MA between the participants with Down syndrome and the TD children indicating that the groups were matched on MA. A chi square analysis revealed no significant differences between the groups on gender ($X^2 = 2.4$, $p = .121$). Please see Table 1 for details on sample characteristics for the temporal bisection task.

For the temporal generalization task, the participants with Down syndrome were older than the TD children. Specifically, independent samples t-tests revealed a significant difference in CA age between the two groups ($t(23) = 8.46$, $p = .01$). There was no significant difference in MA ($t(23) = .39$, $p = .97$) indicating that the groups were matched on MA. A chi square analysis revealed significant differences between the groups on gender ($X^2 = 3.74$, $p = .05$). Please see Table 1 for details on sample characteristics for the temporal generalization task.

Materials

Mental age. All the participants completed The Leiter International Performance Scale-Revised, Visualization and Reasoning Battery (Leiter-R; Roid & Miller, 2013). The Leiter-R is a scale commonly used to measure non-verbal intelligence in children age 2 years to 20 years and is not highly influenced by the child's academic, social, or verbal abilities. As such, it is ideal when assessing the IQ of children with language or other developmental delays. The measure of IQ obtained from the Leiter-R can more adequately predict competency behaviours than measures of IQ that are restricted by language skill and academic ability, and has demonstrated agreement with other measures of IQ ($k = .88$, $p = .0001$) (Tsatsanis et al., 2003). The scores on the Leiter-R were used to match the participants in the two groups on mental age so that any differences between the groups on time perception could not be accounted for by differences in level of functioning due to developmental delays (for a discussion of matching issues, please see Burack, et al., 2004).

Stimuli and Apparatus

Time perception tasks. A temporal bisection and a temporal generalization task were used to test the estimation of short durations of sound. These paradigms have been repeatedly used to test temporal perception in adults (Wearden, 1991), typically developing children (Droit-Volet & Wearden, 2001) and children with autism spectrum disorder (Allman, et al., 2011; Brodeur et al., 2013). They have produced patterns of responses that conform to the predictions of the scalar timing model, and are valid measures of human time perception in typically and atypically developing populations (Wearden, 1991).

The temporal bisection task and temporal generalization task were administered to the participants on a Macintosh Powerbook G4. The responses were made with button presses on the computer keyboard. In both the temporal bisection and generalization tasks, the response key designations were counterbalanced across participants.

Temporal bisection task. The participants were first introduced to two standard tones, the first lasting 250ms and the second lasting 800ms seconds, and seven comparison tone durations (200, 300, 400, 500, 600, 700, 800 ms). All tones were of a 500 Hz frequency. Initially the 250ms tone was presented along with a picture of a small bird centred on the computer monitor, and the 800ms tone was presented along with a picture of a large bird centred on the computer monitor. The participants were told that the 250ms tone accompanied by the picture of the small bird was the sound the small bird makes; that the small bird always makes that sound, and that it was the sound the small bird made because it was a short sound. Similarly, the participants were told that the 800ms tone accompanied by the picture of a large bird was the sound the large bird makes; that the large bird always made that sound, and that it was the sound the large bird made because it was a long sound. Following a 2 second pause, the participants were then presented with a series of 7 comparison tones, each accompanied by images of the small and large birds on the computer monitor, positioned to represent the position of the buttons for a small bird or a large bird response.

Following the introduction to all tone durations both standard tones were presented five more times, in alternating order. The participants were asked to determine whether each sound presented on the subsequent trials was more like the sound the small bird or the large bird makes by pressing the button corresponding to the picture of either the small bird or the large bird. Seven practice trials, one for each comparison duration, were completed following the task introduction. The experimental session was comprised of 35 trials (5 trials for each comparison duration). The presentation order of the tones was randomized and no feedback was provided for any of the trials. The responses were analyzed using the proportion of long responses to tones to each comparison duration. Please see Appendix A for a depiction of the temporal bisection task.

Temporal generalization task. The participants were introduced to a standard tone of 500 Hz frequency for 500ms and told that it was produced by the frog depicted simultaneously on the center of the computer monitor. They were told that the sound was the sound that the frog makes. They were also told that it was the sound that the frog makes because of how long it is, and that the frog always makes a sound that is that long. Two 500 Hz tones that varied in duration (250 and 750ms) were then introduced as comparison tones. The participants were told that the 250 ms sound was not the sound that the frog makes because it was too short and that the frog did not make the 750 ms sound because it was too long. They were then provided instructions on which button they should push when they hear the frog sound and which they should push when they hear a sound not made by the frog. In order to facilitate response-key mapping, the presentation of the tone was accompanied by images of two frogs near the left and right hand sides of the screen. One frog was crossed out with an "X", and the other was the same as the originally presented frog. When the comparison sound was judged to be the same duration as the sound that the frog makes (yes response), the participants were instructed to press the key corresponding to image of the frog. For the sounds judged to have a duration different from the one made by the frog, the participants were instructed to push the button corresponding to the image of the frog crossed out with an "X".

Every participant completed eight practice trials with one presentation of each of seven comparison tones (125, 250, 375, 500, 625, 750, and 875 ms) and the standard tone (500 ms). Following the practice trials, the participants were familiarized with the standard tone again with five presentations of the standard tone, accompanied by the picture of the frog. The experimental session followed and consisted of 64 trials (8 trials for each of the 7 comparison durations and 8 trials for the standard tone). The presentation of the trials was randomized within each block. Feedback was provided after each trial. A red circle with an "X" through it appeared if a participant was incorrect in indicating that a test tone was similar to the standard. A happy face appeared if a participant was correct in indicating that a test tone was similar to the standard. Responses were analyzed using the proportion of yes responses made to each comparison duration. Please see Appendix B for an example of the temporal generalization task.

Procedure

Each child's guardian was asked to sign a consent form after being briefed on the purpose of the investigation as well as the tasks their child were required to complete. The demographics questionnaire was administered to parents at this time. The experimenter then administered the Leiter-R followed by a 15 minute break and then tested the child's temporal abilities using the temporal bisection and generalization tasks. The participants with Down syndrome were tested in a private room in the camp, and the TD children were tested in a similarly private room within a university laboratory. The time estimation tasks were presented in counterbalance order. Total testing time for both tasks was 20 minutes.

Results

Temporal Bisection

The individual psychophysical functions for each participant were fitted with a sigmoidal function using a log-linear modeling technique. Data from 2 TD children and 2 participants with Down syndrome were omitted since it could not be modeled as has been done in previous studies (e.g., Brodeur et al., 2013; McCormack et al., 1999; Wearden et al., 1997).

Proportion long responses. The dependent variable for the bisection task was the mean proportion of "long" responses provided for each of the comparison durations. The proportion "long" responses were analyzed using a mixed design ANOVA with Group (Down syndrome vs. TD) as a between subject variable and Duration (200, 300, 400, 500, 600, 700, and 800ms) as a within subject variable. Sphericity was not assumed ($\chi^2 = 36.06$, $p = .02$). Greenhouse-Geisser corrected probabilities were used to assess significance for repeated measures effects.

A significant main effect of Duration [$F(6, 168) = 58.51$, $p < .001$] was found, indicating that the mean proportion of "long" responses increased with increasing duration across groups.

Although no main effect was found for Group [$F(1, 28) = 2.03$, $p = .17$], a marginally significant Group by Duration interaction was found [$F(6, 168) = 2.15$, $p = .08$]. As illustrated in Figure 1, the distribution of responses across the two durations was similar for both groups, although the participants with Down syndrome may have produced fewer “long” responses at the longer durations than the TD children. Please see Table 2 for a summary of the analysis of the repeated measures ANOVA for the temporal bisection task.

Psychophysical measures. Once the data were modeled, three measures of bisection performance from each sigmoidal function were calculated. One, the Bisection Point (BP) is the subjective midpoint between the long and short durations (i.e., judged “long” 50% of the time) and is often interpreted as a measure of response bias. Two, the Difference Limen (DL) a measure of slope, indicating estimation precision; steeper slopes indicate more precision, whereas shallow slopes indicate more variability. The DL is calculated by subtracting the duration at which the participants’ judge “long” 25% of the time from the duration judged “long” 75% of the time and dividing it by 2. Three, the Weber Fractions (WF), a standardized measure of timing variability or precision that is independent of the duration being timed, is calculated by dividing the DL by the BP. A lower WF is indicative of more sensitive temporal perception.

The average bisection point was the same for the participants with Down syndrome and for the TD children. Independent samples t-tests revealed no significant difference in BP between the groups. Independent samples t-tests revealed possible differences in the WF between the groups, as the WF of the participants with Down syndrome was marginally significantly higher than the WF of the TD children ($t(28) = 4.75$, $p = .06$). Please see Table 3 for values of the psychophysical measures.

Temporal Generalization

All of the individual generalization functions from the temporal generalization task were visually examined prior to analysis and tested for the presence of the standard quadratic pattern defined as the largest difference between the proportions for two duration conditions being greater than 0.50 (Brodeur et al., 2013). Three participants with Down syndrome and two TD children produced flat functions and were excluded from the analysis.

Proportion yes responses. The dependent variable was the average proportion "yes" responses to each comparison duration. The proportion "yes" responses were analyzed using a mixed design ANOVA with Group (Down syndrome vs. TD) as a between subject variable and Duration (125, 250, 375,500, 625, 750, & 875ms) as a within subject variable. The assumption of Sphericity was met ($\chi^2 = 29.20$, $p = .09$).

A significant main effect of Duration [$F(6, 138) = 11.78$, $p < .001$] was found. Further inspection of the within subjects contrasts indicated that this effect followed a quadratic pattern of responses [$F(1, 23) = 3.34$, $p < .001$]. As illustrated in Figure 2, the mean proportion of "yes" responses increased with durations closer to the 500ms standard for all participants. No main effect was found for Group [$F(1, 28) = 000$, $p = .99$], and no significant Group by Duration interaction [$F(6, 23) = 1.76$, $p = .11$] was found. Please see Table 4 for a summary of the analysis from the repeated measures ANOVA for the temporal generalization task.

Discussion

Findings from the Temporal Bisection Task

Children and adolescents with Down syndrome performed similarly to the MA matched TD children on both the temporal bisection and the temporal generalization tasks of time estimation. For the temporal bisection task, the findings revealed a significant main effect of duration indicating that both the persons with Down syndrome and the TD children correctly identified the shorter test durations as similar to the short standard and the longer test durations as similar to the long standard. Although the pattern of responding across the two groups was similar, the marginally significant group by duration interaction suggested some differences in responding between the persons with Down syndrome and the TD children, who tended to be more accurate in their responses. Further inspection of the WF lends some support to this conclusion as it was marginally significantly higher for the Down syndrome group indicating less temporal sensitivity among the persons with Down syndrome as compared to the MA matched TD children. These results cannot be explained by developmental differences since both groups were matched on MA, nor can they be explained by non-perceptual aspects of motor impairments since the temporal bisection and temporal generalization tasks require very little motor movement.

Implications for the cognitive profile of persons with Down syndrome. The analyses also revealed no significant differences between persons with Down syndrome and the TD children on the BP point, indicating that the response bias of the subjective midpoint between long and short durations (i.e., the amount of durations judged "long" 50% of the time) was similar for both groups. The BP can be used as an indication of the relative speed of the internal clock. For example, if the BP for one group is lower than the mean of the test durations, their internal clock would be assumed to be slower since over all they encode durations as shorter. A slower internal clock can be related to slower information processing speed. Since persons with Down syndrome are reported to display slower information processing, we hypothesized there might be differences observed in time perception between persons with Down syndrome and TD children related to the internal clock. However, as revealed by the finding that there were no differences in the BP point between the groups, the possible differences in time perception in persons with Down syndrome are not likely due to a slower internal clock caused by the slower information processing speed.

The similarity in the BP between the persons with Down syndrome and the TD children also indicate that the marginal interaction in the bisection task may be evidence that attention and working memory contribute to deficient timing among persons with Down syndrome. This is consistent with the developmental profile of persons with Down syndrome as they are reported to have deficits in attention and working memory. Since the SET proposes a significant contribution of both these abilities in accurate time perception, impairments in these abilities likely contribute to possible disturbances in time perception among persons with Down syndrome.

Implication for understanding time perception in TD. The finding that the internal clock was not related to the marginal difference in time perception among the persons with Down syndrome is consistent with the argument by Wearden and Jones (2013) that the internal clock does not influence temporal variability. They state that differences in the rate of the internal clock would likely not lead to differences in temporal sensitivity in bisection and generalization because a slower clock rate would not create differences in temporal judgement relative to a person with a faster clock rate since *both* the standard and test durations would be recorded with the respective faster or shorter clock rates.

This finding informs research on the development of time perception in typical development. Temporal sensitivity in children does not appear to reach the same level as adult temporal sensitivity until 8 years old (Delgado & Driot-Volet, 2007; Droit-Volet & Wearden, 2001; McCormack, et al., 1999; McCormack, et al., 2004; but see also Droit-Volet, 2013 for a review), with the source of the increased temporal variability related to long term memory reported by some researchers (Droit-Volet & Rattat, 2007; Lustig & Meck, 2011; McCormack et al., 1999; McCormack et al., 2004; Penny, Gibbon, & Meck, 2000), to attention or working memory by others (Delgado & Droit-Volet, 2007; Zelanti, & Droit-Volet, 2011; 2012), or to clock speed (Droit-Volet, 2013). Wearden and Jones (2013) offer an explanation for these discrepancies stating that it may be problematic that some of these studies involved SET statistical models to determine the source of variability in time perception in children. They explain that, although using a SET statistical model can be helpful in determining how patterns in temporal responding are related to a set of possible underlying causes, pinpointing the exact mechanisms responsible for group differences in responding may be difficult, if at all, possible (Wearden & Jones, 2013). This is because different psychological factors affecting time sensitivity, such as memory distortion, clock rate, and random responding to the time task, can show up as similar effects in the results of a SET statistical model (Wearden & Jones, 2013), thereby complicating the determination of the possible cause of the problem. Based on the suggestion by Wearden and Jones, the findings of this study are informative about whether the mechanism hypothesized to be responsible for variability in time perception in TD children is consistent with the mechanism responsible for variability in Down syndrome. Since clock rate can be ruled out as a contributor to possible temporal variability among the persons with Down syndrome, the age-related changes found among TD children in psychophysical measures of temporal variability may not be attributable to the internal clock (Droit-Volet & Wearden, 2001; McCormack et al., 1999; 2004).

Findings for the Temporal Generalization Task

The findings for the temporal generalization task revealed a significant main effect of duration indicating that both the persons with Down syndrome and the TD children were more likely to respond that the test durations close to 500ms were similar to the 500ms standard, and such responding tapered off as test durations became closer to 125ms and 875ms. No differences in responding between the groups were found as the group by duration interaction was not significant. Consistent with the findings from the temporal bisection task, which indicated similar responding among the persons with Down syndrome and the TD children, these results indicate that disturbances in time perception are minimal or may not be present in some instances in Down syndrome.

Implications for the profile of persons with Down syndrome. The finding that persons with Down syndrome displayed similar responding to the TD children on the temporal generalization task is surprising given their deficits in attention and memory and the importance of these abilities in accurate time perception in the SET model. Since long-term memory is also hypothesized by the SET to contribute to accurate time perception, the performance of persons with Down syndrome on this task might have been aided by long-term memory. The findings of persons with Down syndrome on the temporal generalization task strengthens the argument that long-term memory is an important contributor to time perception (e.g., McCormack et al., 1999) and may contribute to research on long-term memory in Down syndrome. Impairment in long-term memory has not been clearly delineated with conflicting evidence for both intact and impairment in this ability (Carlesimo, Marotta, & Vicari, 1997; Jarrold, Baddeley, & Philips, 2007). In a study investigating long-term memory, Carlesimo et al. (1997) found that persons with Down syndrome performed worse than MA-matched TD persons on a verbal list learning task in which the participants were required to recall a list of words and to recall a short story. Conversely, a similar study investigating long-term memory by Jarrold et al. (2007) found list recall among persons with Down syndrome to be intact. If long-term memory did contribute to enhancing the accuracy of the performance of persons with Down syndrome on the temporal generalization task, then it supports research like that of Jarrold et al. (2007) that reports this ability to be intact.

Since the evidence suggests that time perception influences motor timing (Allman & Meck, 2012; Smith et al., 2002) a disturbance in time perception was also expected to influence these impairments in Down syndrome. However, based on the findings from the temporal generalization task, such disturbances do not likely influence (or have a very minimal effect) impairments in these abilities. Issues related to anatomical characteristics and other perceptual processes are alternative explanations for contributors to motor control in Down syndrome. For example, motor impairments are thought to be related to resistance in limb mechanics and muscle organization as well as low muscle tone (Lawrence et al., 2013). Motor impairments may also be related to other perceptual processes such as issues with visual perception. This was demonstrated by Virji-Babul and Brown (2004) who examined the role of visual perception in motor control in Down syndrome using a paradigm that examined the movement strategies of persons with Down syndrome as they crossed obstacles at high heights. They reported that visual information about the obstacles was not used consistently to modulate movements (Virji-Babul & Brown, 2004). Further investigation of time perception in persons with Down syndrome will provide important information on the mechanisms involved in their disturbances in motor control and their cognitive abilities.

Limitations

The present study is limited in ways that are inherent to this type of research. The number of participants is small and the numbers are further decreased in the temporal bisection task due to the omission of data that could not be modeled and in the temporal generalization task because the data that did not follow a quadratic function. The resultant diminished statistical power may account for the marginally significant findings in the bisection task and the lack of consistency in findings between the temporal bisection task and the temporal generalization tasks. However, even with the reduced number of participants on the bisection task, the number of participants included in the final analyses was similar to other investigations examining differences in time perception in other special populations and TD individuals (e.g., Allman et al., 2011; Brodeur et al., 2013; Smith et al., 2002).

The second limitation is that the notion that the role of attention and working memory could be linked to the ability to estimate time could not be evaluated directly. Although temporal bisection tasks permit the calculation of the BP which determines if any differences in time perception are due to the internal clock, it does not allow for further differentiation between difference related to attention or working memory in relation to the internal clock.

The third limitation was that the flatter functions observed for both the TD children and the persons with Down syndrome for the temporal generalization task is some indication that both groups found this task challenging. Thus, no conclusions can be made with regard to whether the similarity in responding between these two groups in the temporal generalization task was due to similarity in temporal perceptual abilities or similarity in the difficulty both groups experienced making temporal judgments for the task. However, the fact that two psychophysical tasks measuring temporal perceptual abilities were included helps offset any results that may be biased due to specific aspects of either task and can also be considered a relative strength of this study.

Conclusion

The findings indicate a possible deficit in time perception among persons with Down syndrome. Differences are unlikely due to the speed of the internal clock and thus, the slower processing speed typical of persons with Down syndrome. Based on the developmental profile of persons with Down syndrome and research from previous investigations implicating attention and working memory in time perception of short durations, such differences may be related to deficits in attention and working memory in persons with Down syndrome. In addition to considering the difficulty of the temporal generalization task and increasing sample size, future directions of this study will further examine the role of attention and working memory by implementing measures assessing these abilities in persons with Down syndrome to examine the possible relationship to temporal perceptual abilities. If more concrete conclusions can be made on temporal perceptual abilities in persons with Down syndrome, it will be possible to examine how they affect other related areas of functioning.

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Table 1. Sample characteristics for the participants with Down syndrome (DS) and the TD children.

	Temporal Bisection		Temporal Generalization	
	DS n=15	TD n=15	DS n=12	TD n=13
CA (SD)	M=13.54(3.44)	M=6.26(4.48)	M=13.34(2.80)	M=5.92(1.41)
MA (SD)	M=5.37(86)	M=5.72(.80)	M=5.48(3.95)	M=5.33(1.00)
Gender (n^{o} males)	12	8	10	6

Table 2. Results of the repeated measures ANOVA for the temporal bisection task

Variable	*df*	*MS*	*F*	*p*
Group	1	.141	2.03	.17
Duration	4.15	3.28	58.51	.00
GroupxDuration	4.15	.12	2.15	.08
Error	116.08	.05		

Table 3. Group means (SE) of psychophysical measures associated with the temporal bisection task.

	Group	
	DS	TD
Bisection Point	474(31.09)	416(26.3)
Weber Fraction	.55(.07)	.16(.05)

Table 4. Results of the repeated measures ANOVA for the temporal generalization task

Variable	*df*	*MS*	*F*	*p*
Group	1	7.969E-7	.00	.99
Duration	6	.38	11.78	.00
GroupxDuration	6	.06	1.76	.11
Error	138	.03		

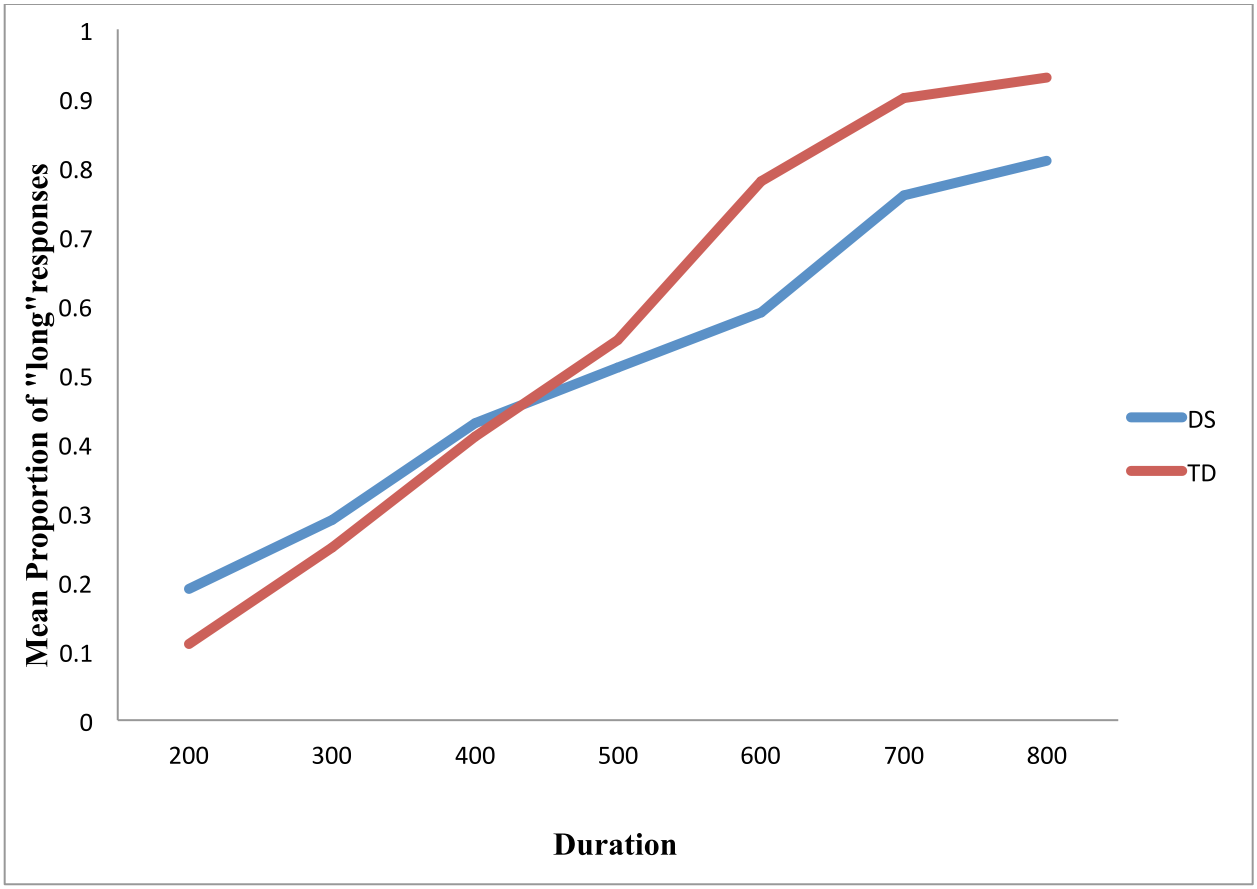


Figure 1. Mean proportion long responses for the temporal bisection task as a function of stimulus duration and group.

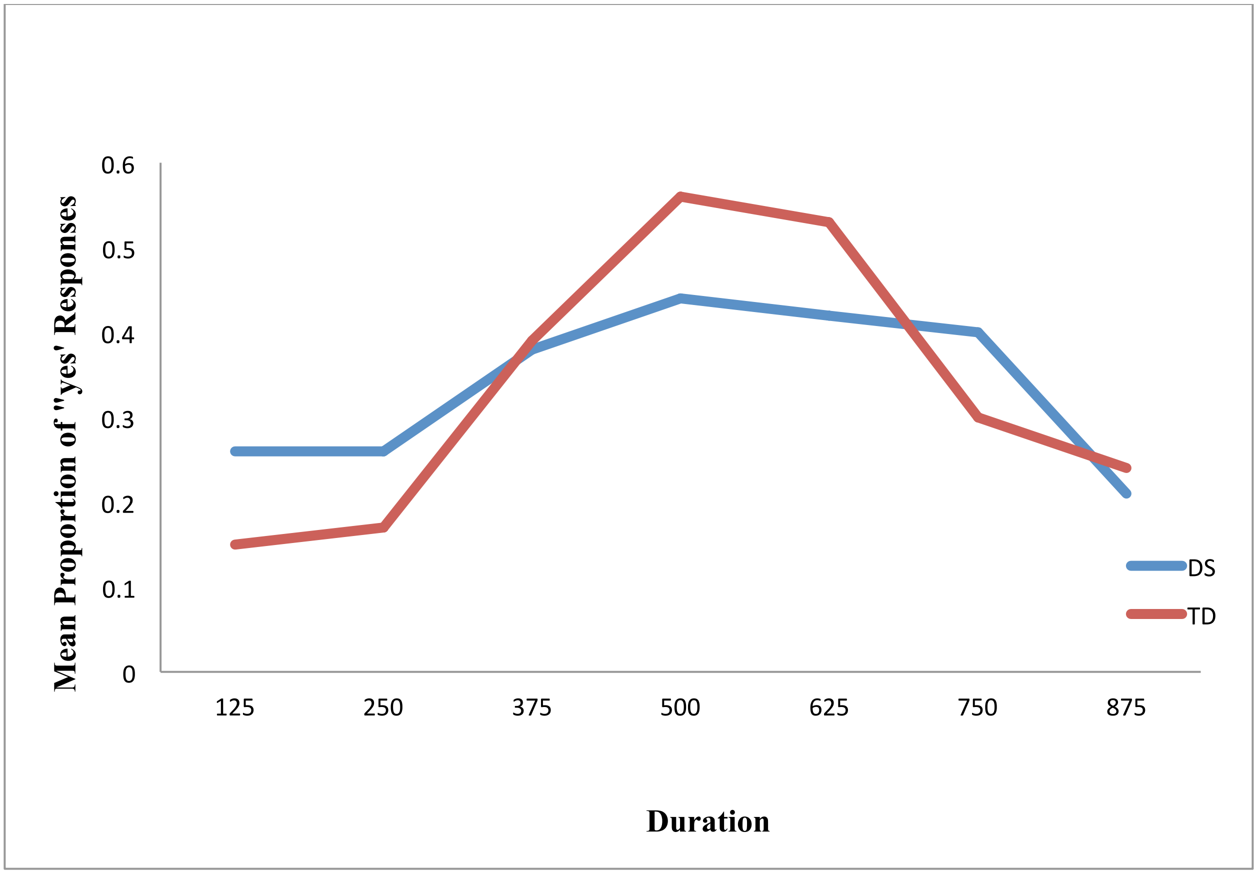


Figure 2. Mean proportion yes responses for the temporal generalization task as a function of stimulus duration and group.

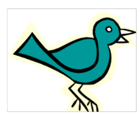
Appendix A

Example of the Temporal Bisection Task

Temporal Bisection

Demonstration phase:

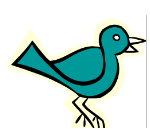
- Presented with 200ms (short tone) and an image of a small bird



- Presented with 800ms (long tone) and an image of a large bird

Temporal Bisection

Testing phase:



Appendix B

Example of the Temporal Generalization Task

Temporal Generalization

Demonstration phase

Temporal Generalization

Test phase