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Time processing skills in typical and impaired development

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Abstract

Time processing has been found relevant to explain some differences in the performance of students with ADHD, but also in students with other special educational needs, i.e. Borderline Intellectual Functioning and Specific Learning Disorders.
The aim of this study was to devise an instrument suitable to measure time processing skills influencing learning and behavior of children with typical and impaired development.
A Time Perception (TP) test was built, measuring by a computerized device simple reaction times, basic spontaneous rhythm, time reproduction and time discrimination.
The sample for the standardization of the test consisted of 395 primary school students (mean age 9.12 years), equally divided by gender, of which 60 with Special Educational Needs: Specific Learning Disorders, ADHD, Borderline Intellectual Functioning.
Psychometric properties of TP are reported, i.e. test-retest reliability and factor structure of the tasks, and the comparisons between groups with typical and impaired development, to confirm the validity of the

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instrument, useful both for research and educational and/or clinical purposes.

Keywords: Time processing; TP Test; Special educational needs; ADHD; Learning disorders.

1. Introduction

1.1. Time perception

Time perception and time processing represent essential skills for everyday life, e.g. for coordinating movements, reacting and responding at the right time, anticipating future events, planning activities. Time processing is a very complex function, which requires different levels of analysis: from the simple perception of a time interval of a few milliseconds, to also include the ability to program activities to plan in a day or a week.

As regards assessment, it is necessary to differentiate the abilities of time processing by those implying other cognitive abilities, such as working memory and executive functions; these functions are involved when the processing activity is complex and times to consider are longer. The model proposed by Ivry (1996) and Mangels and Ivry (2001), has suggested that short intervals i.e, milliseconds) may be more related to an internal timing mechanism while long intervals (i.e., seconds) may be more related to working memory. Time intervals longer than one second exceed sensory and motor processing, thus requiring the involvement of sustained attention and working memory. This model implies that strategies to improve performance in carrying out time processing tasks (for example, count mentally to evaluate the duration of a time interval) can be used only for times that exceed the duration of the second.

These two different mechanisms for time processing involve different brain areas: the basic mechanism of time perception involves the cerebellum, the basal ganglia and the prefrontal cortex (Harrington, Haaland, & Hermanowicz 1998; Ivry & Fiez, 2000), while for longer times the processing takes place in the cortical areas.

The cerebellum plays a key role in the motor system, in particular with respect to coordination of voluntary and complex movements, motor learning and control balance. It appears involved in many tasks associated with processing time: e.g., in the establishment and execution of timed movements (Ivry & Gopal, 1993), in task discrimination of duration (Mathiak, Hertrich, Grodd, & Ackermann, 2004), in accurate movement timing when there is an explicit, event based temporal goal, such as finger tapping to a cue (Spencer & Ivry, 2005). Cerebellar damage impairs the ability to discriminate time intervals in the range of milliseconds, whereas prefrontal damage causes deficit in temporal discrimination only in the range of seconds (Mangels, Ivry, & Shimizu, 1998). Given that cerebellar patients do not show perceptual deficits on non-temporal tasks, such as those requiring frequency discrimination, the cerebellum may be specific to those tasks that require a precise internal representation of the fine timing between events (Casini & Ivry, 1999), even in the absence of a motor response.

The basal ganglia, composed of the corpus striatum, globus pallidus, substantia nigra and subthalamic nuclei, have typically been associated with the control of posture and movement, but appear to mediate also temporal information processes. In particular, the striatum and substantia nigra are involved in the ability to discriminate timed intervals (Meck, 1996), as demonstrated in patients with Parkinson's disease (affecting the substantia nigra) whose performance in duration discrimination tasks are less accurate than the controls. The basal ganglia may be mostly involved in specific aspects of temporal processing: they seem critical for accurate time estimation (Nenandic, Gaser, Volz, Rammsayer, Hager, & Sauer, 2003), but not for accurate movement timing (Spencer & Ivry, 2005).

The prefrontal cortex (specifically in the right hemisphere) is involved in those tasks that require time processing of longer intervals and therefore involve the intervention of working memory skills. The prefrontal cortex is activated in the estimation of time intervals in the range of seconds (Onoda, Takahashi, & Sakata, 2003) and in memory-timed finger-tapping. Several studies revealed that frontal lobe patients with lateral prefrontal cortex lesions were impaired on long interval duration discrimination (Rao, Mayer, & Harrington, 2001), but not on short intervals (Mangels *et al*., 1998).

The cerebellum, basal ganglia, and prefrontal cortex are implicated in temporal information processing, but their contributions are not modular, as these different regions can interact during temporal information processing. For example, there have been several speculations on the link between cerebellar and frontal processes in timing (Mangels *et al*., 1998), including the possibilities that both the frontal and cerebellar regions regulate timing functions, and that the prefrontal cortex may not be integrally involved in timing, but may support the maintenance, monitoring, and organization of temporal information.

1.2. Time processing deficits and their measurement.

Several studies have evaluated the time processing deficits in ADHD, considering impulsivity as a matter connected to this difficulty. Toplak, Dockstader and Tannock (2006) summarize a number of studies about time perception and processing skills in people with ADHD, that detect the presence of a deficit in these skills. In particular, they show deficits in tasks of duration discrimination, finger tapping and duration reproduction tasks. Other studies confirmed in ADHD high variability in reaction times (Borella, Chicherio, Re, Sensini, & Cornoldi, 2011, Tamm, Narad, Antonini, O'Brien, Hawk, & Epstein, 2012; Kofler, Rapport, Sarver, Raiker, Orban, Friedman, & Kolomeyer, 2013; Sjöwall, Roth, Lindqvist, & Thorell, 2013; Adamo, Di Martino, Esu, Petkova, Johnson, Kelly, Castellanos, & Zuddas, 2014); and other deficits in "time processing" (Mullins, Bellgrove, Gill, & Robertson, 2005; Plummer & Humphrey, 2009; Quartier, Zimmermann, & Nashat, 2010; Hurks & Hendriksen, 2011). The neuroimaging research in ADHD provides converging evidence of functional alteration in regions associated with temporal information processing, such as the cerebellum, basal ganglia, and prefrontal cortex. Sonuga Barke, Bitsakou and Thompson (2010), assessing children with ADHD in tasks of time processing, inhibitory control and delay aversion, demonstrated that subjects with ADHD differ in all three aspects from the control group, suggesting that the deficits in time processing can be considered as a neuropsychological component of ADHD.

Time processing deficits have been signalled not only in ADHD, but also in dyslexic readers (Habib, 2000; De Martino, Espesser, Rey, & Habib, 2001; Share Jorm, Maclean, & Matthews, 2002; Gooch, Snowling, & Hulme, 2011, 2012; Fostick, Bar-El, & Ram-Tsur 2012; Tamm, Epstein, Denton, Vaughn, Peugh, & Willcutt, 2014). Moreover, dyslexia is often comorbid with ADHD, and some authors propose a "multiple deficit model" (Willcutt, Betjemann, McGrath, Chhabildas, Olson, DeFries, & Pennington, 2010; McGrath, Pennington, Shanahan, Santerre-Lemmon, Barnard, Willcutt, & Olson, 2011; Gooch Snowling, & Hulme, 2012; Sheikhi Martin, Hay, & Piek, 2013).

A common problem in these studies is to develop reliable instruments suitable for measuring, as objectively as possible, the time processing deficits. Currently standardized measures for evaluating the ability of time processing have not been devised; consequently, the data presented in the various studies could not agree because of the heterogeneity of the experimental tasks used.

1.3. Aim of the study

In the present study a computerized test based on studies by Toplak and Tannock (2005a; 2005b) has been created, with the aim of evaluating the time processing abilities in children with and without learning and cognitive difficulties.

2. Method

2.1. Time Processing Test

The *Time Processing* (TP) test is composed of a series of exercises developed in Visual Basic programming. It has to be administered individually at school, using a computer and headphones and trying to minimize the possible distractions. The TP requires 15-20 minutes and is structured into four subtests:

1. *Simple reaction times:* The subject is required to press the space bar as quickly as possible to the presentation of the visual target on the screen. Each pressing time and the number of omissions are recorded. The score is the median time of response (the median score, instead of the mean, permits to minimize the effect of outlier pressures).
2. *Basic spontaneous rhythm:* It requires the subject to drum (beat with the finger on the space bar) to speed a rhythm that is considered as the most natural and acceptable. The number of beats per minute is recorded.
3. *Rhythm reproduction:* The task requires the subject to learn a regular rhythm proposed by the computer (in auditory modality) and play it on his own, pressing the spacebar, as accurately as possible. The rates proposed are two: 1000 ms and 400 ms. The software records the subject's rate, i.e. the sequence of intervals between a pressure of the spacebar and the subsequent. Two scores for both rhythms are obtained: the median difference between the intervals and the targets (respectively, 1000 and 400 ms); and the coefficient of variation (ratio of intra-subject standard deviation and mean interval, according to the formula proposed by Toplak and Tannock, 2005a: $SD / M * 100$).
4. *Time duration discrimination:* The subject listens to two time intervals (circumscribed by a start sound and an end sound) and should discriminate the longest time interval between the two. In the first part, the target has a duration of 1000 ms; in the second part of 200 ms. The first comparison is between 1000 ms and 1600 ms and the stimuli are proposed in a sequence of increasing or descending difficulty according to the answers of the subject (with variations of 25 ms). In the second part the first comparison is between 200 ms and

320 ms and the stimuli are proposed in a sequence of increasing or descending difficulty according to the answers of the subject (with variations of 5 ms). All the answers of the subject and the threshold at which the subject can correctly discriminate between the two stimuli are recorded. For example, a subject that discriminates correctly the stimulus of 1000 ms from that of 1400 ms, has a threshold of 400 ms. In the two subtests of time intervals discrimination (1000 ms and 200 ms), the first block of stimuli (made of 8 items) was the same for all subjects, while the successive stimuli were presented in blocks of increasing or decreasing difficulty depending the correctness of the answers.

The subtest 3 and 4 were built to reproduce the experimental tests used by Toplak and Tannock (2005a; 2005b).

The computerized test was administered by an expert psychologist individually, in a face-to-face setting, without the presence of teachers or parents.

2.2. Participants

The sample for the psychometric study of TP test was composed of 395 students of primary school, females 49.4%, age 7-14, mean age 9.19, standard deviation 2.14.

For the discriminant validity study a sub-sample was chosen, composed of 60 students with Special Educational Needs, 39 males and 21 females, matched with a control group of 60 students with typical development and learning, 39 males and 21 females, all between 8 and 9 years of age. The 60 students with special needs were diagnosed by the neuropsychiatric équipe, as Specific Learning Disorders (n = 25), ADHD (n = 22), and Borderline Intellectual Functioning (n = 13). For this diagnosis, intelligence, learning and behavioral tests, in Italian standardizations, were used: WISC-IV (Wechsler, 2012); MT-2 (Cornoldi & Colpo, 2011); AC-MT (Cornoldi, Lucangeli, & Bellina, 2012); BIA (Marzocchi, Re, & Cornoldi, 2010).

2.3. Results

Differences between genders were preliminary assessed. None of the variables was statistically significant at $p < .05$ level; consequently the whole sample was used for the subsequent analyses.

Test-retest correlations were computed in as sub-sample of 25 subjects randomly extracted from the overall sample. The Pearson coefficients ranged from .77 (for discrimination at 1000 ms) to .47 for spontaneous rhythm, with a mean test-retest reliability of .58. It should be noted that a range of intra-subject variability is foreseeable and acceptable in this kind of tasks.

The discriminant validity of the TP was tested comparing the two groups with and without Special Educational Needs for each variable measured by TP test. Table 1 shows the differences, significant for 6 tasks out of 8.

Table 1 - *Comparison between Special Educational Needs and control groups (single TP scores)*

	Special Education Needs (n = 60)		Control group (n = 60)			2 tail sign.
	M	*SD*	*M*	*SD*	*t*	(*df* = 118)
Simple reaction time	443.32	60.63	338.35	58.31	5.06	< .001
Spontaneous rhythm (beats per minute)	209.67	127.98	157.40	77.09	2.71	.01
Rhythm reproduction: median shift from target 1000 ms	215.68	191.71	128.02	192.60	2.49	.01
Rhythm reproduction 1000 ms – variation	17.72	18.57	14.10	13.99	1.20	.23
Rhythm reproduction: median shift from target 400 ms	32.75	81.88	26.72	55.75	0.47	.52
Rhythm reproduction 400 ms – variation	20.38	22.41	13.10	9.27	2.33	.02
Discrimination threshold (target = 1000 ms)	1559.62	108.60	1452.23	118.35	4.90	< .001
Discrimination threshold (target = 200 ms)	324.62	28.04	302.23	27.58	4.18	< .001

To study the construct validity an exploratory factorial analysis, with Varimax rotation, was performed, using as concurrent criteria for the extraction of the factors both eigenvalues > 1 (Kaiser criterion) and Cattell's Scree Test. Three factor were detected as best solution, explaining 56.58% of total variance. Table 2 shows the rotated matrix of loadings.

Table 2 – *Results of factorial analysis, after Varimax rotation (n = 395). Loadings > .50 in bold*

	Fact. 1	Fact. 2	Fact. 3
Discrimination threshold 200 ms	**.80**	.17	.01
Discrimination threshold 1000 ms	**.70**	.06	.27
Reaction times	**.61**	-.07	-.03
Reproduction at 400 ms	-.03	**.78**	.21
Reproduction at 1000 ms	-.07	**.68**	-.21
Spontaneous rhythm	.02	**.59**	.20
Variation at 1000 ms	.03	.05	**.84**
Variation at 200 ms	.12	.13	**.79**
Total of Variance explained	1.52	1.48	1.51
%	19.04	18.54	19.00

In the first factor the two discrimination thresholds and the reaction times are mainly loaded; the factor can represent the difficult to discriminate and manage temporality, with higher thresholds and reaction times.

The second factor includes the shift from the target rhythm of reproduction both at 1000 and 400 ms, and the beats for minute: this factor can represent the difficulty to have a faster and less adequate temporal rhythm.

The two variation coefficients are loaded in the third factor, representing an higher intra-individual variability.

A confirmatory factor analysis proved the reliability of the three-factors solution: CFI = .91, RMR = .04 and RMSEA = .05.

The three factor scores were computed as means of the standardized scores of the variables loading each factor. These factors, while not completely orthogonal, are scarcely correlated each other (table 3), confirming the usefulness of the separated consideration for research and/or educational and clinical aims, besides using the single variables scores.

Table 3 – *Intercorrelation among factors*

	Fact. 1	Fact. 2	Fact. 3
Fact. 1	1.00		
Fact. 2	.14	1.00	
Fact. 3	.21	.19	1.00

The distribution values and the standardization of the factorial scores (i.e., means of *Z* scores for the variable loading the three factors) are shown in table 4. The distributions are satisfactory for the first two factors (skewness = .03 and .67 respectively; kurtosis = -.30 and 1.11). The third factor shows an asymmetrical distribution (skewness = 2.20, kurtosis = 5.93), determined by a general tendency to obtain lower scores for these variables; this is useful for detecting clinically relevant exceptions (high intra-individual variability is significant over the 75th percentile, i.e. a factor score greater than .15).

Table 4 – *Distribution and percentiles of the Z scores for the three factor*

	Fact. 1 Time management	Fact. 2 Rhythm speed	Fact. 3 Intra-individual variation
Minimum	-1.71	-2.11	-.74
Maximum	2.11	2.15	3.16
M	-.04	-.05	-.08
SD	.70	.64	.63
Percentiles			
10°	-.97	-.75	-.56
25°	-.60	-.46	-.48
50°	.00	-.13	-.31
75°	.47	.32	.15
90°	.83	.86	.69

The comparison between the two groups with and without Special Educational Needs was repeated for the three factor scores (tab. 5). The factors “Time” and “Rhythm speed” differentiate significantly the two groups, confirming the discriminant validity of the TP, while the factor “Intra-individual variation” results not discriminant: as reported in table 1, for the single variables loading this factors only the variability at 400 ms differentiated significantly the groups with typical and atypical development.

Table 5 - *Comparison between Special Educational Needs and control group (factor Z scores)*

	Special Education Needs (n = 60)		Control group (n = 60)		2-tail. sign.	
	M	*SD*	*M*	*SD*	*t*	(*df* = 118)
Fact. 1 – Time management	.46	.66	-.01	.60	4.12	< .001
Fact. 2 – Rhythm speed	.31	.88	-.17	.67	3.65	< .001
Fact. 3 – Intra-individual variation	.23	1.02	.06	1.00	1.00	.32

3. Conclusions

The literature outlined a time processing deficit in ADHD, explaining the impulsive behavior of these persons, but our data demonstrated that a similar deficit is present also in students with learning impairments and other educational needs. The finding of a time processing deficit in different types of atypical development (specific learning disabilities, borderline intellectual functioning and ADHD), can be explained supposing a common impairment involving the neural correlates of time perception skills: cerebellum, basal ganglia and prefrontal cortex. In particular, the presence of a cerebellar deficit is linked with shorter decision times and poorer performances in executive functions tasks.

Further studies are needed to verify the links between cerebellum and other neural circuits involved in time perception and to create a coherent explicative model including this deficit. Nicolson and Fawcett (2007) stated that research in developmental disorders is fragmented, emphasizing differences rather than commonalities and proposed that reunification might be achieved by using a “neural-systems” approach.

A standardized test for the assessment of time processing skills is useful to proceed in this field of research, and this was the aim of the study reported here.

The TP test shows psychometric qualities suitable for the use both for research and educational and clinical assessment. It allows detecting deficits in time perception and processing, which are present in several impairments of the development. The scores both in the single variables of the test and in the three factors identified in the study appear to be reliable and valid for research and applicative purposes.

A limit of this methodological study refers to the impossibility to verify in special educational needs reliable causal models including external measures: this was due to the small number of the specific subsamples, used with the aim of studying the overall validity in atypical development.

Another limitation of the study is the specificity of the sample, especially regarding age range. In the future, the test could be adapted to measure the same variables in adult and older samples, so to cover all the ranges of lifespan in clinical assessment of the time processing.

References

Adamo, N., Di Martino, A., Esu, L., Petkova, E., Johnson, K., Kelly, S., Castellanos, F. X., & Zuddas, A. (2014). Increased Response-Time Variability Across Different Cognitive Tasks in Children With ADHD. *Journal of Attention Disorders*, *18*, 434-446.

Borella, E., Chicherio, C., Re A. M., Sensini, V., & Cornoldi, C. (2011). Increased intraindividual variability is a marker of ADHD but also of dyslexia: a study on handwriting. *Brain and Cognition, 77*, 33-39.

Casini, L., & Ivry, R. B. (1999). Effects of divided attention on temporal processing in patients with lesions of the cerebellum or frontal lobe. *Neuropsychology, 3*, 10-21.

Cornoldi, C., & Colpo, G. (2011). *Prove di Lettura MT-2 per la Scuola Primaria*. Firenze: O.S.

Cornoldi, C., Lucangeli, D., & Bellina, M. (2012). *Test AC-MT 6-11 – Test di valutazione delle abilità di calcolo e soluzione di problemi*. Trento: Erickson.

De Martino, S., Espesser, R., Rey, V., & Habib, M. (2001). The "temporal processing deficit" hypothesis in dyslexia: New experimental evidence. *Brain and Cognition, 46*, 104-108.

Fostick, L., Bar-El, S., & Ram-Tsur, R. (2012). Auditory temporal processing and working memory: Two independent deficits for dyslexia. *Psychology Research, 2*, 308-318.

Gooch, D., Snowling, M., & Hulme, C. (2011). Time perception, phonological skills and executive function in children with dyslexia and/or ADHD symptoms. *Journal of Child Psychology and Psychiatry and Allied Disciplines*, *52*, 195-203.

Gooch, D., Snowling, M. J., & Hulme, C. (2012). Reaction time variability in children with ADHD symptoms and/or dyslexia. *Developmental Neuropsychology, 37*, 453-472.

Habib, M. (2000). The neurological basis of developmental dyslexia: An overview and working hypothesis. *Brain, 123,* 2373-2399.

Harrington, D. L., Haaland, K. Y., & Hermanowicz, N. (1998). Temporal processing in the basal ganglia. *Neuropsychology, 12*, 1-10.

Hurks, P. P. M., & Hendriksen, J. G. M. (2011). Retrospective and prospective time deficits in childhood ADHD: The effects of task modality, duration, and symptom dimensions. *Child Neuropsychology, 17*, 34-50.

Ivry, R. B., & Fiez, J. A. (2000). Cerebellar contributions to cognition and imagery. In M. S. Gazzaniga (Ed.), *The new cognitive neurosciences,* 2nd ed. (pp. 999-1011). Cambridge, MA: MIT Press.

Ivry, R. B. (1996). The representation of temporal information in perception and motor control. *Current Opinion in Neurobiology*, *6*, 851-857.

Ivry, R. B., & Gopal, H. S. (1993). Speech-production and perception in patients with cerebellar lesions. *Attention and Performance, 14,* 771-802.

Kofler, M. J., Rapport, M. D., Sarver, D. E., Raiker, J. S., Orban, S. A., Friedman, L. M., & Kolomeyer, E. G. (2013). Reaction time variability in ADHD: A meta-analytic review of 319 studies. *Clinical Psychology Review*, *33*, 795-811.

Mangels, J. A., & Ivry, R. B. (2001). Time perception. In B. Rapp (Ed) *The handbook of cognitive neuropsychology: what deficits reveal about the human mind*. Pennsylvania, USA: Psychology Press.

Mangels, J. A., Ivry, R. B., & Shimizu, N. (1998). Dissociable contributions of the prefrontal and neocerebellar cortex to time perception. *Cognitive Brain Research, 7,* 15-39.

Marzocchi, G. M., Re, A. M., & Cornoldi, C. (2010). *BIA – Batteria italiana per l'ADHD*. Trento: Erickson.

Mathiak, K., Hertrich, I., Grodd, W., & Ackermann, H. (2004). Discrimination of temporal information at the cerebellum: functional magnetic resonance imaging of nonverbal auditory memory. *Neuroimage, 21,* 154-62.

McGrath, L. M., Pennington, B .F., Shanahan, M. A., Santerre-Lemmon, L. E., Barnard, H. D., Willcutt, E. G., & Olson, R. K. (2011). A multiple deficit model of reading disability and attention-deficit/hyperactivity disorder: searching for shared cognitive deficits. *Journal of Child Psychology and Psychiatry, and Allied Disciplines, 52,* 547-557.

Meck, W. H. (1996). Neuropharmacology of timing and time perception. *Cognitive Brain Research, 3*, 227-42.

Mullins, C., Bellgrove, M. A., Gill, M., & Robertson, I. H. (2005). Variability in time reproduction: Difference in ADHD combined and inattentive subtypes. *Journal of the American Academy of Child and Adolescent Psychiatry, 44,* 169-176.

Nenandic, I., Gaser, C., Volz, H. P., Rammsayer, T., Hager, F., & Sauer, H. (2003). Processing of temporal information and the basal ganglia: new evidence from fMRI. *Experimental Brain Research, 148,* 238-246.

Nicolson, R. I., & Fawcett, A. J. (2007). Procedural learning difficulties: reuniting the developmental disorders? *Trends in Neuroscience, 30,* 135-141.

Onoda, K., Takahashi, E., & Sakata, S. (2003). Event-related potentials in the frontal cortex, hippocampus, and cerebellum during a temporal discrimination task in rats. *Cognitive Brain Research, 17,* 380-387.

Plummer, C., & Humphrey, N. (2009). Time perception in children with ADHD: The effects of task modality and duration. *Child Neuropsychology, 15*, 147-162.

Quartier, V., Zimmermann, G., & Nashat, S. (2010). Sense of time in children with attention-deficit/hyperactivity disorder (ADHD). *Swiss Journal of Psychology, 69,* 7-14.

Rao, S. M., Mayer, A. R., & Harrington, D. L. (2001). The evolution of brain activation during temporal processing. *Nature Neuroscience, 4*, 317-323.

Share, D .L., Jorm, A. F., Maclean, R., & Matthews, R. (2002). Temporal processing and reading disability. *Reading and Writing*, *15*, 151-178.

Sheikhi, A. R, Martin, N., Hay, D., & Piek, J. P. (2013). Phenotype refinement for comorbid attention deficit hyperactivity disorder and reading disability. *American Journal of Medical Genetics – Part B, Neuropsychiatric Genetics, 162,* 44-54.

Sjöwall, D., Roth, R., Lindqvist, S., & Thorell, L. B. (2013). Multiple deficits in ADHD: executive dysfunction, delay aversion, reaction time variability, and emotional deficits, *Journal of Child Psychology and Psychiatry, 54,* 619-627.

Sonuga-Barke, E. J. S., Bitsakou, P., & Thompson, M. (2010). Beyond the dual pathway model: evidence for the dissociation of timing, inhibitory, and delay-related impairments in attention-deficit/hyperactivity disorder. *Journal of American Academy of Child Adolescent Psychiatry, 49*, 345-355.

Spencer, R. M. C., & Ivry, R. B. (2005). Comparison of patients with Parkinson's disease or cerebellar lesions in the production of periodic movements involving event-based or emergent timing. *Brain Cognition, 58*, 84-93.

Tamm, L., Epstein, J. N., Denton, C. A., Vaughn, A. J., Peugh, J., & Willcutt, E. G. (2014). Reaction Time Variability Associated with Reading Skills in Poor Readers with ADHD, *Journal of the International Neuropsychological Society, 20* (3), 292-301.

Tamm, L., Narad, M. E., Antonini, T. N., O'Brien, K. M., Hawk, L. W. Jr, & Epstein, J. N. (2012). Reaction time variability in ADHD: a review. *Neurotherapeutics, 9*, 500-508.

Toplak, M. E., Dockstader, C., & Tannock, R. (2006). Temporal information processing in ADHD: Findings to date and new methods, *Journal of Neuroscience Methods, 151*, 15-29.

Toplak, M. E., & Tannock, R. (2005a). Tapping and anticipation performance in attention deficit hyperactivity disorder. *Perceptual and Motor Skills, 100*, 659-675.

Toplak, M. E., & Tannock, R. (2005b). Time perception: modality and duration effects in ADHD, *Journal of Abnormal Child Psychology, 33*, 639-654.

Wechsler, D. (2012). *Wechsler Intelligence Scale for Children-IV, Italian adaptation*. Firenze: OS.

Willcutt, E. G., Betjemann, R. S., McGrath, L. M., Chhabildas, N. A., Olson, R. K., DeFries, J. C., & Pennington, B. F. (2010). Etiology and neuropsychology of comorbidity between RD and ADHD: the case for multiple-deficit models. *Cortex, 46,* 1345-1361.