Inhibition Development: Comparison of Neuropsychological and Eye Tracking Measures

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Original Article

Abstract

Inhibition is the ability to stop an automatic response when a stimulus is presented. It is one main component of executive function models. Few studies have evaluated the development of this ability between five and eight years of age, particularly using eye tracking measures. The first aim of this exploratory study is to evaluate the performance difference of younger compared to older children. The second aim is to evaluate if inhibition assessed via three different neuropsychological tests develops at a similar rate as inhibition assessed via two eye tracking tasks. Forty-six children aged 5 years and 8 months to 8 years and 5 months completed both types of tests. Results show one neuropsychological test was **sensitive to the children' increasing inhibition ability,** while both eye tracking tests were. Additionally, scores from one eye tracking task correlated with scores from one neuropsychological test. Possible explanations of moderate relations between tasks are discussed.

Resumen

Desarrollo de la inhibición: Comparación de medidas neuropsicológicas y de seguimiento de ojos. La inhibición es la capacidad de detener una respuesta automática. Es una de las funciones ejecutivas principales. Pocos estudios han evaluado su desarrollo en niños de cinco a ocho años utilizando pruebas de seguimiento de ojos. Este estudio exploratorio tiene, como primer objetivo, evaluar la diferencia de rendimiento entre los más jóvenes y los mayores. El segundo objetivo es evaluar si la inhibición se desarrolla a un ritmo similar en tres pruebas neuropsicológicas y dos pruebas de seguimiento de ojos. Cuarenta y seis niños, de 5 años y 8 meses a 8 años y 5 meses, realizaron ambos tipos de pruebas. Los resultados muestran que una de las pruebas neuropsicológicas y ambas pruebas de seguimiento de ojos fueron sensibles a la mejora de la inhibición. Además, resultados de una prueba de seguimiento de ojos y de una prueba neuropsicológica estaban correlacionados. Se discuten las explicaciones posibles de las relaciones entre las tareas.

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1. Introduction

Inhibition is the ability to refrain prepotent responses. Executive functions (EFs) models differ, but inhibition remains as major component for most authors (Carlson, 2005; Diamond & Lee, 2011; Zelazo, Carter, Reznick, & Frye, 1997). According to Miyake and Friedman (2012), inhibition has a key role, being the common EF while shifting and updating were specialised and independent functions.

Zelazo and Müller (2011) suggested that three-year-old children can already inhibit responses to salient aspects of stimuli. This demonstrated inhibition appears early and may have an important

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role in EFs development.

Many studies have investigated the development of EFs in children. One of these (Wiebe, Espy, & Charak, 2008) evaluated children of 2 to 6 years of age. Inhibition and updating were tested with a variety of neuropsychological tests. Through factor analysis authors concluded that one factor including **both functions sufficed to explain the children's** performances. This implied that before age 6, there is no distinction between EFs as identified in adult samples, and that child EFs appear to be a unitary component. Lehto, Juujärvi, Kooistra and Pulkkinen (2003) tested children 8 to 13 years with neuropsychological tests assessing inhibition, shifting and updating. Following their factor analysis, a three factor model, the same factors Miyake and Friedman (2012) identified with adults, explained their results with children. That study suggested that, in older children, EFs had developed in a way that made them separable and independent, similar to adults. These two studies with children suggest there is a shift in in EFs between ages five and eight, because results were explained by a one component model before age six and by a three component model after age eight.

Clinical assessment of EFs typically uses standardised psychometric tests to measure and **quantify participants' cognitive abilities. Tests** commonly used by neuropsychological clinicians are usually validated with important samples and demonstrate good fidelity. Nevertheless, neuropsychological evaluation faces many challenges. For some authors (Kaplan, 1988; Stuss, & Alexander, 2000), there often is a possibility that a test destined to evaluate performances of one particular cognitive function, also taps in other abilities (color perception, reading ability, reaction time and motor speed, etc.), and so a thorough evaluation and study of convergence of results is necessary before conclusions about the development of EFs, and particularly inhibition, are drawn.

Other than neuropsychological tests, it is possible to assess cognitive functions and EFs with eye tracking saccade paradigms (Karatekin, 2008). Saccades are rapid eye movements that are used to locate a specific visual target in the fovea. These eye movements are therefore a good way to assess a change in visuospatial attention. Eye tracking researchers have been using the antisaccades paradigm to evaluate inhibition in normal and clinical

sample for over fifteen years (Karatekin, 2008). Antisaccades are voluntary eye movements directed towards the opposite direction of the target stimulus appearing laterally in an experimental task (Karatekin, 2008). Eye tracking technology thus provides a way to evaluate inhibition abilities without relying on other cognitive functions, unlike classical neuropsychological tests.

So far, most studies used antisaccade tasks with samples older than eight years old (Everling & Fischer, 1998). Success rate at antisaccade tasks before that age is low (Luna, Velanova & Geier, 2008). A handful of studies with clinical participants over 9 years (Clementz, McDowell, & Zisook, 1994; Loe et al., 2012) have used a fixation task with simpler instructions: **"Keep looking at the center of the screen when the** central fixation point disappears and the distractor **appears laterally". This task's simpler instruction puts** less demand on working memory.

To the best of our knowledge, only two studies have used both antisaccade tasks and neuropsychological tests in children research: Christ, White, Brunstrom and Abrams (2003), and Friedman, Miyake, Robinson and Hewitt (2011). Despite the use of neuropsychological tests and eye tracking tasks, neither of these studies compared or evaluated the convergence of eye tracking tasks and neuropsychological tests.

A limited number of studies have focused on converging evidence of eye tracking measures and neuropsychological tests. Doing so is essential before drawing conclusions that one type of testing evaluates the same ability as the other one (Nieuwenhuis, Broerse, Nielen, & de Jong, 2004). Therefore, the first aim of the present study is to investigate how inhibition develops between five and eight years of age. This may shed light on how EFs can be explained by a single component model before six, and by a three components model after eight. The second aim is to evaluate how inhibition performance develops on both types of measures. A third aim is to evaluate if a fixation task is better to assess inhibition via eye tracking with participants aged five to eight than a conventional antisaccade tasks.

2. Method

2.1. Participants

A sample of 53 French speaking children from two schools in Trois-Rivières (Canada) participated in

this study. Participants' age ranged from 5 years 8 months to 8 years and 5 months (Table 1). Mothers' number of years of education was used as socio economic status variable. Non-inclusion criteria included previous head trauma and visual impairments uncorrected by glasses. Children were recruited by letters to parents distributed through the schools. All experimental procedures were reviewed and approved by the Université du Québec à Trois-Rivières' human research ethics commitee. Parents provided informed consent, and children provided assent. Participants were compensated for participation with personalised diploma and stickers. Seven participants were excluded from analyses: one for unforeseen visual problems, two for being unable to remain calm during eye tracking evaluation, and three for procedure errors. One participant started the evaluation but refused to complete. Forty-six participants were included in final analysis.

Table 1.
Age and gender distribution of participants completing tasks.

Group	1	2	3
Mean age (*SD*)	6y (2m)	6y 9m (3m)	7y 11m (5m)
Range	5y 8m-6y 4m	6y 4m-7y 1m	7y 2m-8y 5m
Male	8	8	10
Female	8	8	4
MNYE*	16.1(1.7)	14.1(2,7)	15.3(2.0)

*Mean (*SD*) mothers' number of years of education

2.2. Procedure and instruments

Participants were evaluated individually in their school, during free time periods. Eye tracking tasks and neuropsychological tests were conducted by trained graduate and undergraduate students. Eye tracking tasks were presented in fixed order while neuropsychological tests were presented in random order.

2.2.1. *Neuropsychological testing.* Inhibition was evaluated with three measures commonly used by clinical neuropsychologist.

Walk Don't Walk (WDW), a subtest from Test of Everyday Attention for Children - TEA-Ch (Manly, Robertson, Anderson & Nimmo-Smith, 2006). When participants hear a regular tone, they need to draw a **line (one "step") along a path of successive squares**

printed on a sheet of paper. When a different tone is heard, no further step must be drawn. One point is **recorded when participants' mark stops in the** appropriate square. If a mark is drawn in the next square, a failure is recorded. Number of correct answers out of 20 tria**ls constitutes the participant's** score. The French version of the TEA-Ch Battery was validated with a sample of 379 children aged 6 to 13 recruited and tested in France. Raw scores were used for analyses.

Tower of London (ToL). The ToL (Culbertson & Zillmer, 2006) involves a set of 3 colored balls, placed on 3 pegs of different heights. An initial state of the balls has to be converted to a goal state illustrated on a model set. This has to be completed in a minimum number of movements. Scores are obtained for number of moves and time taken to complete. Rule breaks are recorded when more than one ball is moved at a once, or when too many balls are placed on a stick. ToL is used by clinicians to assess planning abilities, but rule breaks are known to imply inhibition difficulties (McCormack & Atance, 2011). This latter measure will be used as an inhibition index. Best score would be zero (for no rule broken). This test was validated with an American and an English speaking Canadian sample aged from 7 to 80 years old, with 110 children in the 7 to 9 group. Log transform of raw scores of «*rule breaks*» will be used for statistical analysis, because this test is known to have an important ceiling effect.

Knock and Tap (KT). This subtest from the NEPSY battery (Korkman, Kirk & Kemp, 2003) is designed to evaluate motor inhibition abilities. For the first 15 trials of test, when the evaluator knocks with a closed fist on a surface, the child has to hit the surface with an open hand and vice versa. Participant has to inhibit imitation and follow the learned rule. For the last 15 trials the rules change: when the evaluator knocks with a closed fist on a surface, the child has to hit the surface with the side of his hand; when the evaluator hits the surface with the side of his hand, the child has to knock with a closed fist on a surface; and when the evaluator hits the surface with an open hand, the child has to stay still. Participants have to inhibit imitation and the previously learned set of rules for these latter trials. Maximum score is 30. The French version of the NEPSY Battery was validated with a sample of 325 children aged 3 to 12 recruited and tested in France. Log transform of raw scores will be

used for statistical analysis, because this test is also known to have an important ceiling effect.

2.2.2 Eye Tracking Test Procedures. Participants were tested in a quiet room, positioned 60 cm from an eye tracker screen in a custom made chin and forehead rest to reduce head movement. Gaze and pupil data were collected at a 60Hz sampling rate, using a Tobii T120 eye tracker (Tobii Technology, Stockholm, Sweden) equipped with an integrated 34 × 28 cm screen (1.280 × 1.024 pixel resolution; 60-Hz refresh rate). Stimuli were displayed using E-Prime software

(Psychology Software Tools, Inc, Pittsburgh, Pennsylvania). After a 5-point calibration procedure, the first eye tracking task was verbally explained while screenshot pictures of the task were shown. Participants were asked to repeat instructions to make sure they understood. After completion of the first task, the second task was explained and so on. Target stimuli for all tasks were circles 0.5 degree of visual angle in diameter randomly presented 5, 10 or 15 degree of visual angle at left or right of central fixation cross. For every task, 36 trials were presented with a break after a first block of 18 trials (Figure 1).
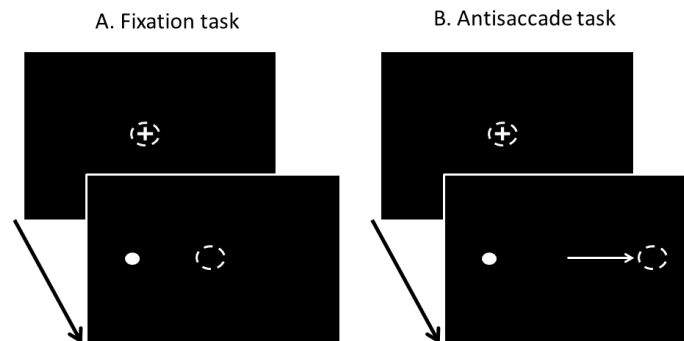

Figure 1. A. *Fixation task*: look maintained towards center of screen. B. *Antisaccade task*: Saccade towards opposite side of target.

Fixation task. Participants fixated a central cross (0.5 degree high by 0.5 degree wide) appearing on the computer screen. When it disappeared, they held their gaze at central fixation area while distractor stimuli appeared for 2 seconds. Eye movements more than 2.5 degree right or left from central location were considered as errors. Looks toward the distractor were considered inhibition errors. Looks toward distractor corrected within 1000 milliseconds were considered corrected inhibition errors (indicating task was understood but behaviour could not be inhibited). Looks in opposite direction from distractor were considered as directional errors (behaviour was inhibited but looks did not remain in central area as instructed). Percentages of successes and of each type of error were calculated.

Antisaccade task. Participants fixated a central cross (0.5 degree high by 0.5 degree wide) appearing on the computer screen. When it disappeared, they were asked to look in the opposite direction of a stimulus, which appeared for 2 seconds. Looks toward distractor were considered inhibition errors and looks toward distractor corrected within the first second

were considered corrected inhibition errors. Percentages of success and of each type of error were calculated. Latency was measured for successful trials.

2.2.3. Eye Movement Analysis. Eye movement recordings were analyzed offline using in-house programs written in MATLAB (MathWorks, Inc, Natick, Massachusetts). The program automatically identified and analysed fixations and saccades of eye tracking protocol in a given time-window. This used an algorithm based on the *Dispersion-Threshold Identification* method, which determines saccades from the degree of dispersion of X and Y positions of recorded gaze data (Salvucci, 2000).

3. Results

3.1. Preliminary analyses

All tests were 2-tailed; significance was set at $p <$ .05.Initial analyses were conducted to determine whether there was any left–right or position asymmetry in any of the eye tracking measures. No differences were found for the fixation or antisaccade task data, therefore response side and position were

not included as a variable in subsequent analyses. Means and standard deviations for neuropsychological and eye tracking measures are shown in Table 2.

Table 2.
Mean and standard deviation of neuropsychological and eye tracking variables

Variable	Mean (*SD*)
WDW	10.53 (3.78)
KTlog	0.37 (0.29)
TOLlog	0.27 (0.26)
Correct fixation	35.51 (20.78)
Fixation directionnal error	4.42 (5.21)
Fixation uncorrected error	13.40 (11.28)
Self-corrected fixation	46.67 (18.64)
Correct Antisaccade	33.41 (16.65)
Antisaccade uncorrected error	16.36 (11.78)
Self-corrected antisaccade	50.22 (14.92)
Antisaccade latency (MS)	435 (105)

3.2. Correlation of inhibition measures and age
The first aim of this study was to investigate how inhibition develops between 5 and 8 years of age. To **assess potential changes, Pearson's correlations with** age were calculated for each variable.

Table 3.
Neuropsychological tests variable correlations with age.

Variable (%)	Age	
	r	*p*
WDW	.496	.001
KTlog	.089	.555
TOLlog	-.255	.087

3.2.1. Neuropsychological tests. Table 3 displays correlations of performance on the three tests with age. Performances of older children were better at WDW than younger children. As mentioned earlier, KT and ToL, data were examined after log transformation, which was performed to correct for lack of normal distribution in both variables for all age groups. Neither tests showed statistically significant sensitivity to development, and therefore were not used for further analysis of convergence between neuropsychological tests and eye tracking tasks.

3.2.2. Eye tracking tasks. Table 4 displays correlations with age of performance on both tasks. This research being of an exploratory nature,

significance level was primarily set at $p < .05$ and then Bonferroni correction for multiple comparisons was applied at $p < .0125$. With regards to the reaction time measure, older children have shorter latencies when initiating antisaccades successfully.

The eye tracking variables that correlated significantly with age were percentage of correct fixations, percentage of uncorrected errors on fixation task, percentage of correct antisaccades, and percentage of uncorrected errors on the antisaccade task. This shows older children made more correct responses on both tasks, and when an error was made, older participants were more prone to correct it immediately.

3.3.   *Convergence between neuropsychological and eye tracking tests*
The second aim was to evaluate how inhibition performances evolve with age on both types of measures. To investigate if accuracy data of inhibition measures from fixation and antisaccade tasks were related to inhibition measured by WDW, correlations were calculated and results are shown in Table 4.

The variables that correlated significantly with WDW score were *percentage of fixation directional error* and *percentage of self-corrected fixations*. Since WDW score was related to age as well, first-order partial correlations controlling for the effect of age were conducted to identify the sole influence of inhibition measured by the neuropsychological test.

Percentage of fixation directional error correlation remained significant, indicating that age had a minimal impact on that relationship. This suggests that children who performed better on WDW were also those who made saccades to the opposite side of the screen relative to where the target appeared, even though it was not part of this task's instructions. Once age was partialed out, percentage of self-corrected fixations was no longer significantly correlated to WDW, indicating that the correlation between measures was better explained by age related changes.

Table 4.
Saccade variable correlations with age and WDW score.

Variable (%)	Age	WDW	WDW age partialled out
Correct fixation	.381 **	.138	-.063
Fixation directionnal error	.087	.387 **	.397 **
Fixation uncorrected error	-.368 **	.084	.330 *
Self-corrected fixation	-.225	-.313 *	-.238
Correct Antisaccade	.374 **	.244	.071
Antisaccade uncorrected error	-.469 **	-.181	.073
Self-corrected antisaccade	-.038	-.129	-.124
Correct antisaccade latency	-.306 *	-.032	.148

$^*p < .05;$ $^{**} p < .0125$

Correlation with age also showed percentage of uncorrected errors at fixation task to significantly decrease with age, indicating that when oldest participants in the study committed inhibition mistakes on the antisaccade task, they were significantly more prone to correct them instantly. A relationship appeared when age was partialed out of the equation: correlation between this type of error and WDW becomes significant, indicating that those who perform better on the neuropsychological test also commit fewer mistakes on the eye tracking task.

3.4. *Eye tracking tasks difference*

The third aim was to evaluate if the fixation task is better to assess inhibition relative to conventional antisaccade tasks. To assess if participants performed better on the fixation task than on the antisaccade task, a one-way analysis of covariance (ANCOVA) was conducted with Task (fixation vs. antisaccade) entered as a within-participant independent variable and Age as a continuous covariable. Neither the main effect of Task nor the interaction between Task and Age reached statistical significance (respectively, $F_{(1, 44)} = .263$, $p = .611$, and $F_{(1, 44)} = .392$, $p = .535$).

4. Discussion

To better understand development, it is important to use a wide array of evaluation tools (Karmiloff-Smith, 2010). The present study evaluated inhibition, using neuropsychological tests and eye tracking tasks. The first aim of this study was to investigate inhibition development in a sample of children aged five to eight years, an age group seldom studied for they usually perform poorly on eye tracking tasks. Correlations with age demonstrated that children's performance on WDW improved with age, as it had been demonstrated previously (Manly et al., 2001), but other neuropsychological tasks failed to point out statistically significant inhibition development.

Kramer, Gonzalez de Sather and Cassavaugh (2005) evaluated a sample of 8 to 25-year-olds and concluded that mean antisaccade latencies accelerated between the ages of 8 and 16 due to the maturation of the brain's visual pathways. Latencies' relationship with age measured in the present study shows how this acceleration has already begun in younger children.

Participants' ability to inhibit reflexive saccades increased with age on both eye tracking tasks. This improvement of performance was in line with results from Luna, Velanova, and Geier (2008), who reviewed literature on the subject and found that performances on antisaccade tasks increased until 18 years of age.

When the oldest participants in the present study committed inhibition mistakes on the antisaccade

task, they were significantly more prone to correct them instantly, a behaviour usually interpreted as remembering instructions despite being unable to inhibit responses (Karatekin, 2008). This might indicate that youngest participants performed poorly because they forgot instructions more often than older ones.

The second aim of this research was to investigate if inhibition measured by two eye tracking tasks used in neuroscience research was related to inhibition measured by neuropsychological tests commonly used by clinicians. Results showed that participants who performed better on some neuropsychological measures also committed fewer mistakes on the eye tracking tasks. This finding could be explained by the fact that some participants were better at controlling the mistakes they made, and that this ability was idiosyncratic characteristics of cognitive control. This may be consistent with Miyake and Friedman's (2012) recent findings with twins. They suggested that genes might contribute to the variability of inhibition more than they contribute to the variability of shifting and updating. Nevertheless, they stated that with proper training, all three functions can be trained.

Every participant in the present study completed the eye tracking tasks in the same sequence, so none of them had practiced antisaccades before the fixation task. Therefore, it was unexpected that participants with the highest level of inhibition used a better strategy, namely looking in the opposite direction of the target even when it was not part of the instructions. This appears to be a strategy they developed, most likely "accidentally", to better perform on this task.

The third aim of this study was to evaluate if children under eight years of age performed better on a fixation task than on an antisaccade task, since the former task was an inhibition task with simpler instructions than the latter. Overall, both tasks assessed inhibition in a similar way, with participants performing at the same level as previous studies had found (Everling & Fischer, 1998). Participants did not perform better on a task designed to be simpler, showing that inhibiting prepotent responses was probably the greatest difficulty of these tasks, not remembering the instructions.

It is customary for developmental research to use samples with an age range of 10 years or more (Kramer et al, 2005; Friedman et al., 2011). Therefore, one of the possible explanations of our moderate results might be the smallness of our sample, and the youth and narrow age range of our participants. A greater sample would have enabled a Principal Component Analysis to be performed, which would have allowed to measure if eye tracking and neuropsychological test variables loaded on same factors or not. This is a potentially promising avenue for future research.

Overall, only a limited number of eye tracking variables were moderately related with the neuropsychological measures. As Kaplan (1988) noted, neuropsychological tests often tap more than a single cognitive ability, therefore care must be taken before conclusions are drawn from performance on one single test. This might very well be the case of the present study. Two of the neuropsychological tests used displayed important ceiling effect and lacked sensitivity to participants' development. A third test used (WDW) was designed to assess inhibition, but it also required working memory and sustained attention (Manly et al., 2001), and this might have affected performance.

Other studies have had findings that displayed lack of correlation between tasks designed to assess inhibition as well. Huizinga, Dolan and van der Molen (2006), using three neuropsychological tests, one involving reading (Stroop), one demanding motor responses (Stop-signal), and one presented on computer screen (Flanker task), also obtained results showing tasks performances were unrelated. The scarceness of links between neuropsychological and eye tracking measures leads us to agree with Nigg (2000), who suggested that motor and oculomotor inhibition were not the same ability. Friedman and Miyake (2004) also suggested that researchers used the term «inhibition» too loosely, and that they needed to be more specific when using the term and when evaluating the ability.

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