DEVELOPMENTAL PATTERNS OF RELATIONSHIPS BETWEEN INHIBITORY CONTROL AND READING SKILL IN EARLY-SCHOOL CHILDREN

ANNA KAMZA

Institute of Psychology, Adam Mickiewicz University, Poznań, Poland

Abstract
Inhibitory control is one of the most important components of executive functions, which allows to suppress or regulate prepotent attentional or behavioral responses. It was proved to be a crucial factor for school achievement, including math abilities and reading acquisition. In the present cross-sectional study Ober's assumptions about the developmental patterns of relationships between inhibitory control and reading skill were examined. The sample consisted of 256 grade 1-3 primary school children. Decoding and comprehension, the two subcomponents of reading skill, were assessed using Prolexia Test, while cognitive inhibitory control was measured with the Color Word Stroop Task. Simple correlation analyses showed that comprehension ability was related to inhibitory control but only among boys from 1st and 2nd grades (but not among 3rd graders), and no relations between reading subcomponents and inhibitory control were found among girls. However, hierarchical regression analyses controlling for other reading subcomponent did not yield a significant effect of interaction. Instead, it was found that inhibitory control was related to reading only in the 1st graders. Also, some gender differences between 1st and 2nd graders in their reading ability were observed. Those findings suggest that although gender plays a significant role in reading skill development of early school children, it does not moderate the developmental links between inhibitory control and reading skill.

Keywords: comprehension, decoding, early school age, inhibitory control, reading skill.

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Corresponding author: Adam Mickiewicz University, Institute of Psychology, ul. Szamarzewskiego 89/AB, 60-568 Poznań, Poland, e-mail: anna.kamza@amu.edu.pl.

1. INTRODUCTION

Effective attention control, especially inhibitory control, seems to be the prerequisite of reading ability, both at the start of reading acquisition, and at the mastering that competence. It's involvement at the level of decoding makes it possible to capture differences and similarities in the shapes of letters, size and location of the graphic characters and phonemic relations. In turn, at the level of comprehension it facilitates not only understanding the literal meaning of text, but also assimilation and accommodation of the new knowledge to already existing structures. In the present paper, the role of one important aspect of executive functions, inhibitory control, in early-school reading acquisition is discussed, both theoretically and empirically. Also the results of an own study verifying Ober's conception assumptions (Ober & Ober-Łopatka, 1998; Ober, Dylak, Łopatka, Czarnecki, Balcer, Nowak, & Herczyński, 2006) about the developmental pattern involving the release of inhibitory control from decoding to comprehension between the 1st and the 3rd graders are presented and discussed.

1.1 Reading competence

The vast majority of authors who study reading skill agree about the fact that it is a complex competence requiring the coordination of many cognitive processes (Conners, 2009). Moreover, in the last 30 years much effort was done to decompose reading competence. Phonemic awareness, spelling competence, grammar, working memory, phonological decoding or understanding are just some of the those broadly described in the literature (e.g., Borowsky & Besner, 2006; Hoover & Gough, 1990; Perfetti, 2001; Vellutino, Tunmer, Jaccard, & Chen, 2007). Such a large number of factors creates methodological difficulties, therefore in recent years a new trend in the research field has emerged. Namely, researchers have started to strive to characterize the reading process by using as simple and predictive concepts as possible (Conners, 2009).

One of the most fruitful conceptions complying with those requirements is the Simple View of Reading (SVR) that was created in the 1980's by Gough and Tunmer (1986). According to SVR, reading skill (R) results from two core processes: (1) reader's accuracy in decoding words (D) and (2) comprehension (C). Due to Hoover and Gough (1990, p. 130), decoding can be defined as *the ability to rapidly derive a representation from printed input that allows access to the appropriate entry in the mental lexicon, and thus, retrieval of semantic information at the word level.* In a beginning reader, the lexical access goes via phonological codes. However this way may not concern skilled readers, who may have a more direct grapheme-based route. In turn, comprehension is defined as *the ability to take the lexical information (e.g., semantic information at the word level) and derive sentence and discourse interpretations* (Hoover and Gough, 1990, p. 131), whereby the authors note that reading comprehension involves the same ability that language comprehension does, but relies on visual information. The SVR does not deny that reading is a complex process. However, it states that this complex process can be divided into the two aforementioned subcomponents, each of equal importance. Decoding and comprehension can be double dissociated as the phenomena of dyslexia and hyperlexia demonstrate (Joshi, Padakannaya, & Nishanimath, 2010; Ober & Ober-Łopatka, 1998), however, as Hoover and Gough (1990) claim, in ordinary readers this will not be the case, and both components will be associated in a more straight fashion. Indeed, the authors summarize the results of existing studies on normal reading as follows: In the early school grades, decoding and linguistic comprehension are unrelated, but in the latter grades the strength of that relationship increases. However, it is worth mentioning that other studies report decoding and comprehension to be substantially correlated also in the early school years (e.g., Conners & Olson, 1990). Also a meta-analysis of Ripoll-Salceda, Alonso, and Castilla-Earls (2014) showed that decoding and comprehension are moderately correlated through primary school grades, and that they both are highly correlated with overall reading ability and explain 50% of its variance. Despite some disagreement about the formula of their joint impact on reading skill, researchers have shown that both additive (R = D + C) and multiplicative (R = D x C) models of the SVR account for approximately 40–80% of the variance in reading comprehension (Hoover & Gough, 1990; Keenan, Betjemann, Wadsworth, DeFries, & Olson, 2006; Vellutino et al., 2007).

One of the most interesting findings about reading is that there are some gender differences in reading acquisition efficacy. According to Sochacka (2004), data from many countries show that girls achieve significantly higher scores in reading tests than boys. Similar conclusions are also provided by Rutter and colleagues (Rutter, Caspi, Fergusson, Horwood, Goodman, Maughan, & Carroll, 2004). There are different explanations of those differences in the literature. Some authors, accounting for methodological factors, claim that some evidence suggests that more boys score in the tail of the distribution, and hence they are consequently identified as poor readers (Flannery, Liederman, Daly, & Schultz, 2000). Others maintain that boys demonstrate greater variability in scores or perceive the cause of boys' backwardness in teachers' stereotypic attitudes (Retelsdorf, Schwartz, & Asbrock, 2015). However, this area of research has focused on reading generally; little research has been conducted on boys' variability in specific aspects of reading. Meanwhile boys might demonstrate greater variability in scores in specific facets of reading and related skills (Limbrick, Wheldall, & Madelaine, 2012).

1.2 Attention control as coordinating mechanism in reading competence

Processes involved in decoding and comprehension must be coordinated by some mechanism in order to get coordinated properly (see Conners, 2009). Many authors suggest that it is attention control that serves as such a coordinating contrivance (e.g., Conners, 2009; Facoetti, Zorzi, Cestnick, Lorusso, Molteni, Paganoni, &

Mascetti, 2006; Walczyk, 1989 & 2000; Walczyk, Marsiglia, Johns, & Bryan, 2004). According to Facoetti (2006; in: Marzocchi, Ornaghi, & Barboglio, 2009, p. 568), reading involves such attentional controlling processes as: orienting along the lines of text relative to the area of the visual field; controlling of saccades to enable focus on consecutive graphemes; inhibiting the premature processing of contiguous graphemes; maintaining attention for a sufficient time on a specific grapheme to ensure optimal processing (decoding); or transferring the focus to the other parts of the text.

Similarly, Walczyk in his Compensatory-Encoding Model of Reading (Walczyk, 2000; Walczyk et al., 2004) emphasizes the role of attention control, especially in the aspect of inhibition, in reading skill acquisition. Namely, he argues that reading involves monitoring, which can interrupt the process when there is a problem, and initiate an alternate, compensatory one, such as pausing, looking back, and rereading. For example, if a meaning of the word was incorrectly inferred and it does not fit into the broader context, it can be suppressed and replaced by another, more appropriate one. In turn, if the word was mistakenly decoded, further processing must be halted for re-decoding with a greater involvement of attention resources.

Moreover, Conners (2009) postulates attention mechanisms to be even the additional, third factor in the SVR. In her empirical study, she found that attention control contributes significantly to the growth of reading skill variance, and that it serves as a better predictor than IQ, articulation speed, phonemic awareness and verbal short-term memory. Further evidence comes from studies on reading disorders. For instance, in Willicutt's and Pennington's study (2000) some coexistence of attention deficits and reading difficulties was found. Van der Shoot, Licht, Horsley, and Sergeant (2000) found also that 9–12 years-old dyslexics were generally worse at response inhibition than controls and that dyslexic guessers' reading style was explained by failure to suppress inappropriate reading responses and not by a tendency to overuse the context (see also Conners, 2009). Finally, Bednarek and colleagues (Bednarek, Saldaña, Quintero-Gallego, García, Grabowska, & Gómez, 2004) observed that difficulties in reading acquisition were associated with low executive attention parameters, especially in girls with dyslexia.

Many authors suggest that children's ability to concentrate on task-relevant stimuli and ignore extraneous information improves with age, and by early adolescence children are able to modify their approach upon realizing the strategy that maximizes their performance (e.g. Hagen & Hale, 1973).

Inhibitory control as an executive function. Inhibitory control, sometimes called attentional inhibition, or in brief inhibition, is considered to be one of the most important attention mechanisms (Howard, Johnson, & Pascual-Leone, 2014). Therefore, besides working memory and cognitive flexibility, it is also an important component of the set of higher order cognitive processes involved in the conscious control of thought and action, which are usually called executive functions (e.g., Carlson & Moses, 2001; Zelazo & Müller, 2002).

Inhibitory control is defined as the ability to suppress previously activated cognitions and inappropriate actions and to resist to interference from irrelevant stimuli (Bjorklund & Harnishfegar, 1995; Zelazo & Muller, 2011). In other words, it enables maintaining the focus on relevant stimuli in the presence of distractors, and it is essential in everyday functioning, especially in such domains as learning, emotion regulation or social competence (Blair & Razza, 2007; Zhou, Chen, & Main, 2012). Inhibitory control is thought to be the primary executive function preceding the development of other executive functions (Altemeier, Abbott, & Berninger, 2008; Jabłonski, 2013). It is established that this cognitive function emerges very early in the life, even at the age of 2 (eg. Diamond, 2002), develops rapidly in preschool years, and that its growth extends through late childhood and adolescence up even to the early adulthood (Jonkman, Lansbergen & Stauder, 2003).

Recent studies show that inhibitory control is regulated by the frontal lobes (e.g., Otero & Barker, 2014), has strong genetic underpinnings, and its heredity amounts to 38-51% (Gagne & Saudiono, 2010). Like in the case of reading, it was also found that gender plays an important role in individual differences in inhibitory control. Certainly, girls outperform boys in many of inhibitory control tasks (e.g., Naglieri & Rojahn, 2001; MacDonald, Beauchamp, Crigan, & Anderson, 2014; Moilanen, Shaw, Dishion, Gardnem, & Wilson, 2010; Samuels, & Turnure, 1974). There are several possible explanations for those trends. For instance, authors refer to different patterns of glucoze metabolism in different areas of the brain among men and women, to some differences in the volume of the frontal and temporal areas of the brain among both genderes, or to the potential impact of testosterone on the rate of maturation of prefrontal regions (Overman, 2004). Another account refers to sociocultural determinants such as differences in socialisation of boys and girls (Overman, 2004).

1.3. Developmental patterns of the relations between inhibitory control and reading competence

Inhibitory control is considered to be one of the key components of school readiness and school achievement (McClelland & Cameron, 2011; Molfese, Molfese, Molfese, Rudasill, Armstrong, & Starkey, 2010) and it was proved to be a good predictor of efficacy in reading and writing acquisition (Altemeier, Abbott, & Berninger, 2008; Schmid, Labuhn, & Hasselhorn, 2011). Some authors suggest that the importance of inhibitory control varies depending on the stage of reading and writing ability development (Christopher, Miyake, Keenan, Pennington, DeFries, Wadsworth, Willcutt, & Olson, 2012; see also: Jabłoński, 2013). For instance, Jabłoński (2013) found that in preschool children one of the earlier stages of written speech development (i.e. the naïve stage of written speech development, characterized by relatively poorly development of skills such as picture-print discrimination, drawing-writing discrimination and visual recognizing names of objects presented on pictures—see: Jabłoński, 2002,2003) is associated with a lower level of inhibitory control, and one of the later stages (i.e. the outer stage, with relatively good developed skills associated with writing such as object names writing and words copying)—with a higher level of it (please note that Jabłoński studied aspects other than decoding or comprehension because of the children's age).

In general, in the context of decoding, attention dysfunctions may result in confounding letters and words, skipping them, transposing their order, and even changing the direction of reading. In the context of comprehension, attention difficulties result in loose of mental set and wandering thoughts. During reading, attention executive processes involve both the coordination of automatic and controlled processes.

According to Ober and co-workers (Ober & Ober-Łopatka, 1998; Ober, Dylak, Łopatka, Czarnecki, Balcer, Nowak, & Herczyński, 2006) there is a normative, developmental change involving the release of attentional (executive) resources from decoding to comprehension subprocesses. If it does not occur, some obstacles emerge in the development of reading ability. More precisely, Ober and colleagues distinguish three stages of reading acquisition. During the first one, called '*prototyping'*, decoding employs all of the available executive attention resources. Here, the purpose of attention and inhibitory control is supervising the differentiation of similar looking letters and recalling the corresponding phonemes, and—in case of errors—suppression of incorrect associations in grapheme-phoneme relationships. The most characteristic feature of the second stage, called by Ober '*improvement'* or '*the crisis of the 2nd and 3rd grade'* is allotting attention resources between both decoding and comprehension of the text. Such simultaneous engagement of cognitive resources causes that none of these reading subprocesses can be performed successfully. In case of a successful solution of that developmental crisis, attentional resources are released from decoding, which enables the development of understanding. In the last step, called '*mature reading',* decoding is automated, whereas executive attention resources are involved in comprehension of the text and referencing its meaning to the existing knowledge system.

To my knowledge, despite the conceptual elegance of Ober's conception, no empirical verification of it in the context of inhibitory control has been made. Hence, no study has investigated developmental patterns of relationship between inhibitory control and the two core components of reading skill (decoding and comprehension) in early school children yet. Also, despite the proven existence of some gender differences both in reading ability and in inhibitory control, no gender differences in relations between inhibitory control and reading subcomponents have been explored.

2. RESEARCH

The main aim of the present study was to broaden the existing knowledge about the developmental patterns of relationships between inhibitory control and reading skill by answering the following research questions: (1) Are there age differences in the patterns of relationships between inhibitory control and decoding and comprehension? (2) Are there gender differences in those patterns?

First, in line with Ober's conception (Ober & Ober-Łopatka, 1998; Ober et al., 2006), it was expected that in the first-graders inhibitory control would be strongly associated only with decoding, whereas in the second-graders inhibitory control would be associated both with decoding and comprehension, and in the third-graders, inhibitory control would correlate only with comprehension ability (and no longer with decoding).

2.1. Participants and procedure

The sample consisted of 256 grade 1-3 primary school children, of which 33% were first-graders, 31% were second graders and 36% were third graders. The children were between the ages of 7;0 and 9;11 (*M* = 101.63 months, *SD* = 10.83 months). There were 133 (52%) girls and 123 boys in the sample. The parents' educational status was quite homogenous. Among mothers, 86% of them had a master's level or a professional degree, 10% had a high school diploma, and 4% had some vocational education, and among fathers, 78% of them had a master's level or a professional degree, 5% had a high school diploma, and 7% had some vocational education.

The analyses presented here pertain to the part of the data obtained in research carried out at the end of the 2008/2009 school year, in May and June 2009. Recruitment to the study was conducted in several primary schools in Poznań and was based on voluntary submissions. All of the subjects had received parental permissions to participate and were informed about the study's purpose. Verbal consent was also gathered from students. The children were tested individually in a quiet room by a specially trained female experimenter in one 45-minute session. All instructions were read aloud by the experimenter while children read along and answered all the questions during the testing sessions. Children with any reading disabilities were excluded from the study.

2.2. Measures

During the session, the participants were first asked to complete the Color-Word Stroop Task and then the Prolexia Test.

The **Prolexia Test** (Ober & Ober-Łopatka 1998; Ober, Dylak, Łopatka, Czarnecki, Balcer, Nowak, & Herczyński, 2006) was used to measure phonological decoding and comprehension which substantially correspond to the two subcomponents of reading skill in the Simple View of reading. As such, the task consists of two subtests: (1) word-chain test and (2) sentence-chain test. The former one measures phonologic decoding ability and includes three trials consisting of 44 chain-words each. Each of them consists of 11 letters, which can be separated so that the resulting two words range in their size from 3 to 8 letters. A child is given 1 minute time limit for each trial. The dependent variable in that subtest is the number of correctly extracted words in the second trial.

In turn, the sentence-chain test assesses comprehension ability and consists of two trials. In each of them, 31 sentences begin with a lowercase letter and do not end with a period (however, the uppercase is preserved in the proper names). A child is to extract sentences by putting the marks at the right places. The time is also limited here; a child receives three minutes per trial. The dependent variable is the number of correctly extracted sentences in the second trial. Thus, the theoretical range for decoding is 0-44, and for the comprehension 0-31 points.

It should be noted that the Prolexia Test is still at the experimental stage, due to the fact that the works on its standardization and the assessment of accuracy and reliability are still in progress (see, e.g., Nowotnik, 2012). Although it is not a popular, typical test of reading in Poland, it was used in order to verify Ober's conceptional assumptions. In the present study, both the word-chain and the sentence-chain tests were proved to have high internal consistency among 1-3 graders (Cronbach's alpha varied between .91-.93 for the word-chain test and .90-.94 for the sentence-chain test). Both subtests were also quite strongly correlated witch each other (r = .60).

The **Color-Word Stroop Task for children** by Golden, Golden and Freshwater (2003) was used to assess inhibitory control (Stroop, 1935). The measure consists of three pages. The first one (called *the color-names*) includes three color names (*'blue', 'green', 'red'*) printed in black ink in five columns and twenty rows; the second one includes sharps ('XXX') printed in color, and the third one (called *the color-words*) includes words from the first page printed in colors from the second page (the color and the word do not match). The child's task is to go down each sheet reading words (the first page) or naming the ink colors (the second and the third page) as quickly as possible within a 45 seconds time limit. The test yields three scores based on the number of items completed on each of the three stimulus sheets. A derived variable is the difference between the color-names and color–words scores. A lower score means less interference from incongruent words when naming the colors in the color–word condition, and thus higher inhibitory control ability. In order to ease the interpretation of the data, the interference score of each child was multiplied by (-1), so high scores indicated high inhibitory control.

The satisfactory reliability of the Color-Word Stroop Task was proved in many studies with children—Cronbach's alphas were above .75 (e.g. McLeod, 1991). Also in the present study the measure was proved to have quite satisfactory internal consistency among 1-3 graders (Cronbach's alpha varied between .70-.77). Graf and colleagues (1995) found also that high correlation coefficients were obtained between the results of the Stroop Task and processing accuracy and planning capacity factors in the WAIS-R.

3. RESULTS

First, descriptive statistics for all of child's measures were calculated separately for each grade. To investigate associations between reading skill and inhibitory control, zero-order correlations for those measures were computed. Next, a series of separate hierarchical regression analyses for each grade were run to determine whether the expected associations were present after controlling for child's gender and the other subcomponent of reading skill. Results of the preliminary analyses showed no significant correlations between child's variables and the educational status of parents, hence the latter one was excluded from further analyses.

Table 1 shows the descriptive statistics for child's age and grade and the scores achieved on the Color-Word Stroop Task and Prolexia Test.

Table 1.Descriptive statistics (N = 256)

Measure	1st graders (n = 85)		2nd graders (n = 79)		3rd graders (n = 92)	
	M (SD)	Range	*M (SD)*	Range	*M (SD)*	Range
Prolexia (1) - decoding	8.65 (4.79)	0-25	14.35 (7.13)	1-32	19.68 (9.50)	5-44
Prolexia (2) - comprehension	8.75 (6.83)	0-27	17.15 (9.93)	0-31	20.57 (9.65)	0-31
Stroop Task - inhibitory control	16.13 (8.73)	-4-33	19.18 (8.59)	-8-41	20.96 (7.99)	-4-35

Girls (M = 102.27, SD = 11.07) and boys (M = 100.95, SD = 10.57) did not differ significantly on age; $t(154) = 0.975$, $p = 0.330$, $d = .12$.

3.1. Inhibitory control and reading skill in relation to child's age, grade and gender – preliminary analyses

First, the relations between inhibitory control, decoding, comprehension and child's grade and gender were examined. For this purpose Pearson's, Spearman's (for child's grade) and binominal (for child's gender) correlations coefficients were calculated (see Table 2). Moderate positive correlations between the two reading components and child's grade were found.

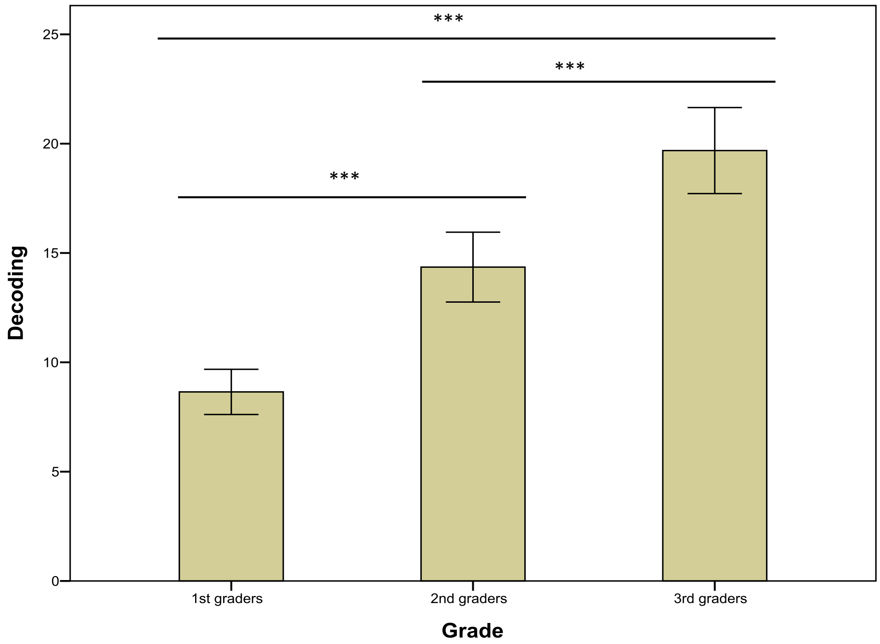
Table 2. Bivariate correlations between two components of reading skill, inhibitory control and child's age, sex and grade in the whole sample (N = 256)

	1	2	3	4	5	6
1. Decoding	-	.60**	.17**	.50**	-.08	.56**
2. Comprehension	.60**	-	.24**	.41**	-.21**	.47**
3. Inhibitory control	.17**	.24**	-	.19**	-.09	.24**
4. Age	.50**	.41**	.19**	-	-.06	.85**
5. Sex	-.08	-.21**	-.09	-.06	-	-.03
6. Grade	.56**	.47**	.24**	.85**	-.03	-

*$p < .05$ **$p < .01$ (all tests two-tailed).

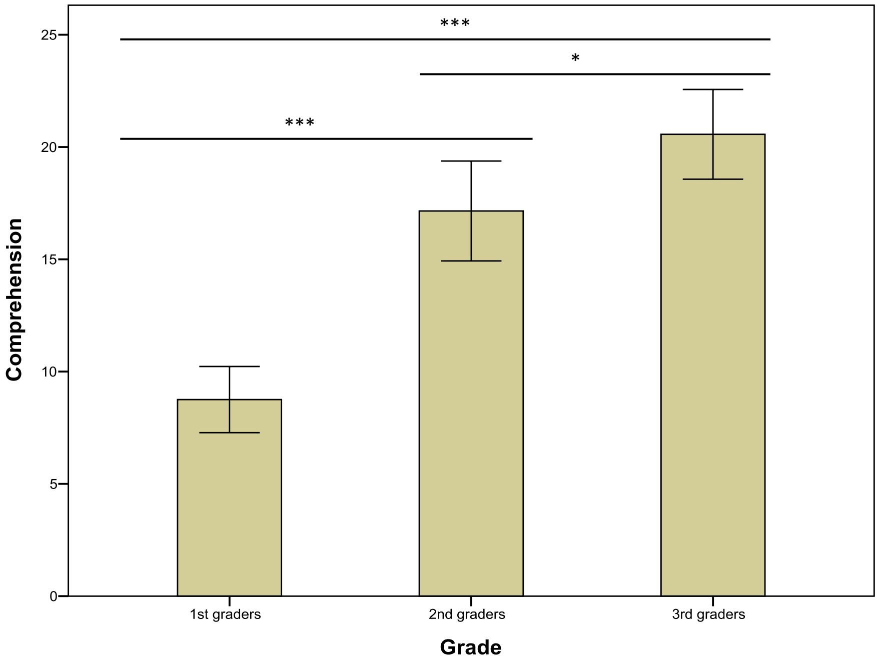
In further two-way ANOVA analyses, a main effect of grade on both decoding (F(2, 253) = 48.27 $p < .001$, $\eta^2 = .28$) and comprehension (F(2, 253) = 40.57, $p < .001$, $\eta^2 = .25$) was found. Bonferroni post-hoc comparisons showed that third-graders had better scores on decoding (M = 19.68, SD = 9.50) and comprehension (M = 20.57, SD = 9.65, $p < .001$) than second-graders (M = 14.35, SD = 7.13, $p < .001$ for decoding; M = 17.15, SD = 9.93, p = .039 for comprehension), and first-graders (M = 8.65, SD = 4.79, $p < .001$ for decoding, and M = 8.75, SD = 6.83, $p < .001$ for comprehension), and second-graders outperformed the first-graders ($p < .001$ for decoding; $p < .001$ for comprehension) (see Figure 1 and Figure 2.). No significant effect of gender for decoding was observed, F(1, 254) = 0.96, p = .33, $\eta^2 = .02$, but there was a significant interaction of grade and gender, F(2, 250) = 3.55, p = .03, $\eta^2 = .03$. Simple effects tests revealed that the advantage of girls over boys in decoding was significant only for third-graders, F(1, 250) = 3.86, p = .05. As far as comprehension is concerned, a significant effect of gender was found, F(1, 254) = 12.01, p = .001, $\eta^2 = .05$. Bonferroni post-hoc comparisons showed that girls (M = 17.32, SD = 9.53) outperformed boys (M = 13.54, SD = 10.48, $p < .001$; see Figure 3). However, no significant interaction effect of gender and grade for comprehension was found, F(2, 250) = 1.73, p = .18, $\eta^2 = .01$.

Figure 1. Effect of grade on decoding ability—Bonferroni post-hoc comparisons.



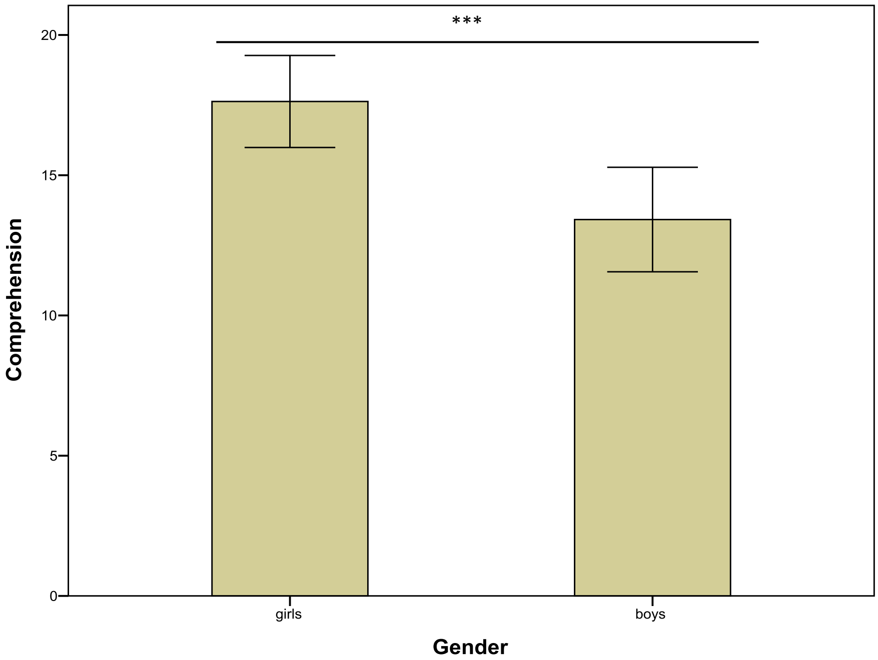
Note. Stars above the bars indicate significant post-hoc tests: ****p* < .001

Figure 2. Effect of grade on comprehension ability—Bonferroni post-hoc comparisons.



Note. Stars above the bars indicate significant post-hoc tests: *p < .05 and ***p < .001

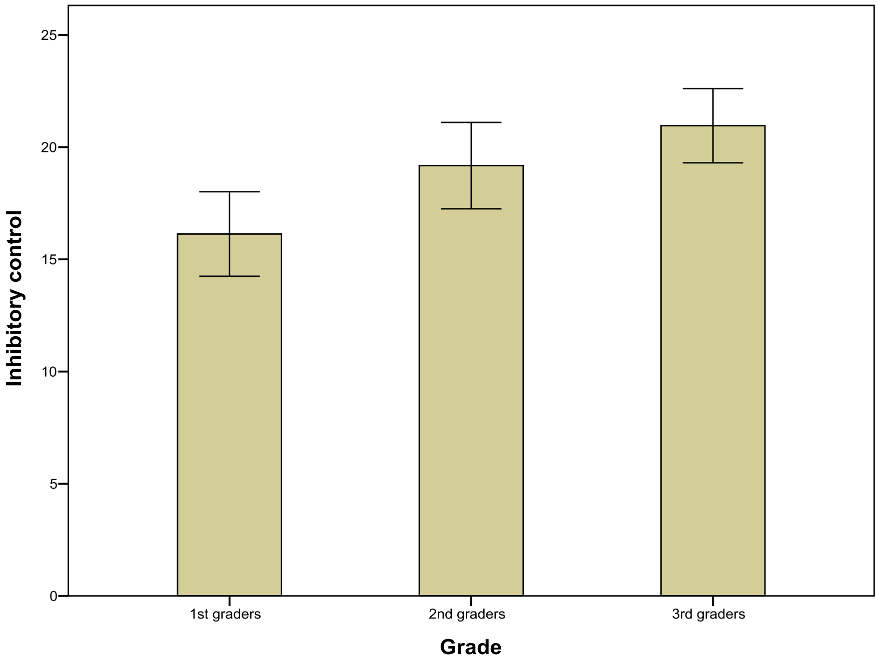
Figure 3. Effect of gender on comprehension ability—Bonferroni post-hoc comparisons.



Note. Stars above the bars indicate significant post-hoc tests: ****p* < .001

Furthermore, child's grade was weakly and positively related to inhibitory control. Additional analyses revealed only a main effect of grade, $F(2, 253) = 7.36$, $p = .001$, $\eta^2 = .05$. Bonferroni post-hoc comparisons showed that third-graders ($M = 20.96$, $SD = 7.99$, $p = .001$) and second-graders ($M = 19.18$, $SD = 9.93$, $p = .001$) outperformed the first-grades ($M = 16.13$, $SD = 8.73$) on the inhibitory control measure (see Figure 4). No significant effect of gender ($F(1, 250) = 2.10$, $p = .15$, $\eta^2 = .00$) nor an effect of grade and gender interaction ($F(2, 253) = 0.08$, $p = .92$, $\eta^2 = .00$) were observed.

Figure 4. Effect of grade on inhibitory control—Bonferroni post-hoc comparisons.



Note. Stars above the bars indicate significant post-hoc tests: ***$p < .001$

In the whole sample inhibitory control was weakly but positively correlated with both decoding and comprehension abilities. Decoding and comprehension were also positively and substantially correlated to each other, what is in line with findings of other studies (e.g., Conners & Olson, 1990; Vellutino et al., 2007).

3.2. Inhibitory control in relation to reading skill by grade and gender

In order to explore developmental patterns of relationships between inhibitory control and the two subcomponents of reading skill, Pearson correlations by grade and gender were calculated (see Table 3).

Table 3. Bivariate correlations between two components of reading skill and inhibitory control by grade and sex

	Inhibitory control						Comprehension					
	1st graders		2nd graders		3rd graders		1st graders		2nd graders		3rd graders	
	Girls (n=42)	Boys (n=43)	Girls (n=41)	Boys (n=38)	Girls (n=49)	Boys (n=43)	Girls (n=42)	Boys (n=43)	Girls (n=41)	Boys (n=38)	Girls (n=49)	Boys (n=43)
Dec.	-.16	.12	-.18	.26	.03	.13	.60**	.67**	.70**	.73**	.27	.18
Comp.	.24	.46**	-.08	.32*	-.03	.05	-	-	-	-	-	-

*$p < .05$, **$p < .01$. (all tests two-tailed).

It was found that inhibitory control was related to comprehension, but only among boys from the 1st and the 2nd grades (not among boys from the 3rd grade). No relation between comprehension and inhibitory control were found in girls. Also, no significant relation between decoding and inhibitory control was found in both genders in each grade. Decoding and comprehension were strongly and positively correlated both in boys and girls, but only among 1st and 2nd graders, what partially confirms the findings of Conners and Olson (1990) and Ripoll-Salceda et al. (2014) who found some positive correlations between those two variables among 1st to 3rd graders. On the other hand, it is contrary to the claims of Hoover and Gough (1990). In the third-graders there was no significant correlation between decoding and comprehension. Also, neither decoding nor comprehension were related to inhibitory control.

To determine the extent to which inhibitory control accounts for the 1st and 2nd graders' decoding or comprehension beyond the other component of reading ability (i.e. decoding—when comprehension was the dependent variable, or comprehension—when decoding was the dependent variable) and beyond gender, series of hierarchical linear regression analyses were conducted for the 1st- and the 2nd-graders separately (see Tables 4 and 5). Including decoding or comprehension as a covariate in the regression equation was motivated by the fact that both subcomponents of reading skill were correlated in 1st and 2nd graders. Apart from this, decoding can be seen as a precursor of comprehension, and it can be influenced by linguistic context as well.

Because the results of the correlation analysis suggest that child's gender and inhibitory control impact differently on the 1st and 2nd graders' comprehension ability (see Table 3), interaction terms were created as the products of standardized (z-transformed) versions of inhibitory control and dummy-coded gender variable (coding: *0* for girls and *1* for boys), and their effects were tested in those analyses. In each of the regression analysis, child's gender and one of the reading subcomponents (comprehension or decoding, accordingly to the dependent variable) as covariates was entered in the first step, inhibitory control as a predictor was entered in the second step and the interaction term of gender and inhibitory control was entered in the third step.

Table 4 shows the results of the regression analyses involving **decoding** as dependent variable. Among the *1st graders*, when the child's gender and comprehension were entered in the first step, they contributed significantly to the regression model, $F(2, 82) = 30.99$, $p < .001$, and accounted for 43% of the variation in decoding. Introducing inhibitory control in the second step explained an additional 5% of variation in decoding, and this change in R^2 was significant, $F(1, 81) = 7.78$, $p < .01$. In that step both comprehension (β = .74, $p < .001$) and inhibitory control (β = .24, $p < .01$) had their significant partial effects on decoding. Finally, the addition of the interaction term explained an additional 1% of the variation, but this change in R^2 was not significant, $F(1, 80) = 1.60$, $p = .21$. Together, the four independent variables accounted for 49% of the variance in decoding and the full model was significant, $F(4, 80) = 19.26$, $p < .001$.

Table 4. Hierarchical linear regression testing effects of inhibitory control on the child's decoding ability with sex as a moderator.

Step	Inc. R^2	F-change	*B*	β	t-value	sr^2
1st graders (n = 85)						
Step 1: covariates						
Child's sex	.43	30.99^{***}	-0.52	-.01	-0.11	-.00
Comprehension			0.13	.65	7.32^{***}	.37
Step 2: predictor Inhibitory control	.05	7.78^{**}	0.13	.24	2.79^{**}	-.05
Step 3: sex interaction Sex x inhibitory control	.01	1.60	0.98	.15	1.26	.01
2nd graders (n = 79)						
Step 1: covariates						
Child's sex	.52	41.69^{***}	-3.07	-.22	2.72^{**}	.05
Comprehension			0.50	.70	8.83^{***}	.49
Step 2: predictor Inhibitory control	.00	0.02	0.01	.01	0.14	-.00
Step 3: sex interaction Sex x inhibitory control	.01	0.91	1.12	.10	0.95	.00

Note: *Inc.* R^2: increment in variance accounted for; *B*: unstandarized regression coefficient; β: standardized regression coefficient; sr^2: squared semipartial correlation.
$^{+}p < .1$. $^{**}p < .01$, $^{***}p < .001$

In the *2nd graders,* when child's gender and comprehension were entered in the first step, they contributed significantly to the regression model, *F*(2, 76) = 41.69, *p* < .001, and accounted for 52% of the variation in decoding. After introducing inhibitory control in the second step, the change in R^2 was not significant, *F*(1, 75) = 0.02, *p* = .89. In that stage inhibitory control was not a significant predictor of decoding. However, both gender (β = -.22, *p* < .01) and comprehension (β = .70. *p* < .001) had their significant partial effects on decoding. The addition of the interaction term did not explain an additional variation, *F*(1, 74) = 0.91, *p* = .34. Together, the four independent variables accounted for 53% of the variance in decoding and the full model was significant, *F*(4, 74) = 20.78, *p* < .001.

Table 5. Hierarchical linear regression testing effects of inhibitory control on the child's comprehension ability with sex as a moderator

			1st graders (n= 85)			
Step	Inc. R^2	F-change	*B*	β	t-value	sr^2
Step 1: covariates						
Child's sex	$.47^{***}$	36.56^{***}	-2.83	-.21	-2.52^{*}	.04
Decoding			.86	.61	7.32^{***}	.34
Step 2: predictor						
Inhibitory control	$.10^{***}$	18.97^{***}	.25	.32	4.36^{***}	.10
Step 3: sex interaction						
Sex x inhibitory control	.00	0.27	-.53	-.06	-0.52	.00
			2nd graders (n = 79)			
Step	Inc. R^2	F-change	*B*	β	t-value	sr^2
Step 1: covariates						
Child's sex	$.51^{***}$	39.14^{***}	-3.53	-.18	-2.18^{*}	.03
Decoding			1.01	.72	8.83^{***}	
Step 2: predictor						
Inhibitory control	.00	0.66	.08	.07	.81	.00
Step 3: sex interaction						
Sex x inhibitory control	.00	0.47	1.15	.08	.69	.00

Note: Inc. R^2: increment in variance accounted for; *B*: unstandarized regression coefficient*;* β: standardized regression coefficient; sr^2: squared semipartial correlation.
$^{*}p < .05$, $^{***}p < .01$.

Table 5 shows the results of the regression analysis involving **comprehension** ability as dependent measure. Regarding *1st graders*, when the child's gender and decoding were entered in the first step, they contributed significantly to the regression model, *F*(2, 82) = 36.56, *p* < .001, and accounted for 47% of the variation in decoding. Introducing inhibitory control explained an additional 10% of variation in decoding and this change in R^2 was significant, *F*(1, 81) = 18.97, *p* < .001. When all three independent variables were included in the second step of the regression, child's gender (β = -.17. $p < .05$), decoding (β = .61. $p < .001$), and inhibitory control (β = .32. $p < .001$) had their significant partial effects on the comprehension. Adding the interaction term did not further explain the variation in decoding, $F(1, 80) = 0.26$, $p = .61$, and it was not a significant predictor of comprehension. Together, the four independent variables accounted for 57% of the variance in comprehension and the full model was significant, $F(4, 80) = 26.85$, $p < .001$.

Among *2nd graders* when the child's gender and decoding were entered in the first step, they contributed significantly to the regression model, $F(2, 82) = 36.56$, $p < .001$, and accounted for 51% of the variation in comprehension. Introducing inhibitory control did not explain an additional variation in comprehension, $F(1, 75) = 0.66$, $p = .42$. In the second step, only child's gender (β = -.17, $p < .05$) and decoding (β = .72, $p < .001$) remained significant predictors of comprehension. Entering of the interaction term in the last step did not explain an additional variation, $F(1, 74)$ = 0.26,47, $p = .49$. Together, the four independent variables accounted for 51% of the variance in comprehension and the full model was significant, $F(4, 74) = 19.63$, $p < .001$.

4. DISCUSSION AND CONCLUSIONS

The purpose of this study was to examine the developmental patterns of relations between inhibitory control and reading skill (decoding and comprehension) in early-school boys and girls. It was also the first attempt to verify Ober's conception assumptions, which have not been empirically investigated thus far.

In general, it was expected that in the first-graders inhibitory control would be strongly associated only with decoding, whereas in the second-graders it would be associated both with decoding and comprehension, and in the third-graders only with comprehension ability (and no longer with decoding). The question about the role of gender in developmental relations between inhibitory control and reading ability was also tackled.

Correlation analyses by gender and grade showed that inhibitory control was related only to comprehension and only among 1st and 2nd grade boys. Hence, the interactive effect of gender and inhibitory control was tested in a series of hierarchical regression analyses, controlling for the remaining reading subcomponent. In these hierarchical regression analyses, in which each of the remaining reading subcomponent was also controlled, no significant interaction effect was found. Instead of that, the analyses revealed that inhibitory control was a significant predictor of both decoding and comprehension only in the 1st graders (among both boys and girls). Child's gender, on the other hand, independently predicted comprehension among 1st graders and both decoding and comprehension among the 2nd graders. In the 3rd graders, there were no significant links between inhibitory control, and neither decoding nor comprehension. Therefore, the results obtained did not support the main hypothesis about the developmental pattern involving the release of inhibitory control from decoding to comprehension between the 1st and the 3rd graders. Indeed, in the presented study, among the 1st-graders inhibitory control was already involved both in decoding and comprehension. However, in the higher grades it was linked neither to decoding nor to comprehension. Hence, our results did not support Ober's conception assumptions, and they are also opposed to those of longitudinal studies conducted by Altemeier, Abbott, and Berninger (2008), in which executive functions directly influenced reading over the *initial four* grades of elementary school in USA (see also: Jabłoński, 2013). Also, they are inconsistent with the results of De Jong' and Das-Smaal (1995), where attentional control correlated significantly with reading comprehension even in fourth-graders. Such a surprising outcome has at least three possible (and complementary) explanations. First, both decoding and comprehension involve automatic and effortful processes, and over the course of reading development, some of them that are primarily effortful become automatized. Therefore, detachment of inhibitory control from reading subcomponents in second- and third-graders may indicate a progressive process of reading automatization (Logan, 1997). Thus it would also suggest that Ober's conception assumptions need some revision. Secondly, perhaps the *Prolexia*, an experimental measure of reading ability, was not an appropriate method for Polish elementary school students. Indeed , this method is not a popular, typical test of reading in Poland, and it was used in our study due to the need of verification of Ober's conception. It is possible that another result would be obtained if a different, more sensitive and valid method assessing the reading skill were used. Thirdly, it might be other important cognitive factors that replace inhibitory control and contribute to reading skill in the later stages of its acquisition. Hence, further investigation should include not only other components of executive functions, such as working memory or set-shifting, but also other important factors such as for example reading motivation, working memory capacity, metacognition, reading strategies, language level, phonological awareness, vocabulary etc. These covariates might play an important role in the development of reading skill as they differ with age and sex and consequently can moderate the reading performance to a certain degree.

In our study an interesting pattern of relation between gender and the two reading subcomponents was also observed. Namely, in the first grade, girls and boys did not differ in terms of decoding, however girls outperformed boys in the comprehension. In turn, in the second grade, girls are better than boys both on decoding and comprehension. Eventually, in the third-grade, girls outperform boys again, but only in decoding. That pattern might suggest that there are processes involved in comprehension that push the development of reading ability forward. However, longitudinal studies are needed to verify this issue.

The presented study gives some insight into the patterns of relations between inhibitory control and reading ability in the light of simple models of reading. Apart from this, it confirmed the role of gender in reading skill development, what can be useful in terms of diagnosis and identification of at risk children, so it could provide a theoretical base for prevention and early intervention programs and counseling in the field of educational activities.

Notwithstanding, it should be strongly emphasized that the presented results do not allow one to infer about casual relationships between inhibitory control and reading ability in the process of development. This would require further studies in a combined cross-sectional and longitudinal research design, which would allow observing the development of reading skill along with inhibitory control.

The assessment issue is another case of concern. Some shortcomings of the *Prolexia Test* have been discussed in one of the previous paragraphs. Also the *Stroop Test* might be an inadequate measure for this study because it comprises decoding demands for the subjects. Thus, decoding skills are needed to read the words or to inhibit the word names in the incongruent condition of the task. The logic is the same for the word-chain-part of the *Prolexia Test*. This confounds the measures, and the shared variance diminishes the validity of the findings—it might be that no incremental variance explanation can be detected for inhibitory control in 2nd graders and above due to the suppression effects for the decoding ability measure used. A good alternative would be to resign from involvement of letter recognizing in the inhibitory control measure and to include measures of various types of inhibitory control itself (i.e. a simple and a complex one, a cognitive or a behavioral one, etc.).

Finally, our sample was quite homogenous in terms of parental educational status—86% of the mothers and 78% of the fathers were high educated, and therefore our findings are not generalizable to children from families of lower socioeconomic status. In future research it would be desirable to include more diverse samples. More informative results might be obtained if future studies would overcome all this issues.

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