Inhibition and behavioral self-regulation: An inextricably linked couple in preschool years

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1. Introduction

A day in a child's life is packed with situations that require inhibitory control. Raising the hand before speaking in class or taking turns when playing a game; all these situations involve the ability to suppress a prepotent or spontaneous action. Inhibitory control is defined as the ability to ignore irrelevant information while pursuing the represented goal (Carlson & Moses, 2001; Simpson & Riggs, 2007). Research focusing on individual differences show that inhibitory control develops rapidly in early childhood (Carlson, 2005; Hughes, 1998; Zelazo, Müller, Frye, & Marcovitch, 2003) and continues to develop throughout childhood (Romine & Reynolds, 2005). Despite extensive research on inhibition, the precise mechanisms involved in inhibitory control are not yet fully understood (Best & Miller, 2010; Cragg, 2016). Thus, experimental research on inhibitory control may add to a more comprehensive picture of how distraction can be successfully overcome.

Conflict tasks demand inhibitory control (Ambrosi, Lemaire, & Blaye, 2016; Cragg, 2016; Davidson, Amso, Anderson, & Diamond, 2006). In such tasks, participants are confronted with relevant stimuli but also with irrelevant stimuli. Typical conflict tasks are the Flanker task (Eriksen & Eriksen, 1974), the Simon task (Simon & Berbaum, 1988) or the Stroop task (e.g., MacLeod, 1991). The Flanker task and the Simon task have two particular advantages for examining inhibitory control: Firstly, the tasks are computerized and therefore quantify conflict effects precisely in terms of two different variables (reaction time and accuracy). Secondly, the two tasks do not require a verbal response and thus eliminate confounding language-based influences (Best & Miller, 2010; Mullane, Corkum, Klein, & McLaughlin, 2009).

Various research fields take interest in inhibitory control (Nigg, 2000). For example, research has shown that inhibitory control is critical for cognitive abilities such as attention and memory (Levy & Anderson, 2002; Posner & Rothbart, 2000). Further, it seems to play a key role in academic performance (e.g., Blair & Razza, 2007; St Clair-Thompson & Gathercole, 2006) and social competences (Carlson & Moses, 2001; Cragg, 2016). In addition, inhibitory control is intrinsically involved in self-regulatory skills such as behavioral regulation or emotion regulation (Calkins & Fox, 2002; Howse, Calkins, Anastopoulos, Keane, & Shelton, 2003; Williford, Vick Whittaker, Vitiello, & Downer, 2013). For example, an observational study revealed substantial interrelatedness between behavioral regulation and inhibition. Correlations between the behavioral regulation task, the Head Toe Knee Shoulder task (HTKS; McClelland et al., 2014) and two different conflict tasks (i.e., Simon task and Stroop task) ranged from (r = .29 -.44) in preschool to (r = .37-.50) in kindergarten. When considering the motor component in inhibitory processes (Nigg, 2000; Ridderinkhof, van der Molen, Band, & Bashore, 1997), the relation between inhibition and behavioral regulation seems obvious. And although the relation between inhibition and behavioral regulation is not being questioned, little is known about the quality of the relation. In other words, research is needed to examine *how* inhibition and behavioral regulation are related.

Despite mixed findings concerning inhibition development beyond the age of six (e.g., Klenberg, Korkman, & Lahti-Nuuttila, 2001; Lee, Bull, & Ho, 2013; Romine & Reynolds, 2005), there seems to be more evidence in favour of a continuous but less pronounced improvement during middle childhood (for a review see Best & Miller, 2010). One reason for these partially contradictive results is a methodical one: There are many different tasks to assess inhibition. And even for one type of inhibition such as inhibitory control there are a variety of tasks (e.g., Stroop task, Flanker task, Simon task). Generally, it is difficult to compare performance of various tasks. But it is even more difficult with regard to detecting developmental change. Because different tasks detect developmental change with varying sensitivity (Nigg, 2000). To overcome such methodological issues, Best and Miller (2010) call for a more systematic research approach to address developmental questions regarding inhibition. One of these questions concerns the processes involved in inhibition development

(Best & Miller, 2010) which could be addressed by means of within task manipulations. Such systematic within task manipulations are beneficial to analyze the relation between factors involved in inhibitory control (Garon, Bryson, & Smith, 2008).

Experimental research has mainly focused on the inhibitory process itself. For example, response-cueing studies have shown how cues interact with inhibitory processes. In such studies, brief cues precede the target stimuli. Results consistently show that reliable cues (i.e., only valid cues) decrease reaction times and/or increase accuracy whereas unreliable cues (i.e., valid cues and invalid cues mixed) increase reaction times and/or decrease accuracy (Adam, Hommel, & Umiltà, 2003; Wühr, 2006). Benefits for reliable cues and costs for unreliable cues are consistently found, for both adults and children (Olivier, Audiffren, & Ripoll, 1998; Wühr, 2006). Aside from other processes such as motor inhibition (Ridderinkhof et al., 1997) and attention (Rueda et al., 2004), unreliable cues demand inhibitory control. Because information provided by the cues cannot be relied on, subjects have to ignore the cues and inhibit the prepotent responses (Band, van der Molen, Overtoom, & Verbaten, 2000; Wühr, 2006). To sum up, while correlational research has shown (a) the importance of inhibitory skills for a child’s cognitive and social functioning and (b) revealed a high interrelatedness between behavioral regulation and inhibition, experimental research provides evidence how cue reliability affects inhibitory control. However, what remains less clear is to which extent factors such as age or behavioral regulation affect inhibitory control.

1.1 The current study

The aim of the present research was to gain a more comprehensive picture of the processes involved in inhibitory control. Therefore, we varied inhibitory control demands through within task manipulations. That is, visual cues as previously applied in cueing tasks (Adam et al., 2003; Wühr, 2006) were coupled with the flanker task. More precisely, before presenting the target stimulus, a visual cue appeared briefly in some of the trials. Cues triggered prepotent responses, which subjects had to inhibit. To increase inhibitory control demands, we used unreliable cues (with equal amounts of valid and invalid cues; Band et al., 2000; Rueda et al., 2004; Wühr, 2006).

To gain further insights on inhibitory control, we varied two factors, namely age and cue format. There were two age groups, preschool children and first graders. We expected that regardless of the cue format, younger participants' performance would be affected more severely by the cues than the performance of older children. Cue format was a between subject factor. That is, half of the participants received a salient cue, whereas the other half received a neutral cue. For both cue formats, we expected inhibitory control demands to increase and - as a result - performance to decrease. More specifically, we expected the additional demands to prolong response latencies and decrease accuracy performance. In addition, we aimed to explore if the salient cue would evoke stronger prepotent responses compared to the neutral cue. To sum up, in the present research, we combined an experimental design with an individual differences approach. By varying inhibitory control demands, we were not only able to examine performance difference across different conditions but also able to relate inhibitory control skills to individual differences in behavioral regulation.

2. Methods

2. 1. Participants

The sample (*N* = 125) consisted of 59 preschoolers (mean age: 5 years, 10 months, SD = 7.0) and 66 first graders, (mean age 7 years, 5 months, SD = 4.8). In both age groups, gender was approximately equally distributed with 47.5% females in the younger age group and 51.5% females in the older age group. The children were predominately Caucasian from middle-class families, reflecting the characteristics of the local community. Written consent from the children's parents as well as verbal consent from the child was obtained before testing. Five additional children had to be excluded due to missing data.

2. 2. Materials

2. 2. 1. Cued Flanker Task

We assessed inhibitory control with a modified version of the flanker task (Eriksen & Eriksen, 1974). The flanker task itself has a high re-test reliability (Intraclass correlations of .92; Bauer & Zelazo, 2014) The task was computerized (E-Prime Software, Psychology Software Tools, Pittsburgh, PA) and presented on a tablet (11.6’ screen). Two response buttons were placed in front of the child. Participants responded to the orientation of the centrally presented target (fish) by pressing the left or right response button. In congruent trials, the target and the distractors (also fish, two on each side of the target) were facing in the same direction; in incongruent trials, the target and the distractors were facing in opposite directions. A practice block followed the instruction. If the participant failed the practice criteria (at least four out of seven correct answers), the practice block was repeated (applied to 22.5 % of the sample). To vary inhibitory control demands the actual task contained two experimental blocks. The first block, the standard version of the flanker task (i.e., a random mix of congruent and incongruent trials) served as a baseline measure. For the second block, inhibitory demands were increased by embedding unreliable, visual cues. We did not inform the participants about the appearing cues, they were just asked to play the game once again. The order of the blocks was held constant.

The first block (baseline measure) consisted of 12 congruent and 12 incongruent trials. The target stimulus was presented for 3500 milliseconds (ms) or until the child responded. A fixation cross (100 ms) in the center of the screen separated the trials. The inter-stimulus interval varied between 800 and 1400 ms. At the end of the task, a positive feedback, i.e., an image of a big, laughing fish appeared. In the second block, a visual cue appeared before the target stimulus (see Figure 1). The cue appeared for 200 ms on the same vertical height as the subsequently appearing fish, either in the left or in the right field of the screen.

The cues were unreliable, reaching a validity of 50%. This meant, in half of the cued trials, the cue corresponded with the direction of the target stimulus and was therefore valid. In the other half of the cued trials, the cue appeared opposite to the direction of the target stimulus and was consequently invalid. In total, there were 34 congruent and 34 incongruent trials. Of all congruent trials, 10 were without cues, 24 were cued (12 valid, 12 invalid). Of all incongruent trials, 10 were without cues, and 24 were cued (12 valid, 12 invalid). Except for the cue, the trial components were identical with the first block (see above).

The second block consisted of two different cue formats with distinct saliency: For one half of the sample, the cue was unrelated to the subsequently appearing target (i.e., a neutral, oval shaped spot; see Figure 1a). For the other half of the sample, however, the cue was identical to the subsequent appearing target (i.e., a red fish; see Figure 1b).

We used only incongruent trials to calculate the dependent variables. This is because on congruent trials participants can respond to the orientation of any of the five fish to solve the trial correctly. To solve incongruent trials correctly, subjects had to apply the rule of responding to the orientation of the central target, making inhibitory control highly mandatory. We therefore consider incongruent trials isolated from congruent trials as the purest measure of inhibitory control (see e.g., Lee et al., 2013). Thus, the dependent variables were the following two: Percentage of correct answers on incongruent trials and mean of the reaction time of correct answers on incongruent trials.

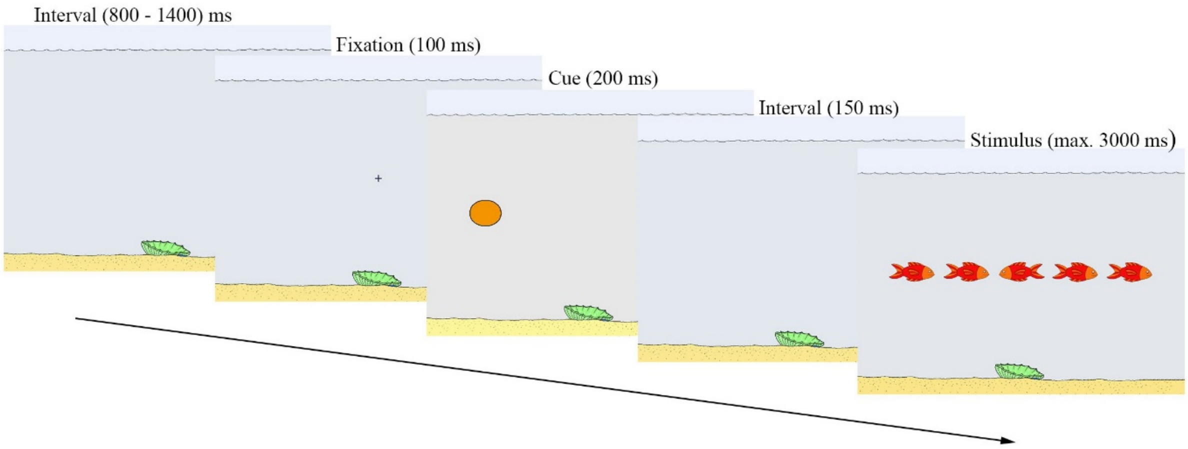

Figure 1a. A valid cued trial (neutral cue)

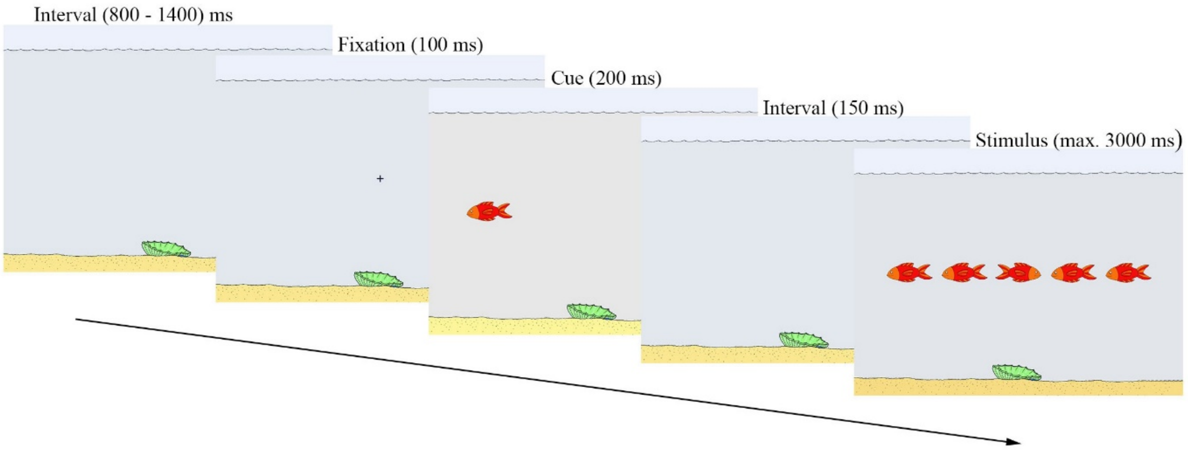

Figure 1b. An invalid cued trial (salient cue)

2. 2. 2. Head-Toes-Knees-Shoulders Task

Behavioral regulation was assessed with the HTKS (McClelland et al., 2014). The task shows high test-retest-reliability (α between .92-.94; McClelland & Cameron, 2012). The child was introduced to a game, in which he or she had to do the opposite of what the experimenter commanded. For example, the child was instructed to touch his or her toes if the experimenter said “touch your head”. The test is composed of three test blocks. For every block, there is an instruction followed by four practice trials and ten test items. Consequently, there is a total of 30 test items with scores ranging from 0 (incorrect), 1 (self-corrected), to 2 (correct) for every item. The sum score, served as the dependent variable (maximum total score = 60).

2. 3. Procedure

A trained experimenter administered all tests. Individual testing took place in a separate room at the children's educational institution. Participants were randomly assigned to one of the two cue conditions (e.g., neutral vs. salient cue for the cued block of the flanker task). The order of the tasks was counterbalanced. After testing, the child received a small reward.

3. Results

3. 1. Preliminary analysis for the modified flanker task

On trial level, reaction times (RT) below 150 ms as well as RT exceeding the inter- and intra-individual mean by more than three standard deviations (SD) were considered as outliers and therefore excluded. This pertained to 2.1% of all data points. For each block, i.e., baseline and cued, we calculated the mean RT (with correct answers only) and an accuracy score (ACC). The ACC was computed from the percentage of correct answers. Descriptive means for all variables are displayed in Table 1.

No gender differences were found for any of the variables (Flanker Baseline: RT, F (1, 123) < 1; ACC, F (1, 123) < 1; Cued Flanker: RT, F (1, 123) < 1; ACC, F (1, 123) < 1; HTKS: F (1, 123) < 1). Therefore, this factor will not be considered any further. To ascertain the assumption of higher levels of interference on incongruent trials compared to congruent trials (Ridderinkhof et al., 1997; Rueda et al., 2004), as well as to ascertain that the flanker blocks (i.e., baseline and cue) were comparable, congruency effects had to be confirmed. The defining characteristics for congruency effects are prolonged mean response latencies or decreased accuracy for the incongruent compared to the congruent trials. As an estimator of the effect sizes partial eta^2 values (η_p^2) are reported. As expected, all congruency effects were significant RT, (baseline $\eta_p^2 = .93$, cued $\eta_p^2 = .95$) and ACC, (baseline $\eta_p^2 = .99$, cued $\eta_p^2 = .99$).

Table 1.

Means and (standard deviations in parenthesis) for all variables

	Age group	
	Preschool	1st Grade
N	59	66
Age, months	70.8	89.8
Flanker baseline [a,b]		
Flanker congruent (ACC)	91 (.12)	97 (.06)
Flanker incongruent (ACC)	84 (.17)	94 (.09)
Flanker congruent (RT)	1251 (338)	911 (196)
Flanker incongruent (RT)	1358 (330)	977 (221)
Cued flanker [a, b]		
Flanker incongruent (ACC)	78 (.22)	92 (.10)
Flanker incongruent (RT)	1654 (421)	1244 (278)
HTKS[c]	47.8 (10.2)	51.4 (6.8)

Notes: [a] Mean of reaction times (RT) and corresponding standard deviation are reported in ms, [b] Accuracy score (ACC) and corresponding standard deviation are reported in %. [c] The score is a sum score of all three blocks.

3. 2. Effects of increased inhibitory control demands

To examine the effects of increased inhibitory demands we calculated a mixed analysis of variance (ANOVA). The two flanker blocks (baseline and cue) were the within-subject factor, age and cue format were the between-subject factors. The analysis revealed a significant main effect of block for both dependent variables, that is, RT, F (1, 121) = 149.3, $p < .001$, $\eta_p^2 = .55$, and ACC, F (1, 121) = 7.8, $p = .006$, $\eta_p^2 = .06$. These results indicate that the cued trials were solved more slowly and less accurately compared to the baseline measure. The main effect of age was also significant in terms of RT, F (1, 121) = 57.5, $p < .001$, $\eta_p^2 = .32$, and ACC, F (1, 121) = 26.8, $p < .001$, $\eta_p^2 = .18$. The main effect for cue format was not significant (RT, *F* (1, 121) < 2; ACC, *F* (1, 121) < 1). None of the possible interactions were significant.

3. 3. Relation between inhibitory control and behavioral regulation

Next, we conducted analyses on individual differences. We examined the relation between age, performance in the flanker task and performance in the HTKS task. Correlations for the two age groups separately revealed considerable proportions of shared variance between the flanker task and the HTKS (see Table 3). As expected, correlations were stronger between the flanker accuracy variables and the HTKS (i.e., both accuracy measures) compared to the correlations between the flanker reaction time variables and the HTKS. Overall, the correlations were higher among the flanker task variables than between flanker task variables and the HTKS. This result underlines the distinctness of the two measures.

Table 3.

Correlations for preschoolers (below the diagonal) and 1st graders (above the diagonal)

	1.	2.	3.	4.	5.	6.	7.	8.	9.
1. HTKS	-	-.24	.15	**-.29***	**.30***	-.15	-.02	.22	**.25***
2. Baseline flanker congruent RT	-.09	-	-.03	**.92****	-.16	**.77****	-.01	**.77****	-.17
3. Baseline flanker congruent ACC	**.40****	-.16	-	-.06	.11	-.01	-.13	.06	-.14
4. Baseline flanker incongruent RT	-.22	**.85****	-.12	-	-.19	**.71****	-.01	**.74****	**-.24***
5. Baseline flanker incongruent ACC	**.48****	**-.29***	**.73****	**-.28***	-	-.01	-.02	-.10	**.61****
6. Cued flanker congruent RT	-.24	**.71****	-.10	**.72****	**-.27***	-	-.10	**.90****	-.12
7. Cued flanker congruent ACC	**.56****	-.02	**.40****	-.07	**.34****	-.13	-	-.06	.16
8. Cued flanker incongruent RT	-.20	**.60****	-.02	**.66****	-.18	**.64****	-.10	-	**-.28***
9. Cued flanker incongruent ACC	**.57****	-.07	**.46****	-.18	**.62****	-.07	**.67****	-.11	-

Note. *n* = 59 for preschoolers, respectively *n* = 66 for 1st graders; $^{*}p < .05$, $^{**}p < .01$.

When comparing correlation coefficients between the two age groups it seems that behavioral regulation (i.e., HTKS) and inhibitory control are more strongly related in preschoolers than in first graders. To address this hypothesis, we conducted a regression analysis. Regression analyses were carried out for each variable, RT and ACC separately. Analyses were run with the PROCESS macro by Hayes (2012), for which all variables were centered. As depicted in Tables 5 and 6, the HTKS and age were both significant predictors for the cued flanker task. This was the case in terms of ACC (Table 5) as well as in terms of RT (Table 6). In addition, the interaction between HTKS and age was significant in terms of ACC but not for RT.

Table 5.

Linear model of predictors for cued flanker (Accuracy)

Predictor	R^2	ΔR^2	*b*	*SE B*	*t*	*p*
Constant	.39**		.866	.013	65.95	$p < .001$
HTKS (centred)			.008	.002	4.84	$p < .001$
Age (centred)			.117	.027	4.33	$p < .001$
HTKS x Age		.04*	-.009	.003	-2.65	$p = .009$

Note. *n* = 125, * $p < .05$, ** $p < .01$

Table 6.

Linear model of predictors for cued flanker (RT)

Predictor	R^2	ΔR^2	*b*	*SE B*	*t*	*p*
Constant	.54**		1437.70	29.78	48.28	$p < .001$
HTKS (centred)			-8.62	3.66	-2.35	$p = .020$

Age (centred)		-379.61	60.92	-6.23	$p < .001$
HTKS x Age	.000	-.412	7.35	-.056	$p = .955$

Note. $n = 125$ * $p < .05$, ** $p < .01$

We ran simple slope analyses to interpret the interaction. The analyses showed that the regression slopes were positive and significantly different from zero for participants with low and moderate HTKS performance (low: $t = 4.31$, $p < .00$; moderate: $t = 4.33$, $p < .00$). For participants scoring high on the HTKS task, the regression slope was also positive, but not significantly different from zero (high: $t = 1.18$, $p = .24$). To visualize the conditional effects of age on performance in the cued block, we choose the same three values (low = minus one SD from the mean; moderate = the mean; and high = plus one SD from the mean) of the moderator. As Figure 3 reveals, it is the preschoolers with low to moderate HTKS performance who, compared to their peers showing high HTKS performance, performed substantially worse in the cued block of the flanker task. Unlike preschoolers, first graders' flanker performance was more independent of the HTKS performance. No interaction between age and HTKS performance was found for the RT variable in the cued block or for any of the variables in the baseline block.

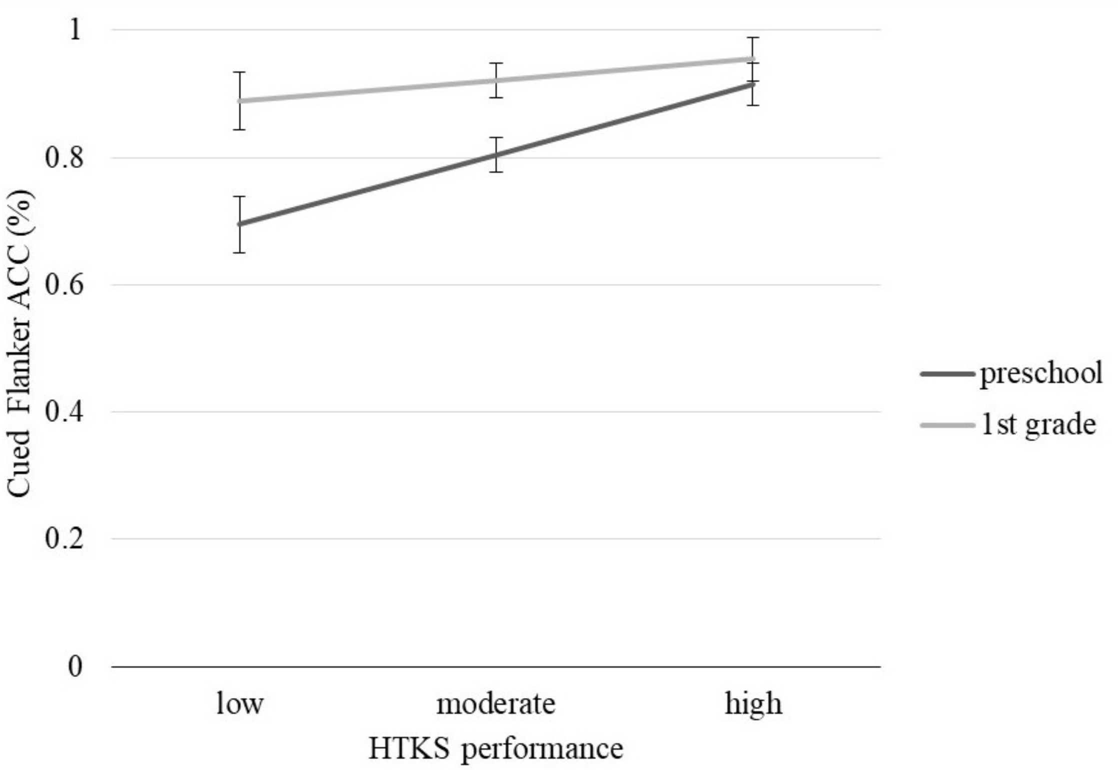

Fig. 3. Graphical depiction of the interaction between age (preschool and first grade) and HTKS performance on accuracy performance in the cued flanker task.

4. Discussion

The primary goal of the present study was to examine inhibitory control processes in children. Therefore, we used within task manipulations to analyse how children deal with changing inhibitory demands. Additional variables such as age, cue salience and behavioral regulation provide further information regarding possible influences on inhibitory processes. Inhibitory demands increased from the baseline block to the subsequent cued block in the flanker task. The analysis revealed a substantial performance decline when inhibitory control demands increased. Surprisingly, the performance decline was similar in both age groups. The additionally assessed factors such as cue format and behavior regulation skills allow for a more detailed picture of the processes at play.

The cue format (i.e., neutral vs. salient) did not have an effect on performance. Yet, it should be kept in mind that in the first block (baseline) participants assigned to both conditions had learned to respond to the target stimulus (i.e., red fish). Thus, for children assigned to the neutral cue condition, the appearing cue in the cued block was not associated with any rule. The salient cue condition, however, corresponded with the previously acquired rule from the baseline block. But even so, the cue format did not affect performance. The most straightforward interpretation would be that inhibitory processes are largely unaffected by the cue's salience. However, it is also possible that the difference between the neutral cue and the salient cue was not as big as we assumed a priori. Following this line of argument, it might be that an oval shaped spot and a fish are too similar to elicit different intensities of reactions. However, the two cue formats applied did not have a different impact on the inhibitory control processes.

Age was the second factor included in the present research design. The analysis revealed an age effect, with older participants outperforming the younger ones in both blocks. However, the increased inhibitory demands affected both age groups similarly. At first sight, these findings are counterintuitive if the development of inhibition continues in middle childhood (Romine & Reynolds, 2005). However, when looking into individual differences by taking behavioral regulation skills (i.e., HTKS measure) into account, then an age-related interaction effect did occur. The results revealed that behavioral regulation abilities seem to have a moderating effect between age and inhibitory control. Follow-up analyses revealed a pronounced age effect. Among preschoolers, participants who performed low to moderate on the HTKS, also performed substantially worse in the flanker task compared to their peers who performed well on the HTKS. Interestingly, we only found such effects in terms of accuracy, but not for speed. This result may indicate that participants with low to moderate behavioral regulation skills were not able to adapt their response behavior, (i.e., decelerate response speed), when faced with increased inhibitory demands. Unlike younger participants, older participants' inhibitory performance seemed more independent of behavioral regulation skills. However, possible ceiling effects for the HTKS might be limiting this conclusion. The age range of the HTKS lies between 4 and 8 years (McClelland et al., 2014). With a mean age of

7.5 years for the first graders, the task might have been a bit too easy for some of them, which might have affected the results.

Previous studies have shown that behavioral regulation and inhibition are related (Howse et al., 2003; Williford et al., 2013). We concur with these findings. Moreover, the current results provide information on the quality of this interrelation. Increased inhibitory control demands decreased performance among all children, regardless of age and behavioral regulation skills. However, preschoolers with low to moderate behavioral regulation skills showed an accentuated weaker performance when faced with increased inhibitory demands. Thus, while in preschool years inhibitory control and behavioral regulation are intertwined, it seems that with increasing age the two skills become more independent. These results have substantial implications regarding early education. Once children enter preschool, they are confronted with many cognitively demanding situations that require inhibition. For such situations, children with poorer behavioral regulation abilities seem to have a disadvantage over their peers with superior regulation abilities. The disadvantage seems to root in a deficit to adapt behavior according to the inhibitory demands. Therefore, fostering behavior regulation skills at an early age may be beneficial for behavioral as well as cognitive outcomes.

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