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Sensitivity to interference and response contingencies in Attention-Deficit/Hyperactivity Disorder

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Background: Current theories on ADHD suggest executive and motivational deficits, but it remains unclear whether these are separate deficits or a unitary deficit. **Method:** ADHD children and matched controls performed on a hybrid disjunctive-choice reaction time task in which target stimuli could be surrounded by flankers signaling either the appropriate response, the competing response, or response inhibition. The task was performed under three conditions; reward only, reward and occasional punishment, and equal probability of reward and punishment. Heart rate and skin conductance measures were taken during task performance. **Results:** Contrary to control children, ADHD children slowed their responses when flankers cueing the appropriate response surrounded the stimulus. Flankers cueing incorrect responses further slowed ADHD children relative to control children. ADHD children also responded less accurately under the threat of punishment. Phasic heart rate did not differ between groups, but immediate reward feedback induced greater heart rate responses in control than in ADHD children. Contrary to expectations, groups did not differ in skin conductance responses. **Conclusions:** ADHD children appear deficient in approach tendencies in the presence of imminent reward, rather than unresponsive to punishment or negative feedback. Executive inhibition and motivational inhibition seemed to exert separate effects on behavior of children with ADHD. **Keywords:** ADD/ADHD, impulsivity, hyperactivity, reaction time, executive function, motivation.

In an extensive review, Barkley (1997) described ADHD children as suffering from poor behavioral inhibition, manifested as poor response inhibition (inhibition of a pre-potent response) and poor interference control (inhibition of irrelevant information). For example, children with ADHD have shown impaired response inhibition on Go/Nogo tasks (Trommer, Hoeppner, Lorber, & Armstrong, 1988; Shue & Douglas, 1992), stop-signal tasks (Schachar & Logan, 1990; Schachar, Tannock, Marriot, & Logan, 1995; Oosterlaan, Logan, & Sergeant, 1998) and interference tasks (Barkley, Grodzinsky, & DuPaul, 1992; Carter, Krener, Chaderjian, Northcut, & Wolve, 1995; Pearson, Yaffee, Loveland, & Norton, 1995; Jonkman et al., 1999).

Douglas (1988), however, emphasized the situational factors that might deregulate ADHD children's behavior. She suggested that ADHD children show especially poor self-regulation in the face of boredom and frustration, when they have to resist immediate response inclinations, or when they have to reorganize behavior when confronted with novel situations. The type of self-regulation described by Douglas (1988) seems strongly related to motivational factors. According to Quay (1997), the motivational aspect is central to the inhibitory deficits of ADHD children. He interpreted the motivation regulation difficulties of ADHD children in terms of the Gray model (1990), and suggested that ADHD might be caused by an under-active behavioral inhibition system.

According to Gray's (1982, 1990) theory, different brain structures mediate signals of appetitive and aversive stimuli. The behavioral activation system (BAS) initiates behavior in response to signals of reward or non-punishment, while the behavioral inhibition system (BIS) inhibits behavior in response to signals of punishment or non-reward. The BIS, therefore, can be defined as a motivational inhibition system related to caution. A third structure, called the nonspecific arousal system (NAS), receives input from both the BAS and the BIS and acts to increase the intensity, but not the directional aspects of behavior. As proposed by Gray, the BAS and BIS compete to influence the focus of behavior, while increases in NAS activity may limit the amount of time and concomitant processing accorded to the simultaneous evaluation of BAS and BIS influence before goal-directed behavior is either emitted or inhibited. According to Quay's interpretation of the Gray model, ADHD children receive less caution or avoidance signals due to an underactive BIS, and are therefore unable to inhibit responding in the face of probable punishment or non-reward.

Thus, current theories of ADHD can be characterized as either 'executive' theories (response inhibition, interference control) or 'motivational theories' (poorly functioning BIS) (Nigg, 2001). Relatively

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few studies, however, have tried to integrate cognitive inhibition and motivation to explain behavioral deregulation in ADHD. Although Quay's interpretation of the motivational aspect of ADHD children's inhibitory difficulties is theoretically promising, we do not know whether cognitive and motivational inhibition are separate aspects of ADHD or if they are closely related facets of a unitary inhibitory deficit.

Fowles (1980, 1988) pointed out that Gray's theory is empirically appealing because it can be tested with psychophysiological measures. Fowles (1980) reviewed evidence that measurements of physiological indices reflect activity in the BAS and BIS. His studies of heart rate and skin conductance demonstrated motivational specificity, in that heart rate responded to increases in appetitive or hedonic motivation (BAS) but not to increases in aversive motivation (BIS). By contrast, nonspecific skin conductance responses were sensitive to aversive stimuli, but not to appetitive stimuli.

Psychophysiological studies with ADHD children have only partially supported the Fowles' concepts. Pliszka, Hatch, Borcherding, and Rogeness (1993) examined ADHD children's heart rate and skin conductance responses to aversive stimuli, presented in a classical conditioning paradigm. Their findings failed to differentiate between control and ADHD children. Iaboni, Douglas, and Ditto (1997) studied heart rate and electrodermal responses in ADHD and control children using a task derived from Fowles (1982; in Iaboni et al., 1997). They found that control children showed the same physiological pattern as adults. During reward their heart rate increased, while during extinction of reward an increase in skin conductance responses was observed. ADHD children showed also an increase in heart rate to reward, but this response habituated faster than that of controls. Most notably, skin conductance responses of children with ADHD were not affected by the response contingencies. This pattern of findings suggested to Iaboni and colleagues a rather complex interpretation. ADHD children may have a BIS deficit, indexed by the absence of skin conductance responses to the extinction of reward, but on the other hand, may also have a BAS deficit, indexed by fast habituation of heart rate responses to reward.

In the present experiment we asked if ADHD children's cognitive inhibitory deficits are related to reward and punishment contingencies. The experimental task was designed to show whether or not motivationally induced response modulation interacts with cognitively controlled response inhibition and interference control. The task was presented in the form of a computer game that allowed children to incrementally master the task. Levels/blocks of trials selectively added elements eliciting response inhibition and interference control. A computer task in which children were navigating a spaceship required the children to respond to arrows at the center of a screen signaling responses to the left or to the right and to inhibit responses to Nogo signals (response inhibition). Additionally they had to inhibit interfering response activation caused by flankers (interference control). Irrelevant flankers, arrows or diamonds, could be added to both sides of the center relevant cue. Eriksen and Schultz (1979) showed that such irrelevant flankers induce competing response tendencies, which then reduce performance speed and accuracy. ADHD children were expected to be less able to refrain from responding to Nogo stimuli and, in trying to avoid commission errors, they were expected to reduce response speed to a greater extent than control children (Trommer et al., 1988; Shue & Douglas, 1992). Under the hypothesis that ADHD children are more susceptible to the conflict of flankers, ADHD children were also expected to be more sensitive to the interfering effect of flankers (Carter et al., 1995; Jonkman et al., 1999).

Within each level of cognitive challenge, response contingencies were varied, starting with all positive reinforcement and subsequent increasing until 50% punishment was present. The response contingencies were based on the hypothesis, derived from work of Newman and Wallace (1993), that inhibitory deficits in ADHD children become prominent when signals for punishment are introduced after a period of signals for reward. During punishment contingencies, active avoidance of punishment required participants to adopt a fast and accurate response style. Under the hypothesis that ADHD children are less responsive to signals for punishment (underactive BIS; Quay, 1997), avoidance behavior was expected to be especially difficult for ADHD children. Analyses could be done for motivational effects at each level of the task, and additional analyses could be performed over separate levels of the task to study interactions between response contingencies and cognitive inhibition requirements, i.e., response inhibition and interference control. This design allowed us to study four important contingencies between response, inhibition and reinforcement valence; these are: reward phases that required responses (approach), reward phases that required withholding (withdrawal), punishment phases that required responses (active avoidance), and punishment phases that required withholding (passive avoidance). If ADHD children experience difficulties with rapid active avoidance, this may be due to an underactive BIS or to poor motor output coordination. Passive avoidance difficulties can be linked to an underactive BIS per se. The last cognitive demand was expected to be especially impaired in ADHD children (Quay, 1997).

The physiological measures, heart rate and skin conductance responding, were examined as indices of respectively BAS and BIS activity (Fowles, 1980, 1988). Following Fowles (1980, 1988), we expected that reward-only signals would elicit BAS as indexed by elevated heart rate levels. ADHD children were predicted to show higher heart rate levels initially, but more rapid habituation during the task (Iaboni et al., 1997). The introduction of punishment to the task was expected to increase the number of skin conductance responses, indexing the activation of the BIS. Given that ADHD children are less sensitive to the threat of punishment than control children, their skin conductance responses should not discriminate between the three response contingency phases of the tasks as well as skin conductance responses of control children (Iaboni et al., 1997). Immediate effects of reward and punishment should result in similar effects between groups. Reward or avoidance of punishment was expected to result in BAS activity and consequently in heart rate increase, whereas punishment and non-reward should result in BIS activity and consequently an increase in electrodermal responses. The heart rate increase following reward and punishment avoidance was expected to habituate faster for ADHD children (Iaboni et al., 1997), and the increase in skin conductance following punishment and non-reward should be less in ADHD children (Iaboni et al., 1997; Quay, 1997).

Method

Participants

The sample consisted of 22 ADHD (5 girls, 17 boys) and 22 control children (9 girls, 13 boys) between the ages of 6 and 12 years. The ADHD children were recruited through the clinical program of the Western Psychiatric Institute and Clinic (WPIC) in Pittsburgh. To be included in the ADHD group, children had to meet DSM-III-R criteria for this disorder, while not being clinically diagnosed for conduct disorder or learning disabilities (American Psychiatric Association, 1987). A psychiatrist, trained in research diagnoses, had recently diagnosed the children as ADHD on the basis of a structured parent interview and teacher ratings. Parents of the children gave consent to be contacted by researchers. Except for five children, the ADHD children were not treated with medication. All children receiving stimulant medication had not been medicated for at least 24 hr before testing. In addition to the diagnosis made by the clinician, we asked parents to fill out the IOWA Conner's Rating Scale and Child Behavioral Checklist (CBCL) for ages 4–18. At least one parent rated the child above the established criterion on the Hyperactivity Index of the IOWA Conner's Rating Scale and above the criteria for attention problems of the CBCL. Children were excluded if they had medical or neurological disorders or if they obtained IQ scores below 70 on the Wechsler Intelligence Scale for Children (WISC-R).

Age-matched control children were recruited through local advertisements. Parents who responded to the advertisement were given a description of the study. If they agreed to have their child participate, parents were asked to fill out the IOWA Conner's rating scale and the CBCL for ages 4–18. Only children who obtained scores below the ADHD inclusion criteria on these scales were included in the control group. The control group did not receive a DSM-III-R interview. Parents of the children in the control group reported no behavioral or neurological problems and the children were not taking medication. The parents of the children also consented to their child's participation. Approximately 80% of the control children contacted and 60% of the ADHD children agreed to participate in the study.

Demographic and clinical characteristics of ADHD and control children are summarized in Table 1. Two sub-tests of the WISC-R were administered to estimate children's IQ: Block Design and Vocabulary. As expected, the ADHD and control group differed significantly on parents ratings on the IOWA Conner's rating scale, $t(42) = 32.67$, $p < .001$, and on the CBCL, $t(42) = -7.68$, $p < .001$. A one-way analysis of variance (ANOVA) showed that the IQ scores of ADHD children were significantly lower than the IQ scores of the control group, $F(1, 41) = 7.78$, $p < .001$. Therefore, all analyses including a group factor were additionally analyzed with IQ added as a covariant factor. The group interactions reported below remain statistically significant when controlled for IQ. Similar analyses showed that the groups did not differ in age and that covarying age does not alter the reported effects. Preliminary analyses revealed that gender differences were absent. Thus, gender was not included as a separate factor in the subsequent analyses. SES levels were not obtained.

Design of the experimental task

The task used in the present study was derived from the Eriksen flanker paradigm (1974, 1979) and was employed previously by Ridderinkhof and Van der Molen (1995) to examine developmental changes in the susceptibility to interference. The Go/Nogo Flanker task was explained as a computer game, in which children had to respond to on-screen arrows and pretend to pilot a spaceship. To do this, the child was instructed to only pay attention to the middle target of the screen, and ignore any other signals. When the middle target was an arrow pointing to the right, the

Table 1 Demographic statistics

Group	Measures	
ADHD	N of boys/girls	13/9
	Age (mean (SD))	9.0 (1.9)
	IQ (mean (SD))	91 (14.2)
	IOWA	17.02
	CBCL	70.73
Control	N of boys/girls	17/5
	Age (mean (SD))	9.0 (1.8)
	IQ (mean (SD))	99 (16.8)
	IOWA	2.68
	CBCL	53.45

Note: IQ (intelligence quotient) was estimated from WISC-R vocabulary and block design. IOWA refers to IOWA Conner's rating hyperactivity scale; CBCL refers to child behavioral checklist.

child was instructed to move the joystick to the right as quickly as possible, when the arrow was pointing to the left, the child should move the joystick to the left. When the middle target was a diamond (Nogo target) the child was instructed to withhold responding. The task was presented in 7 levels, with increasing inhibitory demands. Each level was preceded by 5 warm-up trials to make sure that instructions were understood. A schematic presentation of trial types and levels is presented in Table 2. Within each level, the different stimulus-types were presented in a pseudo-random order.

First a practice series (level 0) was presented. This practice level consisted of 40 pseudo-randomly presented left- and right-pointing arrows. Each level after the practice level included 5 warm-up trials and 40 replications of each individual trial type. The first level consisted of 80 left- and right-pointing arrows. Children were required to make a binary choice to a single target stimulus pointing to the left or right. At this level, the demands on inhibitory control were negligible and the stimuli did not elicit interference. At the second level, 40 trials with single Nogo-diamonds were interleaved with 80 trials with left- or right-pointing arrows. The children were instructed to refrain from responding to the diamond-shaped stimuli. At this level, the stimuli did not elicit interference, but the task required inhibitory control. The third level consisted of 80 congruent left- or right-pointing arrays (target stimuli surrounded by similar oriented flankers). Identical arrays did not elicit interference and, at this level, did not require the identification of the central target stimulus. At the fourth level, 80 trials with congruent arrays were interleaved with 80 trials with diamond-shaped Nogo stimuli surrounded by arrows. At this level, the central target needed to be identified. The diamond-shaped stimuli surrounded by arrows induced a conflict between response activation elicited by the flankers and response inhibition required by the central target. At the fifth level, besides 80 congruent arrays and 80 Nogo-targets surrounded by arrow flankers, 80 trials with arrow targets with Nogo-flankers were inserted. The sixth level consisted of 80 congruent arrays and 80 incongruent arrays (i.e., target arrow was surrounded by arrows pointing in opposite direction). The seventh level contained 80 nogo-diamond targets surrounded by arrow-flankers, 80 arrow targets surrounded by diamond-flankers and 80 incongruent arrays.

The background color of the screen signaled punishment and reward trials. The screen turned blue or red 500 ms before the stimulus was presented. The blue reward screen indicated that the child was in a 'safe zone'. The stimulus and blue background stayed on the screen until the subject responded with the joystick, then the screen turned black for 500 ms. When the child responded fast and accurately, he or she won a penny and a dollar sign appeared 500 ms after the response. If the child made a wrong response or responded slower than the established threshold, the screen stayed black. The next trial appeared after 2 seconds. The red punishment screen indicated that the child was in a 'danger zone'. When the child responded inaccurately or slower than the established threshold, he or she lost a penny and the screen was filled with an explosion graphic 500 ms after the response. If the child responded fast and accurately, the screen stayed black and the next trial appeared after 2 seconds. The warm-up trials and the first third of the trials of each level were 'reward-only' trials (blue screen; phase 1). The following third of the trials were 'reward interleaved with occasional punishment' trials (blue and red screens; phase 2), and consisted of 66% reward trials and 33% punishment trials, in pseudo-random order. The last third of the trials were 'equal probability of reward and punishment' trials (blue and red screens; phase 3), and consisted of 50% reward and 50% punishment trials presented pseudo-randomly. Each separate task level was divided into these three contingency phases. The transition of one contingency phase to the other was continuous, i.e., unsignaled; there was no pause or break between them.

The mean reaction time of the practice level was used as a criterion for fast responses at levels 1, 2 and 3. The mean reaction time (RT) during practice level did not differ significantly between ADHD and control children. The mean response speed of level 2 plus 25 ms was used as a criterion for fast responses at level 4. The mean response speed at level 4 plus 15 ms was used as criterion for fast responses at levels 5, 6 and 7.

Table 2 Stimulus presentation: L = left-pointing arrows, R = right-pointing arrows, N = Nogo targets

Level	Stimulus-type	Presentation	Example	N of trials
1	Single go arrows	L or R	➡	80
2	Single go arrows	L or R	➡	80
	Single nogo	N	◆	40
3	Congruent flankers	LLLLL or RRRRR	➡ ➡ ➡ ➡ ➡	80
4	Congruent flankers	LLLLL or RRRRR	➡ ➡ ➡ ➡ ➡	80
	Flankered nogo	LLNLL or RRNRR	➡ ➡ ◆ ➡ ➡	80
5	Congruent flankers	LLLLL or RRRRR	➡ ➡ ➡ ➡ ➡	80
	Flankered nogo	LLNLL or RRNRR	➡ ➡ ◆ ➡ ➡	80
	Inhibit flankers	NNLNN or NNRNN	◆ ◆ ➡ ◆ ◆	80
6	Congruent flankers	LLLLL or RRRRR	➡ ➡ ➡ ➡ ➡	80
	Incongruent flankers	RRLRR or LLRLL	➡ ➡ ⬅ ➡ ➡	80
7	Incongruent flankers	RRLRR or LLRLL	➡ ➡ ⬅ ➡ ➡	80
	Flankered nogo	LLNLL or RRNRR	➡ ➡ ◆ ➡ ➡	80
	Inhibit flankers	NNLNN or NNRNN	◆ ◆ ➡ ◆ ◆	80

Apparatus

The stimuli were approximately 8 cm in size and were presented with a distance of 2 cm from each other. The child was seated approximately 100 cm away from the computer screen.

Measurements of heart rate were obtained using surface electrodes attached via a modified Lead-2 placement (upper right and lower left thorax electrodes) and connected to a Grass 7D Polygraph. A computer using R-wave detection of the electrocardiogram complex was used to sample the data at 1000 Hz. No baseline recordings were made, because comparisons were made between contingency phases. The number of R-waves was detected and transformed into beats per minute (bpm) for each contingency phase.

Skin conductance level was measured using Beckman electrodes attached to the hyper- and hypothenar surfaces of the non-dominant hand. A computer using SCRGAUGE software (Boucsein, 1992) was used to record SCR. A Coulbourn Instrument transducer assessed skin conductance employing a .5 V constant voltage circuit. Skin conductance responses with amplitudes larger than .02 micro-siemens were included for analysis (Boucsein, 1992; Iaboni et al., 1997). The number of skin conductance responses occurring at each level was corrected for length of time required for the level. That is, the number of skin conductance responses was divided by the number of trials at the specific level (n of SCR/n of trials).

Procedure

Children performed the task in a quiet room that contained a table with a computer to run the task, and a comfortable chair. Physiological measures were recorded while children performed the task. The physiological monitoring equipment was in an adjoining room. Before each level, the experimenter gave the child instructions and made sure that the task was understood. There was a period of rest of approximately two minutes after each task level and a larger break of approximately 10 minutes between the fourth and fifth level. The length of the levels varied between 2 minutes and 8 minutes. Levels one, two, three and four lasted approximately 2, 4½, 2 and 6 minutes respectively. Levels five, six and seven lasted approximately 8, 6 and 8 minutes respectively.

The children spent a total of approximately 1.5 hrs in the laboratory, including breaks. During the task, parents were allowed to sit behind the child to make the child feel comfortable, but were instructed not to give any encouragement or speak to the child during the task. At the conclusion of the session, the participants were paid $10 for participation and were also rewarded the incentive pay (approximately $5).

Results

The results will be presented in two major sections. First, the performance data, response latency and accuracy, will be presented with a focus on general effects of response contingencies, the manipulations of the stimulus arrays and on interactions between response contingencies and response inhibition and interference control. These analyses should reveal if cognitive inhibition (response inhibition, interference control) is modulated by motivational inhibition (response contingencies). Secondly, the psychophysiological data, heart rate and skin conductance responses, will be presented focusing on response contingencies and actual feedback.

Response latency and accuracy

Median reaction time (RT) and proportion correct (%) were computed for each child, task level, stimulus type, and response contingency phase. Tables 3 and 4 provide median RTs and percentage correct, for each group, task level, stimulus type, and contingency phase. The data were submitted to repeated measures ANOVAs with group (ADHD vs. control) as a between subjects factor and the experimental manipulations as a within subjects factors. Post-hoc t-test comparisons were done to follow up significant interactions including the group factor. The presentation of the results will follow the order of questions posed in the introduction.

Response contingencies. First, an analysis was conducted to examine the effects of response contingencies on response latency and accuracy for both groups. This analysis should reveal if ADHD children in general adopted a less reflective response style when punishment was introduced following reward-only trials. We assessed the group and response contingency effects by collapsing over all task levels. All children were included in this analysis, except for two control children and two ADHD children who did not complete the experiment after the fourth level (all 6 years of age).

The analysis revealed that children with ADHD responded generally slower compared to control children, $F(1, 37) = 4.93$, $p < .035$. The introduction of punishment (phases 2 and 3) caused faster RTs for both groups compared to the reward-only phase (phase 1), $F(2, 76) = 7.07$, $p < .01$, but there was no interaction between group and contingency for response latency (see Table 3). This analysis was followed up by a comparison of RTs between reward-only-trials in phase 1 ($M = 591$ ms), punishment trials in phase 2 ($M = 569$ ms), reward trials in phase 2 ($M = 589$ ms), punishment trials in phase 3 ($M = 578$ ms), and reward trials in phase 3 ($M = 586$ ms). This analysis revealed that responses were significantly faster following punishment warnings compared to reward warnings, $F(4, 228) = 10.14$, $p < .001$, also when these were compared separately in phases 2 and 3. This result shows that faster response times in phases 2 and 3 were induced by the presence of punishment

Table 3 Median RTs for each task level

		Results for ADHD children				
		Median RT (sd)				
Level	Stimulus-type	Phase 1	Phase 2	Phase 3	Total	*n*
1	Single go arrows	554 (19.8)	546 (17.5)	550 (18.5)	550 (17.9)	22
2	Single go arrows	589 (18.7)	594 (20.3)	575 (16.9)	586 (18.0)	22
3	Congruent flankers	559 (17.6)	558 (19.6)	558 (19.2)	559 (18.0)	22
4	Congruent flankers	622 (19.6)	620 (19.5)	627 (19.2)	623 (18.7)	22
5	Congruent flankers	575 (22.4)	558 (22.5)	568 (23.8)	567 (22.3)	14
	Inhibit flankers	623 (28.2)	594 (26.3)	608 (24.4)	610 (25.0)	14
6	Congruent flankers	560 (23.1)	540 (20.0)	545 (20.4)	548 (20.1)	14
	Incongruent flankers	657 (29.3)	623 (25.9)	653 (23.6)	644 (22.7)	14
7	Incongruent flankers	620 (18.0)	619 (18.5)	620 (17.5)	620 (17.3)	14
	Inhibit flankers	562 (21.6)	553 (20.4)	571 (20.4)	562 (19.8)	14
ALL		603 (17.9)	595 (18.0)	597 (17.4)	598 (17.6)	20
		Results for control children				
		Median RT (sd)				
Level	Stimulus-type	Phase 1	Phase 2	Phase 3	Total	*n*
1	Single go arrows	534 (19.8)	512 (17.4)	530 (18.5)	528 (17.9)	22
2	Single go arrows	563 (18.7)	553 (20.3)	543 (16.9)	553 (18.0)	22
3	Congruent flankers	514 (17.6)	514 (19.6)	517 (19.2)	515 (17.9)	22
4	Congruent flankers	587 (19.6)	571 (19.5)	572 (19.2)	576 (18.7)	22
5	Congruent flankers	562 (20.3)	537 (20.5)	545 (21.6)	548 (20.3)	17
	Inhibit flankers	582 (25.6)	560 (23.9)	563 (22.1)	568 (22.7)	17
6	Congruent flankers	504 (20.7)	488 (17.8)	496 (18.3)	536 (21.3)	17
	Incongruent flankers	571 (26.2)	565 (23.2)	578 (21.1)	571 (20.3)	17
7	Incongruent flankers	564 (16.1)	554 (16.5)	574 (15.6)	564 (15.5)	17
	Inhibit flankers	531 (19.4)	509 (18.3)	538 (18.3)	526 (17.7)	17
ALL		558 (17.9)	544 (18.0)	548 (17.4)	550 (17.6)	20

warning signals, and were not simply due to a practice effect of time-on-task.

A similar analysis for accuracy revealed that children with ADHD responded less accurately in general, $F(1,36) = 4.28$, $p < .05$, and that accuracy decreased as punishment increased, $F(2,74) = 5.21$, $p < .01$. An interaction effect between group and contingency showed that the decrease in accuracy with increase in punishment was only present for children with ADHD but not for control children, $F(2,74) = 5.03$, $p < .025$ (see Table 4). Post hoc comparisons showed that ADHD children responded less accurately in phase 2 than in phase 1, and less accurately in phase 3 than in phase 2. Control children responded equally in the three phases.

Response inhibition. A set of ANOVAs was performed on the first four levels to see if response contingency interacted with response inhibition. RTs to Go trials that were interleaved with Nogo trials at levels 2 and 4 were compared with RTs to Go-trials at levels 1 and 3. This comparison should reveal the effects of the presence of Nogo targets, i.e., forming a Nogo-factor. Within the same analysis, single targets at levels 1 and 2 were compared with congruent arrays from levels 3 and 4 to examine the effect of surrounding the target with flankers, i.e., forming a flanker factor. The last factor 'contingency' should reveal if response contingencies affected performance of control and ADHD children differently.

The ANOVA revealed that the presence of flankers increased response latencies compared to targets alone (flanker main effect), $F(1,41) = 11.25$, $p < .005$. However, as can be seen in Figure 1, the ADHD group difference between conditions was larger than the control group difference between conditions, $F(1,41) = 4.62$, $p < .04$. Contrary to expectations, however, there was no effect of the Nogo-factor, and neither the Nogo-effect nor the flanker-effect was modulated by response contingency phases.

A similar analysis for accuracy revealed that accuracy decreased when flankers were presented in the task compared to single targets only (flanker main effect), $F(1,41) = 7.24$, $p < .01$. This effect interacted with group, showing that ADHD children responded less accurately to targets surrounded by flankers, while control children responded as accurately to both trial types, $F(1,41) = 7.24$, $p < .01$. This effect was also not modulated by response contingencies, and there was no effect of the presence of Nogo targets.

A final ANOVA of this set focused on the ability to inhibit responses on Nogo targets that could be surrounded by flankers. This analysis was performed on the percentage correct inhibitions associated with single Nogo stimuli (level 2) versus nogo stimuli

Table 4 Accuracy (% correct) for each task level

		Results for ADHD children				
		% correct (sd)				
Level	Stimulus-type	Phase 1	Phase 2	Phase 3	Total	*n*
1	Single go arrows	94(.02)	92(.02)	88(.02)	91(.02)	22
2	Single go arrows	95(.01)	92(.02)	90(.02)	93(.02)	22
	Single nogo	98(.01)	96(.01)	98(.01)	97(.01)	22
3	Congruent flankers	93(.02)	88(.02)	87(.02)	90(.02)	22
4	Congruent flankers	91(.02)	87(.03)	84(.03)	87(.02)	22
	Flankered nogo	89(.02)	84(.02)	86(.03)	86(.02)	22
5	Congruent flankers	95(.02)	95(.02)	92(.03)	94(.02)	14
	Flankered nogo	87(.02)	85(.03)	86(.03)	87(.02)	14
	Inhibit flankers	90(.03)	91(.04)	91(.03)	90(.03)	14
6	Congruent flankers	94(.02)	96(.01)	93(.01)	95(.01)	14
	Incongruent flankers	72(.04)	75(.04)	67(.04)	72(.03)	14
7	Incongruent flankers	83(.03)	84(.03)	82(.03)	83(.02)	14
	Flankered nogo	94(.02)	93(.02)	90(.03)	92(.02)	14
	Inhibit flankers	96(.02)	94(.02)	92(.02)	94(.01)	14
ALL		88(.02)	87(.02)	83(.02)	86(.02)	20

		Results for control children				
		% correct (sd)				
Level	Stimulus-type	Phase 1	Phase 2	Phase 3	Total	*n*
1	Single go arrows	92(.02)	96(.02)	95(.02)	95(.02)	21
2	Single go arrows	97(.01)	95(.02)	96(.02)	96(.02)	21
	Single nogo	97(.01)	97(.01)	95(.01)	96(.01)	21
3	Congruent flankers	95(.02)	97(.02)	95(.02)	96(.02)	21
4	Congruent flankers	95(.02)	94(.03)	95(.03)	95(.02)	21
	Flankered nogo	87(.02)	85(.02)	88(.03)	87(.02)	21
5	Congruent flankers	96(.02)	97(.02)	96(.03)	96(.02)	17
	Flankered nogo	92(.02)	85(.03)	86(.03)	88(.02)	17
	Inhibit flankers	93(.03)	94(.04)	94(.03)	94(.02)	17
6	Congruent flankers	96(.02)	97(.01)	97(.01)	97(.01)	17
	Incongruent flankers	80(.04)	74(.03)	74(.04)	76(.03)	17
7	Incongruent flankers	89(.02)	91(.02)	90(.03)	90(.02)	17
	Flankered nogo	91(.02)	90(.02)	92(.02)	91(.02)	17
	Inhibit flankers	95(.02)	96(.02)	98(.02)	96(.01)	17
ALL		92(.02)	93(.02)	92(.03)	92(.02)	19

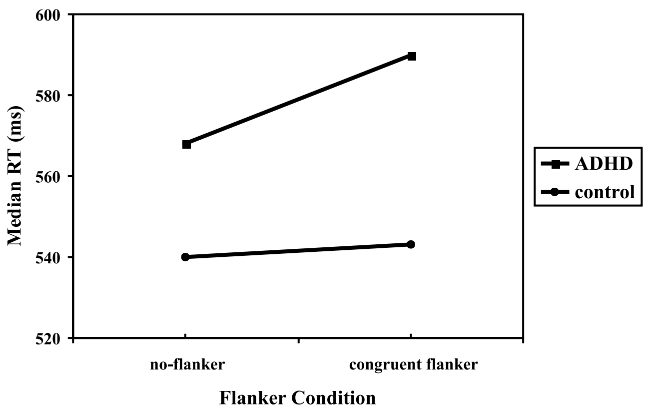

Figure 1 Response time for no-flanker and congruent flanker trials

surrounded by arrow flankers (level 4). Although both groups made more commission errors to Nogo stimuli that were surrounded by flankers than on single Nogo stimuli, $F(1, 43) = 44.45$, $p < .001$, this effect did not differentiate between groups and was not altered by response contingencies (see Table 4).

Response competition. The next set of ANOVAs focused on flanker incongruency effects, and possible interactions with response contingencies, and was performed over the final three levels (levels 5, 6 and 7). More specifically, this analysis examined if the presence of response contingencies interacted with the children's ability to inhibit conflict caused by flankers. Two control children and two ADHD children did not complete the experiment after the fourth level because of unwillingness to cooperate further. Six ADHD children and three control children were excluded from this analysis because their mean accuracy was lower than 60% correct and therefore close to chance level. RTs and accuracy on congruent flanker trials, inhibit flanker trials and incongruent flanker trials that occurred in these levels were compared and possible interactions with contingency phase were examined. Because the flanker-types were presented in different levels and were therefore not counterbalanced, we added a factor reflecting time/sequential levels to the analysis. All flanker-types were presented in two levels (congruent flankers levels 5 & 6, inhibit flanker levels 5 & 7, and incongruent flankers levels 6 & 7). Possible time confounds should therefore result in a significant effect of the added time/sequential levels factor.

The ANOVA on RTs revealed that the target stimuli flanked with Nogo stimuli resulted in an increase in response latency (555 ms) compared to stimuli with congruent flankers (529 ms) and the resolution of response conflict caused by incongruent flankers caused a significant additional increase (600 ms), $F(2,50) = 103.53$, $p < .001$. The interaction between group and flanker-type revealed that this effect was more pronounced for ADHD children than control children, $F(2,50) = 4.01$, $p < .025$. Post hoc analyses showed that for ADHD children the slowing on incongruent flanker trials (632 ms) in comparison to congruent (549 ms) and inhibit flankers (575 ms) was larger than for control children (congruent: 509 ms, inhibit: 534 ms and incongruent 567 ms). This effect, however, did not interact with response contingencies. The time/sequential levels did not result in any significant effects, and therefore did not affect the group × flanker-type interaction.

The ANOVAs performed on accuracy revealed that the percentage correct responses towards congruent flanker stimuli and stimuli surrounded by inhibit flankers were higher (96.5% and 95.4% respectively) than the percentage correct to stimuli surrounded by incongruent flankers (80.1%), (main effect flanker type), $F(2,76) = 78.64$, $p < .001$, but this effect did not interact with group or response contingency.

Summary. ADHD children and control children did not differ in the number of commission errors, but ADHD children responded slower and less accurately when targets where surrounded by congruent flankers compared to single targets than control children. ADHD children also responded slower to targets surrounded by incongruent flankers than control children. Although ADHD children made more errors in general when punishment was introduced to the task, the effects of stimulus arrays were not altered by response contingencies. This finding suggests that cognitive and motivational inhibition deficiencies were not related, i.e., response inhibition and interference control were not influenced by response contingencies for either control or ADHD children.

Heart rate and skin conductance responses

The analysis of the psychophysiological measures focused on the effects of response contingency and effects of feedback on heart rate (HR) and skin conductance responses (SCR).

Response contingency. ANOVAs performed on data collapsed over task levels assessed group and response contingency effects for HR and SCR. HR increased in phases where punishment occurred in comparison to the first phase in which only reward was presented, $F(2,47) = 28.08$, $p < .001$ (reward only: $M = 87$ bpm, $SD = 2.8$, occasional punishment $M = 89$ bpm, $SD = 2.8$, equal probability reward/punishment: $M = 89$ bpm, $SD = 2.9$), but this effect did not differentiate between control and ADHD children. SCR analyses did not result in any significant effects.

Feedback. An additional ANOVA focused on effects of feedback, to examine phasic instead of tonic reinforcement effects (Arnett & Newman, 2000). The ANOVA examined the effect of positive feedback (reward or escape of punishment) compared to negative feedback (punishment or losing reward) on HR. The heart rates of both groups were faster after positive feedback ($M = 89.9$ bpm) compared to negative feedback ($M = 88.5$ bpm), $F(1,39) = 52.35$, $p < .001$. As shown in Figure 2, an interaction between group and feedback revealed that the difference between HR following positive and negative feedback was larger for control children (positive feedback: $M = 92.0$ bpm, negative feedback: $M = 90.3$ bpm) than for children with ADHD (positive feedback: $M = 87.6$ bpm, negative feedback: $M = 86.8$ bpm), $F(1,39) = 5.98$, $p < .02$. Because of the baseline difference in heart rate between control and ADHD children, a similar analysis was performed on percentage differences (positive feedback HR/baseline feedback HR) between responses after positive and negative feedback, which also resulted in a significant difference between heart rate responses of ADHD and control children, $F(1,39) = 5.61$, $p < .025$ (percentage difference for control children: .02, ADHD children: .009). Because of

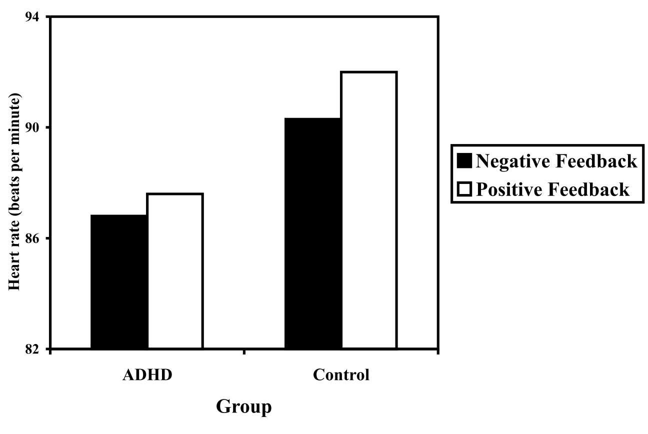

Figure 2 Heart rate after positive and negative feedback

the fast presentation rate of the stimuli, it was not possible to examine phasic SCRs in response to feedback. We did, however, correlate the amount of negative feedback (punishment or losing reward) a child received with the number of skin conductance responses. This analysis did not result in a significant correlation.

Summary. When punishment was added to the task, heart rate increased compared to the task phase in which only reward was present, but this effect was not different for ADHD children. Phasic heart rate changes, however, revealed that a heart rate increase after positive relative to negative feedback was larger for control than ADHD children. Contrary to expectations, SCR analyses did not result in significant results.

Discussion

The present study examined to what extent behavioral deregulation of ADHD children should be interpreted in terms of a distinct cognitive/executive (Barkley, 1997; Nigg, 2001) or motivational (Quay, 1997) deficit, or whether these reflect the same underlying deficit. This hypothesis was examined by presenting a task with varying levels that posed different inhibitory demands. The task levels posed two cognitive inhibitory demands; response inhibition (Go/Nogo targets) and flanker control (different flanker types). This last type of inhibition can be separated into perceptual/central filtering (ability to perceptually screen out any flankers) and interference control (ability to control incorrect responses induced by competing flankers). The task levels were all presented in three contingency phases. In the first phase, reward-only trials were presented, in the second phase reward was interleaved with occasional punishment, and in the last phase reward and punishment trials were equally interleaved, requiring motivational inhibition in the second and third phases.

The results showed that cognitive and motivational inhibitions were surprisingly independent, arguing against a weak BIS system in ADHD children (Quay, 1997). Analysis of 'executive' inhibitory control yielded three important results. First, consistent with previous studies, ADHD children were more sensitive to the interfering effects of flankers (e.g., Hooks, Milich, & Pugles Lorch, 1994; Carter et al., 1995; Jonkman et al., 1999). This result is consistent with executive theories on ADHD children (Barkley, 1997; Pennington, 1997).

Second, the present study failed to show that children with ADHD were less able to inhibit responses to Nogo-stimuli. This result is unexpected, but similar effects have been reported in the past (Jennings, van der Molem, Pelham, Debski, & Hoza, 1997; Scheres, Oosterlaan, & Sergeant, 2001). When tasks and rewards are well structured, ADHD children appear to show intact response inhibition (Sergeant, Oosterlaan, & Van der Meere, 1999). Alternatively, this and our other findings might be influenced by our patient selection. Although the clinical diagnoses of ADHD were based on both teacher and parent reports, in this study the additional diagnostic information was based on parent reports only. Our results should be qualified by the possible consideration that ADHD symptoms were more pervasive at home than at school.

Third, children with ADHD were found to be more sensitive to the introduction of congruent flankers compared to conditions where arrow targets were presented alone. Jonkman et al. (1999) previously studied this effect in a highly similar arrow flanker task. Based on their previous findings they examined the hypothesis that ADHD children suffer from perceptual conflict caused by flankers, and they compared performance of ADHD and control children to single target arrows and target arrows surrounded by congruent flankers. Their results showed a trend towards perceptual conflict in children with ADHD, but did not have enough power to support the perceptual conflict hypothesis. The present study, on the other hand, was conducted in a larger sample with more trials. Our findings suggest that ADHD children are less able to filter irrelevant information, resulting in a general increase in RT when they respond to targets surrounded by congruent flankers. Thus, ADHD children may experience difficulties not only in response selection (more response competition by incongruent flankers), but also in perceptual/central selection (more difficulty filtering relevant information). In the present study, the presentation of stimulus arrays could not always be counterbalanced and effects could therefore be influenced by confounds in time. The difficulties that ADHD children experienced with the introduction of flankers compared to single targets (slower response times and more errors) could be the result of a decrease in task involvement. However, the effects for both RT and accuracy were relatively large, whereas the differences in response time and accuracy during transition to other levels (for example, from level 1 to 2, and from level 3 to 4), were not large for ADHD children. This makes the assumption that time affected the results less plausible. Future studies should examine the deficient perceptual filtering hypothesis in ADHD more thoroughly by varying the perceptual load (Lavie, 1995).

A motivational concept of inhibition was also assessed in the experiment. The addition of punishment trials after a period of reward trials was expected to cause less caution in ADHD children in comparison to control children, resulting in faster response times at the cost of accuracy. Analyses of performance during response contingencies revealed that all children responded faster towards trials with punishment warnings compared to trials preceded by reward warnings, suggesting that children actively tried to avoid punishment. Compared to control children, children with ADHD responded less accurately in phases in which punishment warnings could occur. Motivational and cognitive inhibition demands, however, did not influence each other. Thus, although ADHD children responded less accurately in the face of punishment, they did not inhibit more poorly when punishment trials were presented compared to reward only. This result argues against a weak BIS system in ADHD children (Quay, 1997) and is consistent with Nigg (2001), who concluded on theoretical grounds that ADHD is characterized by executive deficits, whereas deficient motivational processes are not well supported in ADHD, suggesting a distinction between executive and motivational regulatory processes (Mezzacappa, Kindlon, Saul, & Earls, 1998).

From a psychophysiological perspective (based on Fowles, 1980, 1988), we expected that if children with ADHD suffer from a weaker BIS (Quay, 1997), the number of SCR during the task phase with punishment warnings would be less for these children (Iaboni et al., 1997). The skin conductance findings, however, failed to reveal any differences between the groups or contingency phases. According to Fowles' (1980, 1988) argument, the skin conductance data suggest that the task failed to challenge the BIS. Following Fowles, heart rate level was expected to be less elevated during the task phase in which punishment trials were present, especially for children with ADHD. The heart rate findings, however, showed the opposite results. Heart rate level increased when punishment could occur, and did not differentiate between groups. The present task set-up, however, provided BIS triggering warnings of punishment in the second and third contingency phases, indicating that money could possibly be lost, but at the same time gave children the opportunity to avoid punishment by responding fast and accurately, resulting theoretically in BAS activity. Warning cues and actual feedback could therefore have influenced BAS and BIS activity at the same time. Thus, we also performed an analysis that focused on immediate effects of reward, punishment, reward loss, and punishment avoidance, because not only motivational warning cues, but also feedback can activate approach (BAS) and avoidance (BIS) behavior (Nigg, 2001). Analysis of skin conductance responses revealed no significant relation between punishment and non-reward and skin conductance for any of the groups. Heart rate analysis revealed, as expected, that reward and punishment avoidance resulted in heart rate increase, and this effect was somewhat less pronounced for ADHD children. Iaboni et al. (1997) reported similar heart rate results, showing that heart rate responses to reward habituated faster for ADHD children, suggesting a BAS (reward-dependent) instead of a BIS (punishment-dependent) deficit in ADHD children.

Several theoretical models have tried to explain motivational differences between ADHD and control children. Quay (1997) suggested that ADHD may be characterized by a weak BIS. We could not find evidence for this hypothesis, given that executive and motivational inhibition were not related, and skin conductance responses between ADHD and control children did not differ. A second influential line of research that is more in line with the current findings, suggests that ADHD children show deficit approach tendencies in the presence of imminent reward rather than deficits in avoidance behavior (Nigg, 2001). This has been suggested, for example, by Haenlein and Caul (1987), who proposed an elevated reward threshold theory to explain behavior of ADHD children, based on animal pharmacological studies and behavioral and medication studies with ADHD children. They argued that the amount of reinforcement necessary to sustain maximal performance in ADHD children is well above the amount of reinforcement necessary in normal children. In other words, ADHD children need a greater amount of reward than control children in order to achieve the same level of performance. Iaboni et al. (1997) previously suggested that ADHD children might have a BAS deficit, because their heart rate habituated faster toward reward stimuli, similarly as found in this study. A related line of research has shown that ADHD children are more dependent on immediate effects of previously rewarded trials, whereas control children are more influenced by their overall history of reward on the task (Tripp & Alsop, 1999). Thus, the immediacy or amplitude of positive reward, rather than any feature of negative reinforcement may control the behavior of ADHD children, suggesting that reward, rather than avoidance systems may be abnormal in ADHD children (Nigg, 2001).

In summary, the present findings suggest, together with recent research findings, that ADHD children suffer from a deficit in executive functions (filtering) (Barkley et al., 1997; Jonkman et al., 1999; Mezzacappa et al., 1998; Nigg, 2001), and a deficit approach (reward-related) system (Haenlein & Caul, 1987; Nigg, 2001). In this study we made an effort to examine to what extent separate lines of theories (executive-motivation distinction) might reflect a similar underlying construct. The findings revealed no evidence for dependent executive and motivational inhibition systems, arguing against a BIS difference between ADHD and control children. Future research should focus on separate influences of motivational state versus immediate effects of reward and punishment, and to what extent motivational or executive deficiencies are the core deficit of ADHD children's behavioral problems (see also Nigg, 2001, for a review and interesting research suggestions).

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Appendix: Instruction Flanker task

Level 0: Imagine you are the pilot of a spaceship. You have to navigate the ship through the gap. There is a way to do this. Your ship has a radar, which will give you the direction that you should take. Every time the radar gives an arrow to the right, squeeze the handle to the right; when the radar gives an arrow to the left, squeeze the handle to the left. There is an enemy that tries to destroy your ship. You have to be a fast pilot that does not make mistakes.

Level 1: Pay attention to the following. You have been given 5 dollars for this mission. You can make more money if you do well, but you can also lose money when you make mistakes. Every time you enter a blue zone, this means you are in a safe zone. In this zone you can earn money when you are fast enough and don't make mistakes. Every time you do well, the empire will reward you for getting through the gap and you will earn 10 cents. You will see a dollar sign on the screen. But be careful of the enemy; every time you enter a red zone, the enemy is offering a reward for your capture. You have to get through the gap fast, without making mistakes, or your ship will crash and you will lose 10 cents. You will see an explosion on the screen. We will try this out right now; you will get 5 chances to earn money because in this try-out you will only be in the safe zone.

Now the real game is going to start, but remember, you will also enter dangerous red zones now, in which you can lose money. Try to be as fast as possible and try not to make many mistakes.

Level 2: In the next part of the game, you will have to fly to the right and the left again, but sometimes it is better not to change direction at all. When the radar gives you signs to go to the left or to the right you will have to squeeze the handle to the left or right again. But this time the radar will also give you a message not to change direction at all, indicated by a diamond shape. When this happens, don't go right or left. Remember when the screen is blue you are in a safe zone, but when the screen gets red, the enemy will try to get you and you will lose money if you make a mistake or are not fast enough. We will try this out right now; you will get 5 chances to earn money, because in this try-out you will only be in the safe zone.

Now the real game is going to start, but remember, you will also enter dangerous red zones now, in which you can lose money. Try to be as fast as possible and try not to make many mistakes.

Level 3: The enemy is going to make it a little bit more difficult for you now. He will try to distract you by putting extra hints on the screen. The hints can mislead you if you are a careless pilot. The trick is that the right sign is always in the middle. The radar will give you directions to the left or to the right. Try not to let the enemy distract you by the extra signs on the screen, try to focus only on the sign in the middle that gives you the directions from the radar. We will try this out right now; you will get 5 chances to earn money, because in this try-out you will only be in the safe zone.

Now the real game is going to start, but remember, you will also enter dangerous red zones now, in which you can lose money. Try to be as fast as possible and try not to make many mistakes.

Level 4: In this part, the radar will not only give you directions to the left or to the right, but will also sometimes give you signs in the shape of a diamond, that tells you not to change direction at all. In this case you should not move the handle. Beware of the enemy who tries to distract you with extra hints. Only pay attention to the sign in the middle that is the real radar sign. We will try this out right now; you will get 5 chances to earn money, because in this try-out you will only be in the safe zone.

Now the real game is going to start, but remember, you will also enter dangerous red zones now, in which you can lose money. Try to be as fast as possible and try not to make many mistakes.

Level 5: This part is the same as the last part, but the enemy will try to distract you now with other signs. Don't let the enemy distract you and only pay attention to the sign in the middle. When it gives you directions to the right you should squeeze the handle to the right, when it gives you a direction to the left you should squeeze the handle to the left. When it gives a sign not to change direction, you shouldn't pull the handle at all. We will try this out right now; you will get 5 chances to earn money, because in this try-out you will only be in the safe zone.

Now the real game is going to start, but remember, you will also enter dangerous red zones now, in which you can lose money. Try to be as fast as possible and try not to make many mistakes.

Level 6: The enemy is again trying to make it more difficult for you. Don't let the enemy distract you and only pay attention to the sign in the middle. When it gives you directions to the right you should squeeze the handle to the right, when it gives you directions to the left you should squeeze the handle to the left. We will try this out right now; you will get 5 chances to earn money, because in this try-out you will only be in the safe zone.

Now the real game is going to start, but remember, you will also enter dangerous red zones now, in which you can lose money. Try to be as fast as possible and try not to make many mistakes.

Level 7: You are almost there. Don't let the enemy distract you and only pay attention to the sign in the middle. When it gives you directions to the right you should squeeze the handle to the right, when it gives you directions to the left you should squeeze the handle to the left. We will try this out right now; you will get 5 chances to earn money, because in this try-out you will only be in the safe zone.

Now the real game is going to start, but remember, you will also enter dangerous red zones now, in which you can lose money. Try to be as fast as possible and try not to make many mistakes.