MIND, BRAIN, AND EDUCATION

Distinguishing and Improving Mouse Behavior With Educational Computer Games in Young Children With Autistic Spectrum Disorder or Attention Deficit/Hyperactivity Disorder: An Executive Function-Based Interpretation

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ABSTRACT—In this exploratory multiple case study, it is examined how a computer game focused on improving ineffective learning behavior can be used as a tool to assess, improve, and study real-time mouse behavior (MB) in different types of children: 18 children (3.8–6.3 years) with Autistic Spectrum Disorder (ASD), Attention Deficit/Hyperactivity Disorder (ADHD), or comorbid ASD and ADHD, and 5 effectively learning (EL) children (3.5–3.8 years). The children's MB processes, for example "Errors" and "Reaction times," were interpreted in terms of executive functions (EFs). Trajectories of averaged MB were compared among the groups of ASD, ADHD, comorbid, and EL children. Clinical groups showed differences in their MB, which were similar to the expected differences based on EF tests. In addition, a case study of a typical ASD, ADHD, and EL child was included in order to demonstrate typical individual MB patterns across time. MB processes might therefore provide a window into the processes of EF (dys)functioning.

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Children with Attention Deficit/Hyperactivity Disorder (ADHD) or Autistic Spectrum Disorder (ASD) show impairments in executive function (EF) skills (e.g., Barkley, 1997; Happé, Booth, Charlton, & Hughes, 2006; Sarkis, Sarkis, Marshall, & Archer, 2005). EFs refer to higher order cognitive processes that control and regulate abilities and behavior. Examples are response initiation and selection, planning and strategy formation, cognitive flexibility (Frensch & Funke, 1995), and response inhibition (e.g., Happé et al., 2006).

Difficulties with EF are often associated with learning disabilities (Bramham et al., 2009; Mayes & Calhoun, 2007), which may lead to developmental delays (Diamond, Barnett, Thomas, & Munro, 2007). However, ASD or ADHD children tend to have different EF problems (Bramham et al., 2009; Happé et al., 2006).

Interventions have been developed to improve preschool children's EF skills to reduce early developmental delays (Diamond et al., 2007; Thorell, Lindqvist, Nutley, Bohlin, & Klingberg, 2009). Among these, educational computer games can function as effective, practical tools to improve learning behavior in children with ADHD and/or ASD (e.g., Carnahan, Basham, & Musti-Rao, 2009; DuPaul & Eckert, 1998; Klingberg et al., 2005; Passerino & Santarosa, 2008; Shaw & Lewis, 2005).

The aim of this article is to evaluate whether an educational computer game, focused on improving ineffective learning behavior, is able to positively affect and diagnostically assess children with ADHD and/or ASD, based on their mouse behavior (MB). We will present an EF-based interpretation of MB patterns. Effective MB is needed to adequately solve an educational computer task; for example, responses should be planned, initiated, or inhibited. We shall argue that many of the behaviors, particularly the MB, elicited in a computer task for young children described in this article show a striking resemblance with those elicited in a wide variety of tests of EF. However, we do not claim that this game can be seen as yet another way to measure EF (partly because we have not studied the correspondence between MB and results on these EF tests in our sample). On the other hand, the resemblance of the behavioral level is strong enough to support the assumption that MB is sufficiently related to the (unknown) EFs in the children, and to warrant the interpretation that MB can be used as naturalistic analogs of behaviors elicited in EF tests. To support this assumption, we shall first describe differences in EFs among children of various clinical groups, and then show that these groups showed differences in MB that are very similar to the predicted differences based on EF tests.

EF Skills in Different Types of Children

EF impairments have been reported in both children and adults with ADHD or ASD (e.g., Mayes & Calhoun, 2007). Although the majority of studies reported differences in impairments of multiple EF areas in ADHD or ASD children (Bramham et al., 2009), there is still some inconsistency regarding specific impairments in EF domains (Corbett, Constantine, Hendren, Rocke, & Ozonoff, 2009). Most studies report response inhibition, vigilance, working memory, planning, and flexibility as deficits in ADHD children, with problems in inhibition and vigilance as core to ADHD (Boonstra, Oosterlaan, Sergeant, & Buitelaar, 2005; Willcutt, Doyle, Nigg, Faraone, & Pennington, 2005). Despite a lack of specificity in EF problems in ASD children (Happé et al., 2006), response perseveration, planning, and cognitive flexibility problems seem to be core to ASD children (Corbett et al., 2009; Geurts, Verté, Oosterlaan, Roeyers, & Sergeant, 2004; Ozonoff & Jensen, 1999; Ozonoff, Pennington, & Rogers, 1991).

ASD is a relatively heterogeneous diagnostic category, as it comprises core autism, Asperger, and PDD-NOS. However, distinctions among these disorders have been found inconsistent over time (APA, 2011) and literature shows that it is unclear whether their EF dysfunctions can be consistently distinguished per category (Bramham et al., 2009). Therefore, in this article, we do not distinguish subcategories of ASD.

Although ASD as well as ADHD children have problems with planning, flexibility, and working memory, the nature of the problems is different. Most studies reported that ASD children exhibit selective attention (for self-selected tasks) and are able to hyperfocus for a long time, while ADHD children are more inattentive (Mayes & Calhoun, 2007). A meta-study by Bramham et al. (2009) demonstrated that ASD children do not show deficits in response inhibition, in contrast to ADHD children, who most commonly lack inhibition. Furthermore, ASD adults were slow in planning their responses, while ADHD children and adults showed difficulties with withholding a response.

Furthermore, children with impulsive learning behavior exhibit a high response uncertainty with many errors (Kagan, 1965). In comparison with effectively learning (EL) children, ADHD children vary more in their response speed compared to EL children, indicating that they have more problems with performing at a stable level. They also show a higher proportion of inhibition errors and misses in the Go/ No go task as well, which indicates problems with inattention (Barkley, Grodzinsky, & DuPaul, 1992; Fischer, Barkley, Smallish, & Fletcher, 2005; Kalff et al., 2005).

In this article, we define EL children as children who do not have a diagnosed learning disorder, and usually show a reflective cognitive style: They regularly show adequate problem-solving strategies and self-control (Kagan, 1965). Research indicates that even 4-year-old children can inhibit dominant responses (Davidson, Amso, Anderson, & Diamond, 2006). EL children withhold their responses until they have reached a high probability of giving a correct answer (Bornas, Servera, & Llabrés, 1997; Kagan, 1965). They usually gather their information systematically or carefully and evaluate their progress. Therefore, in this article we assume that these children usually do not show EF dysfunctions.

There is a high comorbidity of ASD and ADHD (e.g., Goldstein & Schwebach, 2004). However, most studies that compared EF skills of ADHD and ASD groups excluded the comorbid group with both ADHD and ASD (Bramham et al., 2009; Geurts et al., 2004; Goldberg et al., 2005). One study demonstrated that the comorbid group showed the same impairments as the ADHD group regarding inhibitory control (Sinzig, Morsch, Bruning, Schmidt, & Lehmkuhl, 2008). However, Yerys et al. (2009) demonstrated that the comorbid children show exacerbated impairments in some but not all domains of EF relative to children with ASD only.

Present Study and Hypotheses

On the basis of the idea that ineffective learning behavior can be improved in a playful manner, an educational computer game has been developed (www.samenslim.nl). In this game, the instruction and feedback is adapted to individual problem-solving behavior. The website automatically registers MB per child, such as the number of mouse clicks and errors. With this information, learning behavior during the game can be continuously monitored and described in real time, and insight can be obtained into individual children's learning processes and MB.

We hypothesize that the MB patterns of ASD, ADHD, and EL children correspond to differences in EF dysfunctions typical for these types of children. To analyze this, we selected different MB aspects that can be compared to actions requested in tasks aimed at measuring EF (dys)functioning in children with ADHD or ASD, such as the Go/No go Response Inhibition task, which measures the degree of inhibitory control (e.g., Falkenstein, Koshlykova, Kiroj, Hoormann, & Hohnsbein, 1995), or the Wisconsin Card Sorting Test, which measures perseverative errors and responses (Heaton, Chelune, Talley, Kay, & Curtiss, 1993).

The first aim of this study is to investigate whether these specific MB skills can be distinguished between types of children and correspond to the EF dysfunctions typical for different types of children. Analyses will be conducted on the basis of the MB patterns across time of children with ASD, ADHD, comorbid ASD and ADHD, and EL children (Table 1).

To characterize the differences between the perseverative behavior of ASD children and the high response uncertainty and uninhibited behavior of ADHD children, we will analyze differences in the variability of these variables between the ASD, ADHD, and EL children. We hypothesize that ADHD children will show relatively large variability in their MB characteristics (due to a high response uncertainty and short attention spans) and ASD children relatively low variability (due to perseverative responses and hyperfocused behavior). In the middle, we expect to see the children who regularly show EL behavior, with relatively effective MB skills during the games, but not as uncertain as ADHD children and as rigid as ASD children. Because there is a lack of studies of EF skills, we cannot make clear predictions concerning the children with comorbid ASD and ADHD. As a consequence, our analyses with regard to children with both ADHD and ASD will be exploratory.

Table 1
Summary of Hypotheses: Differences in MB Skills Between ASD, ADHD, and EL Children and the Correspondence Between Mouse Behavior and EFs at an Observational Behavioral Level

		Ordinal Position		
Mouse characteristic	*EF skill*	*Fewest/ lowest/ slowest*	*Moderate*	*Most/ highest/ fastest*
1. Errors	Inhibition	EL	ASD	ADHD
2. No go	Inhibition	ASD	EL	ADHD
3. Missing go	Initiation and inhibition	EL		ASD/ADHD
4. Reaction time	Initiation and inhibition	ASD	EL	ADHD
5. Go	Initiation and inhibition	ASD	EL	ADHD
6. Repeats	Perseveration	EL	ADHD	ASD

MB = mouse behavior; EF = executive functions; ASD = Autistic Spectrum Disorder; ADHD = Attention Deficit/Hyperactivity Disorder; EL = effectively learning.

The second aim of this study is to test the hypothesis that, by playing the games, MB skills of children with ASD, ADHD, and comorbid ASD and ADHD will improve. As adaptive in-game instruction on performances is provided, ineffective MB skills (e.g., a high number of errors in combination with fast reaction times) are likely to be channeled into more effective MB skills (e.g., a decreasing number of errors and slower reaction times). We will test whether specific, EF-related MB characteristics will improve across the games. However, we do not expect improvement in the EL group, since we expect that they show effective MB skills from the beginning.

In short, we formulated two main hypotheses in this article. The first hypothesis is that MB characteristics can be used to *distinguish* four types of children (see for a systematic overview of specifications in Table 1). The second, more general hypothesis is that it is possible to *improve* MB characteristics in the four types of children by means of a computer game.

In view of the labor-intensive nature of this kind of study, the number of children involved in this multiple case study is low. To gain insight into individual MB trajectories, we will present two complementary studies. The first is a study of trajectories of averaged MBs of small groups of ADHD, ASD, comorbid, and EL children. The second is a case study of individual MB trajectories of a typical ADHD, ASD, and EL child. This study will provide insight into actual changes in behavior within individual children typical of a particular clinical group.

METHOD

Participants

Clinical Children

A total of 19 children with ASD and/or ADHD from four medical daycare centers in the Netherlands were recruited for this study, after parental approval. These children were diagnosed by a licensed psychologist at the medical daycare center using DSM-IV diagnostic criteria. To measure behavioral and social emotional problems, the Child Behavior Checklist (CBCL; Achenbach, 1991) and the Sociaal Emotionele Vragenlijst

Table 2
Chronological Age and MSEL Composite Standard Scores and Raw Scores of Four Groups

	ADHD (n = 2)	*ASD (n = 13)*	*Comorbid (n = 3)*	*EL (n = 5)*	*Total (n = 23)*
	M (SD)	*M (SD)*	*M (SD)*	*M (SD)*	*M (SD)*
CA	5.3 (0.80)	5.1 (0.80)	5.0 (0.79)	3.8 (0.14)	4.8 (0.87)
CSS	86 (−)	93.2 (16.6)	98.3 (19.1)	120.2 (10.3)	99.5 (18.0)
FM	43 (−)	44.54 (2.93)	44.67 (2.08)	39.6 (3.91)	43.36 (3.57)
VR	45.50 (−)	45.62 (0.71)	46.33 (3.02)	43.20 (2.08)	45.17 (3.01)
LC	40 (−)	42.46 (3.13)	44 (2.65)	40.80 (2.39)	42.18 (2.92)
LP	40 (2.62)	44.15 (3.27)	46.26 (5.55)	43.80 (3.27)	44.14 (4.65)

CA = chronological age in years; CSS = Composite Standard Scores; FM = Fine Motor Skills; VR = Visual Reception; LC = Language Comprehension; LP = Language Production.

(Social Emotional Questionnaire; SEV; Scholte & Van der Ploeg, 2005a) were administered to parents and teachers. To assess ADHD or ASD, the ADHD Vragenlijst (ADHD Questionnaire; AVL; Scholte & Van der Ploeg, 2005b), the Sociaal Cognitieve Vaardigheden Test (Social Cognitive Skills Test; SCVT; Van Manen, Prins, & Emmelkamp, 2005), the Theory of Mind-test (ToM-test; Steerneman, Meesters, & Muris, 2002) or the Schaal van Vroegkinderlijk Autisme (Scale of Early Autism; Auti-R; Van Berckelaer-Onnes & Hoekman, 1991) were administered.

EL Children

Thirteen children (with no learning disorder) from regular preschool education were recruited from a general population sample and were rated consistently as EL children by three raters (a trained rater, parents, and teachers). The questionnaire consisted of descriptions of behavior of typical unresponsive, reflective, and impulsive children (Veenstra, Van Geert, & Van der Meulen, 2010). The raters had to categorize each individual child into the best fitting category according to their regular learning behavior (for more information on the questionnaire and learning types, we refer to the online Supporting Information: Appendix S1 at www.paulvangeert.nl/articles_appendices.htm). This was done to be relatively sure that no children with ineffective problem-solving behavior (impulsive or unresponsive behavior) were selected in this study.

Selection Criterion for Both Clinical Children and EL Children After Recruitment

Furthermore, to select the children with sufficient motor and language skills to understand the in-game instruction and to move the mouse adequately, a cut-off point of the raw scores on the Mullen Scales of Early Learning (MSEL) of 34 on the subscales Language Comprehension (LC) and Fine Motor Skills (FM) was chosen (for details about criteria: Veenstra, Van Geert, & Van der Meulen, 2008). As a result, 5 EL children (chronological age: 3.5–3.8 years) and 13 clinical children (chronological age: 3.8–6.3 years) were included in this study (Table 2).

On average, the clinical group had lower-educated parents than the group of EL children (on a scale for educational level, categorized from no education (1) until university (8). The mean levels were $M = 4.86$ and 6.10, for clinical and EL children respectively, $SD = 1.57$, $p = .04$. However, the clinical group on average showed higher raw scores on the subtests of the MSEL, which might be caused by a higher chronological age than the EL children. Clinical and EL children also differed significantly in normalized standard scores on the MSEL ($M =$ 93 and 120, respectively, $SD = 10.3$ and $SD = 18.05$, $p < .001$), indicating that the clinical group was relatively cognitively delayed. Therefore, standard scores were controlled (by means of the Composite Standard Scores of the MSEL) in the analyses between the four groups.

Instruments

Normalized Standard Scores

Standard Composite Scores and raw scores on FM, Visual Reception, LC, and Language Production (Table 2) were obtained from the MSEL, in Dutch translation (AGS Edition; Mullen, 1995).

MB Skills

Individual mouse data, such as number of clicks or errors per game, were collected automatically while the children were playing the game on www.samenslim.nl (Veenstra et al., 2010). This resulted in a continuous measurement of the children's level of knowledge and skills within the context of the *samenslim* games. In the game of hide and seek, two children play the leads: "Sim" and "Sanne." The child is supposed to help Sim find Sanne by clicking on objects behind which Sanne could be hiding. If the child clicks on a wrong object, only shifts the mouse or does nothing at all with the mouse, he or she is given simple, helpful pointers (adapted to the mouse performances of the child) from a friendly little bear, for example "you first have to look, then to click" or "no, this was not the right object, look

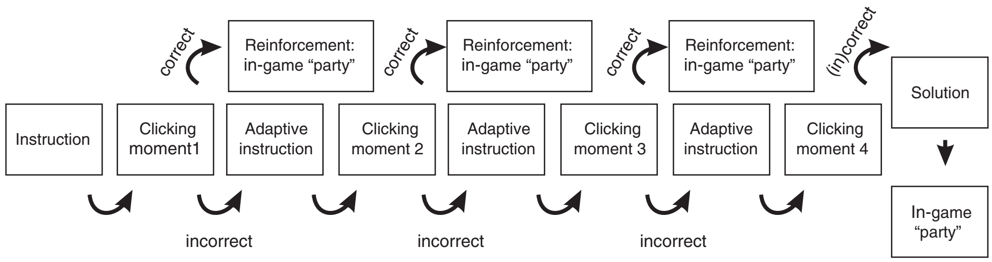

Fig. 1. Design of the game. During the clicking moments, a response is requested from the child.

further." The game consists of five concept levels. In Figure 1, we present the design of the *samenslim* game, which consists of four clicking moments (in which the child is requested to show a response) and four short instruction moments (during which the child is not allowed to show a response). After the fourth clicking moment (if the child has not finished the game earlier), the solution is provided by the bear.

Procedure

MB might reflect differences in fine motor control, prior knowledge, or visual reception. To control for these differences, before playing the games, mouse skills were practiced with a trained supervisor. The level of controlling the mouse was assessed with a computer game for preschool children, which was unrelated to the experimental task, in which the child was requested to click on an animal that corresponds to the sound of that animal. If the child was able to move and click adequately within a reasonable amount of time (irrespective of whether it was the right animal), he was supposed to be able to control the mouse. Thus, after the training, all children showed fully mastered mouse skills.

Furthermore, prior knowledge of concepts used in the *samenslim* games was assessed with an ad hoc test, which was specifically developed for these games. To test prior knowledge used in the games, similar concepts (similar pictures of objects used in the *samenslim* games) ($n = 16$) were assessed. Of all children, one child showed one error in the ad hoc test, while the others showed no errors. Therefore, it can be concluded that all children were able to discriminate and perceive the requested in-game objects.

In the actual study, each child played two or three game sessions (depending on the child's performance) on www.samenslim.nl during 2 or 3 weeks in a quiet room at the medical daycare center or playgroup. A supervisor was present only for technical help. After completing a maximum of seven games during one game session, the child was escorted back to the classroom.

Analysis

Six MB skills of the children were selected from the automatically registered mouse data.

1. *Incorrect object clicks (Errors):* The total number of clicks on the incorrect object (irrespective of clicking moment or instruction moment) (range 0–∞).
2. *Number of clicks during instruction moments (No go):* The total number of (in)correct mouse clicks during the four instruction moments and during the moment of solution (range 0–∞).
3. *No clicks during clicking moments (Missing go):* The frequency of showing zero clicks during a computer-generated clicking moment (range 0–4).
4. *Response times (Reaction time):* The time between the beginning of clicking moment 1 and the first (in)correct mouse click (range 0–15 s).
5. *Number of clicks during clicking moments (Go):* The total number of (in)correct mouse clicks during the four clicking moments (range 0–∞).
6. *Repeated clicks on the same objects (Repeats):* Minimally two mouse clicks on the same object (irrespective of whether it was the requested object or not) during two consecutive moments (e.g., clicking moment two, followed by corrective feedback). A repeat was scored by a "1," with a maximum of a total frequency of nine per game (range 0–9).

The second, third, and fifth mouse characteristic can be compared to actions requested from children in a Go/No go Response Inhibition task, which has been widely used in ADHD research and research on EF in children. "Repeats" are defined as perseveration, since this indicates that a child keeps clicking on the same wrong object while it was instructed to switch to another. As each child played a different number of games (according to a standardized decision model, see for details: Veenstra, 2011, p. 14, which involved skipping games in the middle), each total per game was summed over all games and divided by the total number of games that the child has played (min = 9, max = 13). Every child started at the lowest level and, depending on how well he or she played, reached the highest level sooner or later.

First, we exploratively compared small groups of children, to gain insight into different MB patterns of different types of children. Next, we conducted analyses on differences in individual MB patterns with a case study of an ASD, ADHD, and EL child.

In the case study of individual MB trajectories, the MB data across games were smoothed, to reveal the general form of the trajectory while keeping local spurts, plateaus, and regressions (see Appendix S5 for technical details).

Min–max graphs (Verspoor, Lowie, & Van Dijk, 2008) were used to investigate individual bandwidths of fluctuations in MB over time (see Appendix S6).

Furthermore, the coefficient of variation (CV) was calculated, which is the standard deviation of the residuals relative to the average to use as a relative measure of variability. To calculate the CV, a regression line was set up per mouse characteristic of a group. Next, the data were detrended (see Appendix S3) by subtracting the regression values from the observed values per group (Verspoor et al., 2008). With these residuals, the CV was computed, by dividing the standard deviation of the residuals by the group average.

In a multiple case study, by means of a linear regression, all six mouse variables were corrected for Composite Standard Scores, excepting the improvement scores and the data concerning the CV. The statistical procedures consisted of descriptive analyses performed in Microsoft Excel and permutation tests using Monte Carlo analysis (Good, 1999; Todman & Dugard, 2001) performed in Poptools (Hood, 2008). For a detailed example, see Visser, Kunnen, and Van Geert (2010). Each significance test was based on 1,000 simulations. With this random permutation test, it is possible to combine multiple MB characteristics in one test (for more details on this statistical analysis technique, see Appendix S2).

To measure improvement of specific MB characteristics across the games, we defined improvement scores, based on the regression lines of the z scores of the variables (see Appendix S7) as a relative improvement within a group (e.g., the ADHD group).

RESULTS

Part I: Focus on MB of a Sample of Different Groups of Children

Distinguishing MB Skills

To compare different MB skills of the four groups, we analyzed six different MB characteristics. In this section, we exploratively analyze the comorbid group and compare small groups of children with ADHD or ASD and EL children.

As shown in Figure 2, it is striking that the differences between ADHD children and the other three groups were relatively large, particularly in the "No go" and "Go," "Errors" and "Reaction time" (Table 3), which indicates a high correspondence with the results in the case study.

Taking a closer look at the ASD, the comorbid, and EL group, we also found significant differences between the MB in these groups. However, the differences were smaller than those between ADHD children and the other children (for effect sizes [ES] and p values, see Table 3). The largest differences between the mouse characteristics can be observed in the ADHD group compared to the EL children (ES = 1.2), the comorbid group (ES = 1.6), and the ASD children (ES = 1.7). All three groups showed better performances than ADHD children on all mouse characteristics. However, there were no significant differences between ADHD children and ASD on the "Missing go." They both showed relatively few "Missing go," indicating that the ASD children do show responses when it is requested.

The differences between ASD children, comorbid ASD and ADHD, and EL children were relatively small. ASD children performed better than children with both ASD and ADHD: They made fewer "Errors" and showed lower "No go." Children with comorbid ASD and ADHD, on the other hand, showed a lower "Missing go," a higher "Go" (which was relatively low for ASD children), a shorter "Reaction time" and fewer "Repeats."

Children in the comorbid condition showed fewer "Errors" and a lower "No go" than the EL children. ASD children also exhibited a lower "No go" and fewer "Errors." They also showed a lower "Go." However, it should be taken into account that the ES were relatively small (ASD vs. EL children, ES = .13; comorbid vs. EL children, ES = .38).

However, with these results concerning ES, no insight is gained into the developmental process of MB in different groups. Figure 3 shows the time serial cluster scores for the four groups (for procedural details, see Appendix S4). The first cluster was dubbed "fast errors," since it correlated highly with the variables "Errors," "No go," and "Go," and correlated negatively with the "Reaction time." The second cluster corresponded with the variable "Repeats" and the third with the variable "Missing go." The four groups are characteristically different in terms of their time serial cluster profiles: The ADHD group loads high on "fast error," as expected, the level of which gradually diminishes over the course of the 13 games. The ASD group is typically high on "Missing go," with maximum values at the beginning and at the end of the series of games. The comorbid group scores high on "Repeats." The EL children are characterized by the smallest bandwidth of cluster scores (between −1 and +1).

Taking a more detailed look at the actual stability or variability across time, we measured the degree of rigidity (relatively low variability) or response uncertainty (relatively high variability). The variability of six different MB characteristics (Table 4) was analyzed per group. CV was computed by dividing the standard deviation of the residuals relative to the average of the group.

The results regarding the CV demonstrate that the comorbid children showed on most mouse characteristics the *highest* variability compared to the other children (Table 4), except on "Missing go" and "Repeats." The permutation test showed that the variability differed significantly from the random

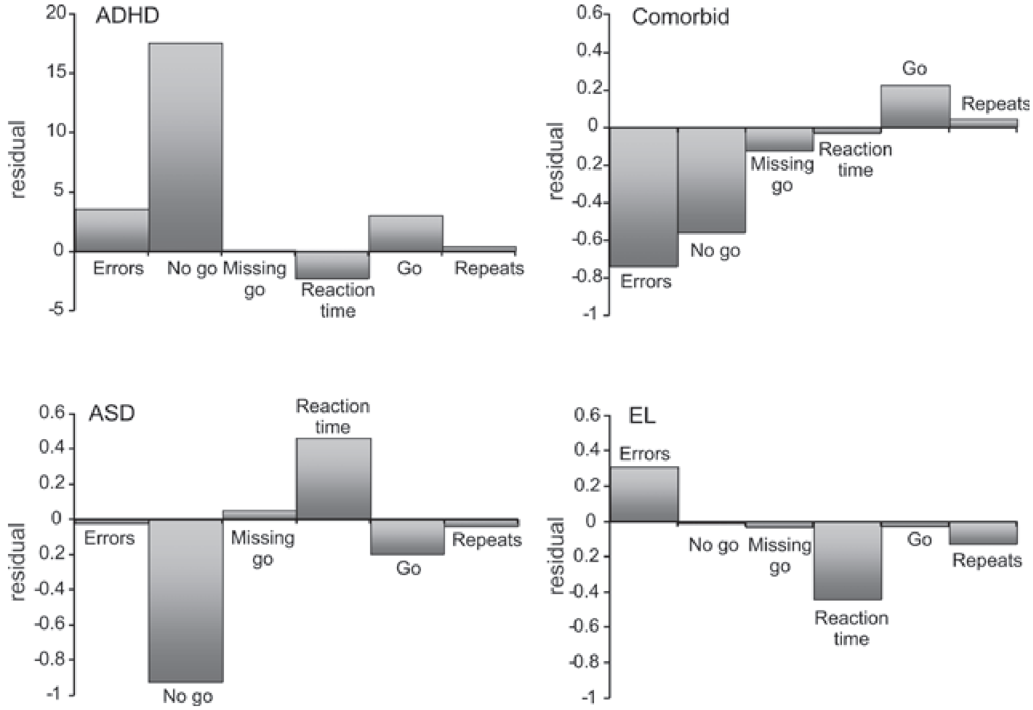

Fig. 2. MB characteristics per group of children (corrected for Standard Scores of cognitive development), relative to the grand mean. MB = mouse behavior; ASD = autistic spectrum disorder; ADHD = attention deficit/hyperactivity disorder; EL = effectively learning.

model ($p < .001$), except for "Go" and "Reaction time." ASD children also showed on most mouse characteristics the *lowest* variability ($p < .001$), except on "Repeats." However, "Missing go" does not seem to be an adequate mouse characteristic to distinguish variability in different children, since only comorbid children differed significantly from the random model ($p = .04$). Children in the comorbid condition and ASD children can be distinguished on multiple mouse characteristics, namely in the variability of "Reaction time" ($p = .001$), "Errors" ($p < .001$) and "Missing go" ($p = .02$). The variability between comorbid children and EL children differed between "Missing go" ($p = .003$), and "Errors" ($p = .05$). The results only support the expected difference in variability between ASD and EL children in "Go" ($p = .04$).

Improving MB Skills

To gain insight into the developmental trends across time, the improvement of MB across the games per group is shown in Figure 4. An increasing line corresponds to an improvement and a decreasing line corresponds to an impairment of learning behavior. For example, we expected to see very short reaction times in ADHD children. Therefore, increasing reaction times are interpreted as an improvement, since they gradually learn to inhibit their responses. For ASD children and comorbid children, a *decrease* of reaction time has been defined as an improvement, since they gradually learn to show faster responses.

The first result is that the EL children did not show a significant improvement of MB across the games (Figure 4). The combination of an improvement of "Missing go" and the small improvement of "Reaction time" (which is presented as an increasing improvement curve, see Figure 4) was not significant ($p = .168$).

The ADHD children showed a significant improvement on all aspects ($p < .01$, for groups of curves), except on the "Go." The ASD children improved on fewer characteristics than the ADHD children. A significant improvement in ASD children was observed in a decrease in "Missing go," and a decrease in "Reaction time" and an increase in "Go" ($p < .01$). No improvement was observed in the "No go," "Errors," and "Repeats," since they were low in the beginning and increased across time. Furthermore, the children in the comorbid condition showed a significant improvement in the "Reaction time," "Repeats," and "Go" ($p < .01$). However, they showed impairments in the "Errors," "No go," and "Missing go."

Part II: Focus on Individual MB Trajectories

For the case study, a typical ADHD, ASD, and EL child were selected, based on theoretically expected maximal differences in MB. We did not select a comorbid child, since we did not have clear expectations about the direction of specific MB characteristics in this type of children.

Table 3
Effect Sizes and *p*-Values of Comparisons of Combined MB Characteristics Between the Four Groups of Children

Comparison	*Combination of MB characteristics*	*p-value*	*Average effect size combination of mouse clicks*
Comorbid versus ADHD	<1, 2, 3, 5, 6; >4	<.01	1.726
ASD versus ADHD	<1, 2, 5, 6; >4	<.01	1.601
EL versus ADHD	<1, 2, 3, 5, 6; >4	<.01	1.230
ASD versus comorbid	<1, 2	.014	0.453
Comorbid versus EL	<1, 2	.005	0.381
EL versus comorbid	<3, 4, 5, 6	<.01	0.366
Comorbid versus ASD	<3, 4, 6; >5	<.01	0.351
EL versus ASD	<3, 4, 6	<.01	0.333
ASD versus EL	<1, 2, 5	<.01	0.125
ADHD versus ASD	<3	.46	0.017

Note. 1: Errors; 2: No go; 3: Missing go; 4: Reaction time; 5: Go; 6: Repeats (see also Table 1). MB = mouse behavior; ASD = Autistic Spectrum Disorder; ADHD = Attention Deficit/Hyperactivity Disorder; EL = effectively learning.

First, we applied smoothing techniques to visualize general increases or decreases in different MB characteristics across time. Based on the smoothed lines in Figure 5, it can be observed that the ADHD child can be distinguished from the ASD child and the EL child on most MB characteristics. The distinction is based on the fact that the ADHD child shows MB at the top or at the bottom, which largely differs from MB

Table 4 Average, Standard Deviations and Variability Per Mouse Characteristic for the Different Groups, With a Relatively Low CV As More Rigid Behavior and a Relatively High CV As More Variable Mouse Behavior

	ADHD	*Comorbid*	*ASD*	*EL*
1. Errors				
Average	4.65	0.56	1.29	1.78
SD	2.70	0.73	0.55	1.28
CV	0.55	1.26	0.33	0.67
2. No go				
Average	20.85	1.72	1.44	1.87
SD	23.47	2.03	0.71	1.23
CV	1.03	1.18	0.45	0.65
3. Missing go				
Average	0.04	0.05	0.21	0.17
SD	0.14	0.13	0.18	0.20
CV	3.59	2.29	0.85	1.17
4. Reaction time				
Average	1.63	5.00	5.37	4.68
SD	0.73	2.49	0.77	1.25
CV	0.42	0.48	0.14	0.27
5. Go				
Average	6.42	3.21	2.82	2.74
SD	3.84	2.70	0.62	1.01
CV	0.60	0.84	0.21	0.37
6. Repeats				
Average	0.81	2.26	0.36	0.25
SD	0.63	1.02	0.21	0.17
CV	0.78	0.45	0.53	0.66

CV = coefficient of variation; ADHD = Attention Deficit/Hyperactivity Disorder; ASD = Autistic Spectrum Disorder; EL = effectively learning.

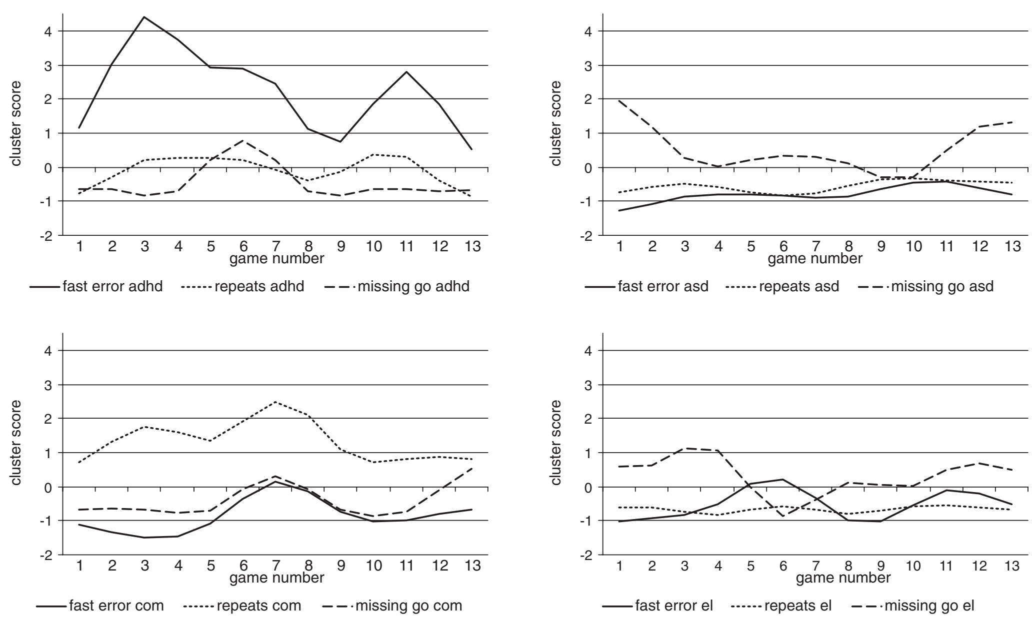

Fig. 3. Clusters of MB variables per type of child per game number. MB = mouse behavior.

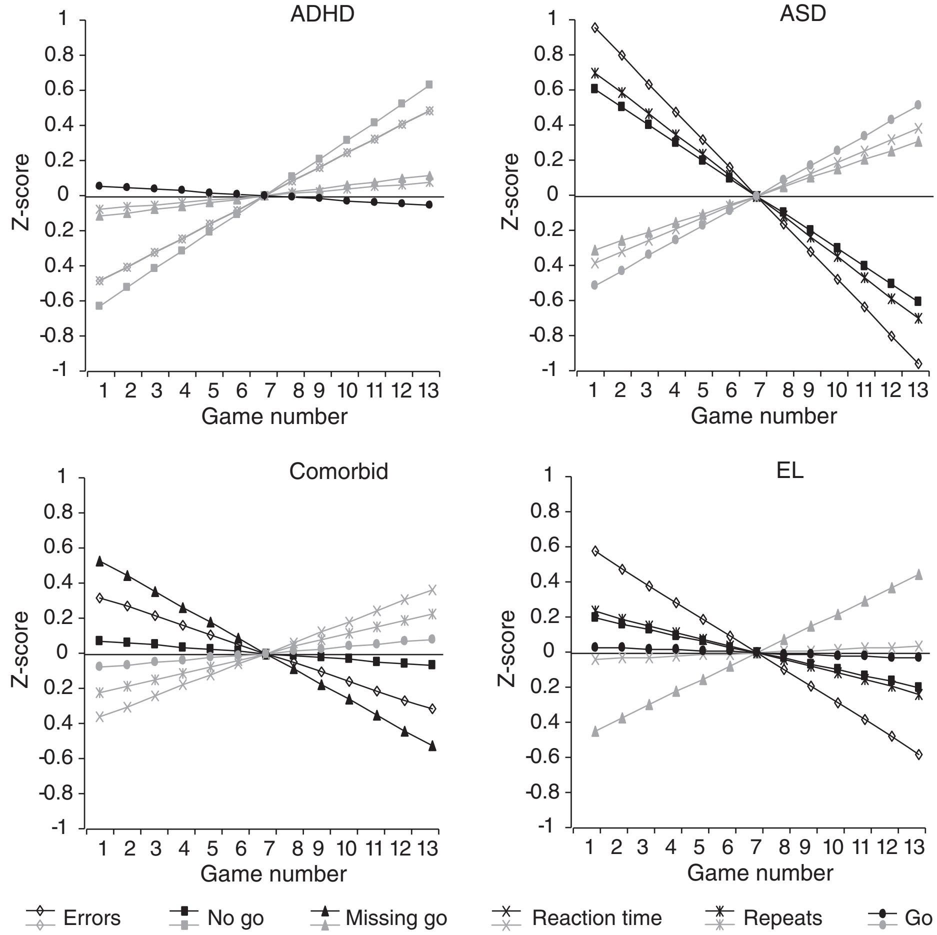

Fig. 4. Improvement scores per mouse characteristic for each group, with black lines indicating impairment and gray lines indicating improvement across the games.

in the ASD or EL child, who are more similar to each other. Most clearly, differences between the ADHD child and the other children can be observed in the peaks during the first games, for example a high number of "Errors" in combination with fast "Reaction times" and a high number of "Repeats." The ASD and EL children can also be clearly distinguished from each other, although less clearly than from the ADHD child. The ASD child shows slow "Reaction times," in combination with almost no "Errors" and a high number of "Missing go." As a consequence of the high "Missing go," the ASD child shows a relatively low number of "Errors" (since the child does not show responses within time). The EL child shows "Reaction times" in the middle of the spectrum in combination with almost no "Errors."

The data in Figure 5 further illustrate that only the levels of multiple MB characteristics, such as the number of "Errors," but also the peaks and fluctuations in the lines differ between the types of learners. Most striking is that a clear decrease of "Errors," "No go," and "Repeats" can be observed in the ADHD child. In line with our expectations, the ASD child shows a clear decrease in the "Missing go" and in the "Reaction times." Unsurprisingly, the EL child does not show such clear increases or decreases in the MB characteristics, but shows relatively effective MB in the beginning (one go per game, no "Missing go," relatively fast "Reaction times" in combination with a low number of "Errors").

As a smoothed line does not reveal variability or structure of the data (Verspoor et al., 2008), we further present a selection of min–max graphs in Figure 6 (for all graphs, see Figure S1), to illustrate the bandwidth of a developmental process (based on the observed values) of each child and its variability within the process. This figure shows that for the ADHD child, the bandwidth of "No go" considerably decreases and becomes smaller, indicating that the number of "No go" decreases and stabilizes across time. Across the games, the minimum remains relatively equal, while the maximum decreases. This indicates that the child is able to show relatively few "No go" during the beginning, but sometimes also shows a high number of "No go" in the beginning. The decrease of the extremely high number of "No go" across time can be interpreted

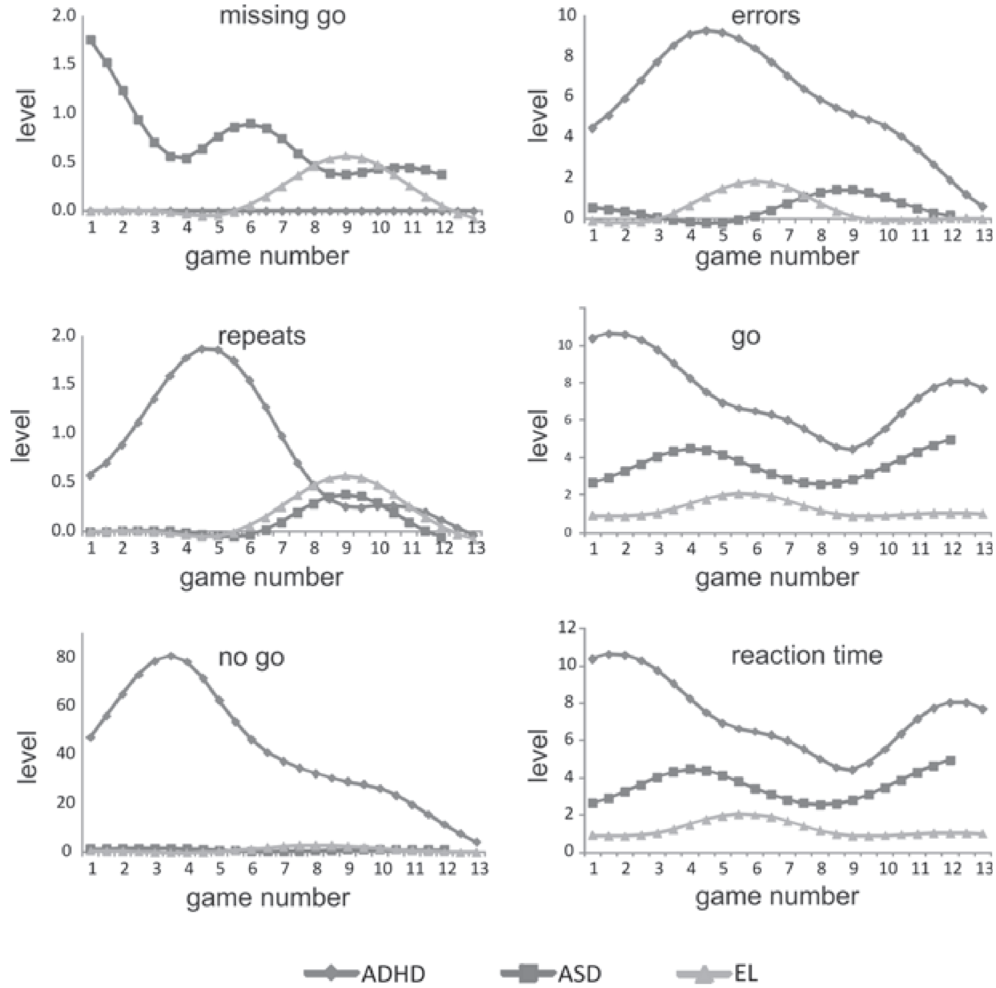

Fig. 5. Development of smoothed lines per mouse behavior characteristic per child across games.

as an improvement. If we take each mouse characteristic per child into account, clear differences and trends between different types of children can be observed. For example, the bandwidth of fast "Reaction times" of the ADHD child remains relatively stable. This is contrary to the ASD child, who shows highly variable "Reaction times," with a relatively large and increasing bandwidth, namely a decreasing minimum and with relatively stable maximum "Reaction times" across time. Furthermore, the ADHD child shows a fluctuating bandwidth of "Errors," namely a highly fluctuating minimum and at the end a fluctuating maximum. On the other hand, the ASD and EL child show a stable minimum, and a relatively stable maximum bandwidth of "Errors," indicating a stable low number of "Errors."

In Figure 6, some children show clear trends in their mouse characteristics. Since an upward or downward trend may cause overestimated variability (Verspoor et al., 2008), we first detrended the data (see Appendix S3).

The results in Figure 7 show that all children show a local peak of variability. However, the three children differ considerably in their initial levels of variability. The ADHD child shows the largest peak in variability at the beginning of the series of games, and then shows a reduction in variability which nevertheless remains high. The ASD child's variability lies between that of the ADHD and EL child, and increases and later decreases over the course of the games. The EL child begins with very low variability, which later increases and then diminishes toward the last game.

DISCUSSION

Part I: Focus on MB of a Sample of Different Groups of Children

Distinguishing MB Skills

Considering the first hypothesis, the results show that MB skills of children with ADHD, ASD, comorbid, and EL children can be distinguished. Furthermore, the MB characteristics seem to correspond to typical EF dysfunctions in different types of children, indicating that the six selected MB

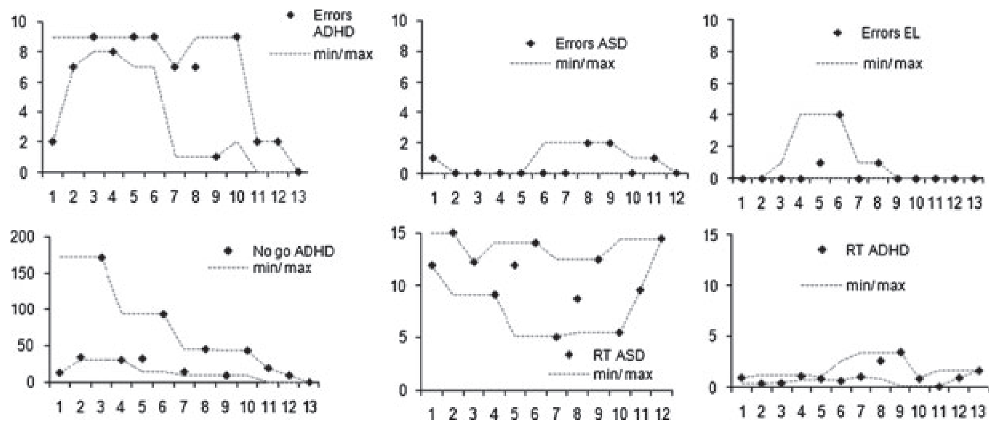

Fig. 6. A selection of min-max graphs representing the development of separate mouse characteristics per game per child. Because there are relatively few points in the trajectory, min-max graphs show a reduction toward the end which is not really adequate; see, for instance, the reaction in the ASD child where the minimum line should in fact stay at the level it had on the third point from the right. RT = reaction time; ASD = autistic spectrum disorder; ADHD = attention deficit/hyperactivity disorder; EL = effectively learning.

characteristics might be representative for different EF skills impairments in different types of children. According to the findings, it can be concluded that children with ADHD only can be most clearly distinguished from the other three types on the six mouse characteristics which seem to correspond to uninhibited behavior. Contrary to our hypothesis concerning variability is that ADHD children are not more variable than the other types of children, since the results indicate that ADHD children behave relatively constantly fast and uninhibited across time. This finding contradicts those of Ota and DuPaul (2002) or DuPaul and Eckert (1998), who reported increases in on-task behavior in ADHD children during computer-assisted instruction as compared to paper-and-pencil tasks. However, Shaw, Grayson, and Lewis (2005) found that ADHD children respond to different types of computer games in a way that typically developing children do not. This indicates that, if ADHD children are fully engaged, they are able to display specific forms of adequate executive functioning and show less uninhibited behavior (Brown, 1999, in Shaw et al., 2005), which suggests that there may be contexts in which uninhibited behavior may be reduced. This suggests that the ADHD children in this study might have played the games in an underaroused state.

The results demonstrate that ASD children have relatively more problems with initiation and show too much inhibited behavior (Robinson, Goddard, Dritschel, Wisley, & Howlin, 2009). They can be clearly distinguished from the EL children and the ADHD children mainly on the "Missing go." The combination of a relatively high increase in "Repeats" as compared to EL children, and the lowest variability in their behavior across time might be an indicator for rigid, perseverative behavior. Although ASD children showed fewer repeats (as a consequence of low initiative in the beginning) and clearly more "Missing go" than ADHD children, the number was clearly higher in proportion to the relatively low number of clicks, indicating that ASD children showed relatively more perseverative behavior, which is in line with the literature (Ozonoff et al., 1991).

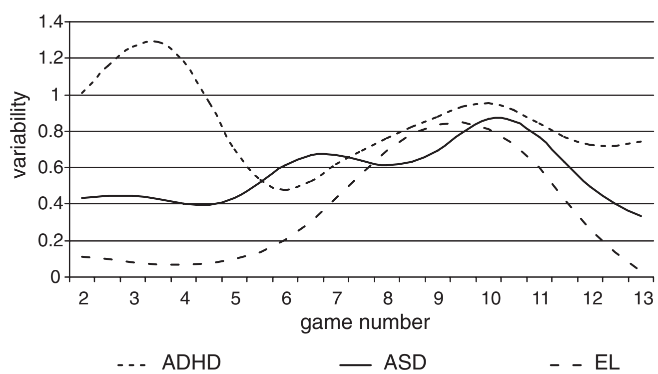

Fig. 7. Detrended lines of a combination of mouse characteristics per child per game.

The results suggest that children in the comorbid condition show more "Repeats" and fluctuations in inhibited and initiating behavior than ASD children, ADHD children, and EL children. However, it can be concluded that it is more difficult to distinguish specific MB skills of children in the comorbid condition from EL children than children with ASD or ADHD from EL children, since comorbid children did not show such large deficits in uninhibited responses or in initiating actions as the ASD or ADHD children (Bramham et al., 2009).

Improving MB Skills

MB improvement scores were computed to analyze differences in the progress of the different children. We can cautiously conclude that all four types of children showed different improvement patterns. EL children showed on average the least progress, which indicates they have less room for improvement since they already showed relatively effective MB skills. It is important to note that ASD children showed an increase in "Errors" and "Repeats" and an increase in "No go" across the games. This might indicate that the ASD children have learned to initiate in interaction. As a consequence of their increase of "No go," they also made more "Errors" and "Repeats," meaning that an improvement of one variable can be connected to an impairment in another variable, since improvement of one variable might hamper control on a different variable. We hypothesize that this impairment will be temporary, if the child has sufficient time for further practice. Another possibility for the increase of "Errors" might be that the games did not provide enough variability or interaction (e.g., sounds or levels) for ASD children and EL children to remain highly motivated across the games, which might have caused a decrease of effective learning behavior. However, with improvement scores, the degree of variability and fluctuations is neglected. Therefore, future research should provide a more in-depth focus on specific MB patterns across time within larger groups of children.

All these findings suggest that with the presented techniques, insight into specific patterns of typical MB trajectories in different types of children can be obtained.

Part II: Focus on Individual MB Trajectories

In the case study, a typical ADHD, ASD, and EL child were selected, based on different MB trajectories. The individual graphs show how a typical representative of each group changes over the course of the 13 games, including intra-individual variability, eventual spurts, regressions, and so on. The individual trajectories were then compared with trajectories based on scores averaged over all children in each group.

On the basis of individual MB trajectories for each mouse characteristic, clear insight into how a child reacts during playing an educational task can be obtained, for instance with regard to the degree of inhibiting responses, initiating responses and the level of problem solving, such as showing repeats. Based on the case study, it can be concluded that MB trajectories not only differ in the levels of different characteristics (such as the number of "Errors" or the length of "Reaction times" across time), but also in the variability and the degree of improvement (an upward or downward trend). The findings from the individual case study strongly resemble those of the small sample study, which indicates that ASD, ADHD, and EL children can be distinguished, based on their MB profiles.

The use of individual and sample-based trajectories combines the two main sources of information about developmental processes, namely the individual on the one hand and, on the other hand, the particular developmental group to which the individual belongs.

General Discussion

By using a microgenetic design, studying the same children repeatedly over short periods of time, we have been able to provide insight into children's behavior while it is changing (Siegler, 1995). The drawback of this approach is that the number of children is small, but the advantage is that the level of detail is high. Limitations of the study are that we did not distinguish different types of ASD, such as Asperger or PDD-NOS, and that the children were not assessed with formal EF tests, such as the Go/No go Response Inhibition task. Therefore, the conclusions concerning ineffective MB that corresponds to EF dysfunctions should be taken cautiously.

However, we have demonstrated that MB shows a striking resemblance with the behaviors elicited in a wide variety of EF tests. Clinical groups showed differences in their MB, which were similar to the expected differences based on EF tests. MBs might therefore be used as naturalistic analogs of behaviors elicited in EF tests. The data provide insight into real-time task behavior of different types of children in a naturalistic setting. As to the effect of these games, we do not expect long-term effects or transfer effects to other learning tasks in educational settings, since the children played the games during only a short period. Nevertheless, this study demonstrates that it is possible to use web-based educational games for young children that on the one hand might result in improvements in MB in some clinical populations, and on the other hand can be used as a naturalistic tool for diagnostic and research purposes.

SUPPORTING INFORMATION

Additional Supporting Information may be found in the online version of this article:

Appendix S1. Preschoolers' learning behavior questionnaire.

Appendix S2. Combining and comparing multiple mouse behavior characteristics in Excel.

Table S1. Empirical and reshuffled fictive data of one MB characteristic per group in Excel.

Table S2. Comparing MB characteristics per group in Excel.

Appendix S3. Explanation procedure of Figure 7.

Appendix S4. Explanation procedure of Figure 3.

Appendix S5. Smoothing procedure.

Appendix S6. Min–max graphs procedure.

Appendix S7. Improvement scores.

Figure S1. Additional min–max graphs of Figure 6: The bandwidth of a developmental process (based on the observed values) of each child and its variability within the process.

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