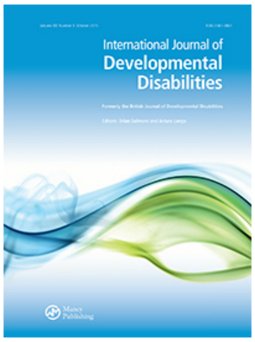

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Children with autism spectrum disorder show increased sensitivity to time-based predictability

Marina Kunchulia[1], Tamari Tatishvili[1], Khatuna Parkosadze[1], Nino Lomidze[1] and Roland Thomaschke[2]

[1]Institute of Cognitive Neurosciences, Free University of Tbilisi, Tbilisi, Georgia, [2]Cognition, Action and Sustainability Unit, Department of Psychology, University of Freiburg, Freiburg, Germany

Objectives: We studied timed-based expectancy as well as general perceptual-motor speed in children with autism spectrum disorder (ASD).

Methods: In Experiment 1, 11 children with ASD and 11 typically developing children (TD) (6–13 years) completed a binary choice response task in which foreperiod duration predicted the response target's location with a probability of 0.8. In Experiment 2, we compared performance between 10 children with ASD (6–11 years) and 10 TD children by using a simple reaction time test.

Results: Employing a binary forced choice task where the duration of a pre-target interval (800 or 1400 ms) probabilistically predicted the target, we found that children with ASD were sensitive to the temporal regularity, whereas TD children were not. Children with ASD were faster for expected combinations of interval and target location but they were also less accurate for those combinations. Results from an additional simple reaction time test indicate that the development of general perceptual-motor processes was delayed in children with ASD. However, the ability for children with ASD to form time-based expectancies was not correlated with their performance in the simple reaction time test.

Conclusion: Children with ASD show significantly greater sensitivity towards time-based predictability than TD children. However, the development of general perceptual-motor processes was impaired in children with ASD.

Keywords: Temporal cognition, time-based expectancy, perceptual-motor process, autism spectrum disorder, timing

Introduction

Dysfunctions in social communication and social interaction, accompanied by a restricted range of interests and stereotyped, repetitive behaviors, are typically considered 'core' deficits in individuals with autism spectrum disorder (ASD; see American Psychiatric Association 2006, Frith 2003). However, clinical reports, as well as studies investigating time perception, suggest that individuals with ASD have another major deficit related to temporal cognition (Boucher 2001, Allman 2011, Allman *et al.* 2011, Falter and Noreika 2011, Martin *et al. 2010*). Brenner *et al.* (2015), for example, showed that adolescents with ASD perform worse in a time reproduction task compared to typically developing individuals. A recent study by Isaksson *et al.* (2018) found that children with ASD show a wide range of abnormalities in temporal processing tasks such as temporal perspective, motor timing, and perceptual timing. In addition, individuals with ASD show deficits in time-based perspective memory (Williams *et al*. 2014).

While various types of temporal cognition have been intensively investigated in individuals with ASD, the ability to form time-based event expectancies in individuals with ASD has only rarely been studied (see Kunchulia *et al.* 2017, for an exception).

Time-based expectancy means that individuals do not expect a certain interval as such (as is typically the case in other temporal cognition paradigms (see Steinborn *et al.* 2008, for a review)), but they expect certain aspects of response targets based on time. This means, in time-based expectancy, time is the source, not the target, of prediction. It is typically investigated with the time-event correlation paradigm, where the duration of a pre-target warning interval predicts, with a certain probability, the current trial's target (Thomaschke and Dreisbach 2013).

*Correspondence to: Marina Kunchulia, Institute of Cognitive Neurosciences, Free University of Tbilisi, 240 David Aghmashenebeli Allay, 0159 Tbilisi, Georgia. Email: m.kunchulia@freeuni.edu.ge

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Table 1 Demographic information from Experiments 1 and 2

	Experiment 1		Experiment 2	
	ASD	TD	ASD	TD
Female subjects	*N* = 1	*N* = 3	*N* = 1	*N* = 1
Male subjects	*N* = 10	*N* = 8	*N* = 9	*N* = 9
Age	M = 9	M = 8.5	M = 9	M = 9.1
	SD = 1.9	SD = 1.8	SD = 1.4	SD = 1.3
	Range 6–13	Range 6–12	Range 7–11	Range 7–11
Nonverbal IQ	M = 86.4	M = 103.2	M = 85.7	M = 103.6
	SD = 12	SD = 9.8	SD = 12.5	SD = 8.4
	Range 71–112	Range 86–119	Range 71–112	Range 86–119

Time-based expectancies are a highly important aspect of human temporal cognition and are essential in many types of interaction with the environment (Aufschnaiter *et al.* 2018a, 2018b, Shahar *et al.* 2012, Thomaschke and Haering 2014), including social interaction such as joint actions (Vesper *et al.* 2017) and verbal communication (Roberts and Francis 2013, Roberts *et al.* 2011, Roberts and Norris 2016). Given that deficits in social interaction and verbal communication are key diagnostic features of ASD, it is particularly interesting to study the ability of formation time-based expectancies in individuals with ASD that could be also important for better understanding those deficits as well.

According to the 'hypothesis of predictive impairment in autism,' the ASD phenotype maybe related to an impairment in predictive abilities . This hypothesis postulates that ASD is linked to deficits in detecting predictive associations between environmental entities. These deficits affect the information processing demands inherent in the typically affected ASD domains (Sinha *et al.* 2014).

However, studies on predictive abilities in individuals with ASD found mixed results. For example, Sheppard *et al.* (2016) found that individuals with ASD were less accurate than TD individuals at predicting of location of moving objects and it was found that participants with ASD show a generally weaker tendency to generate action predictions than TD participants (Schuwerk *et al.* 2016). Children with ASD also show deficits in anticipatory motor planning ability (Scharoun and Bryden 2016). Yet, a recent study by Tewolde *et al.* (2018) found intact prediction abilities for dynamic objects in children with ASD, suggesting that prediction abilities may not be generally impaired in individuals with ASD.

In a previous study on time-based expectancy in children with ASD, Kunchulia *et al.* (2017) found that children with ASD had more accurate time-based expectancies, relative to typical developing (TD) children. In that study, they used a choice-response task with two different pre-target intervals (200 and 800 ms, respectively). The target location was predicted by the duration of the pre-target interval with 80% accuracy and participants had to indicate the left or right direction of a target stimulus. Kunchulia *et al.* (2017) found that the formation of time-based event expectancies was restricted to the 800 ms interval in children with ASD, while TD children showed no time-based expectancy effect. They interpreted that finding as evidence for children with ASD being more similar to typical adults, because in adults time-based expectancy is also often restricted to the longer interval (e.g. Thomaschke *et al.* 2015, Thomaschke and Haering 2014). However, another interpretation is also possible. The short interval in that study was only 200 ms. It might have been too short in general for children with ASD to form any time-based expectancy. This interpretation would be in line with a study by Wainwright-Sharp and Bryson (1993), showing that individuals with ASD had no benefits for briefly (i.e. 100ms) presented spatial cue information; yet when the cue was presented for 800 ms they showed a cue validity effect that was larger than in TD individuals.

In the present study, we aim to distinguish between these explanations, by employing an 800 and 1400ms pair of intervals (Experiment 1). We hypothesized that if longer intervals enable individuals with ASD to make more optimal temporal predictions, children with ASD would show more behavioral benefits after 1400ms (longer) than after 800 ms (shorter).

Previous studies also found that children with ASD were characterized by slower total choice response time (Baisch *et al.* 2017, Kunchulia *et al.* 2017), suggesting less developed perceptual-motor processing in children with ASD (Baisch *et al.* 2017). In the present study, we test the development of perceptual-motor process in ASD children, by comparing performance between children with ASD and age-matched TD children in a simple reaction time test (Experiment 2).

Here, we aim to replicate findings that children with ASD are generally slower than TD children in simple reaction time (Baisch *et al.* 2017) and second to find a correlation between development of perceptual-motor process and time-based expectancy in children with ASD. Since developmental studies show positive correlations between development of time sensitivity and information processing speed (Droit-Volet and Zélanti 2013), we expected to find correlation between processing speed and time-based expectancy in children with ASD.

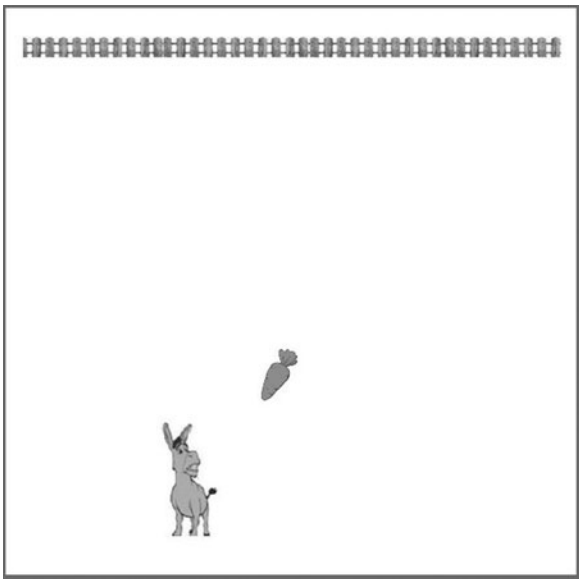

Figure 1 Schematic illustration of the layout of the choice response task. The donkey starts chasing the carrot at the bottom of the screen and 'captures' it at the fence

Method

Experiment 1

The aim of Experiment 1 was to compare the ability to form time-based event expectancies between children with ASD and age-matched TD children by using a binary choice response task, mimicking a basic computer game (Kunchulia *et al.* 2017).

Participants

This study included 11 children with ASD and 11 TD children with age ranges from 6–13 years (Table 1). Children with ASD were diagnosed by experienced clinicians based on the Autism Diagnostic Observation Schedule (ADOS; Lord *et al.* 2000) and the Childhood Autism Rating Scale (CARS; Schopler *et al*. 1980) and had severity level 1 or 2 according to DSM-5 criteria (American Psychiatric Association 2006). None of them had any co-morbid neurological/psychiatric disorders or had any signs of intellectual disability as tested with a non-verbal IQ test (Brown *et al.* 2010, Test of Nonverbal Intelligence (TONI-4)). TD children did not have any neurological or psychiatric diagnoses and none of them had first-order relatives with ASD. All children were right-handed. The study was approved by the local Bioethics Committee and was performed in accordance with the Declaration of Helsinki.

Apparatus

We used E-Prime 2 for running the experiment and for collecting data (Schneider *et al.* 2002). Data were collected via a laptop. Responses were collected using a standard optical mouse. Children responded by pressing right mouse button and left mouse button with the right index-figure and the right middle-figure, respectively.

Procedure

In a binary choice response task, participants had to chase a carrot with a donkey character moving repeatedly from the bottom to the top of the screen in a zigzag left-to-right course until it would be caught at a fence in the upper border of the screen (Figure 1). Participants had to press the left mouse button in order to make the donkey follow the carrot's leftward movement and had to press the right mouse button in order to make the donkey follow the carrot's rightward movement. After the mouse click, the donkey immediately jumped on the carrot. After a short (800 ms) or long (1400 ms) response stimulus interval (i.e. from mouse click to next carrot movement), the carrot jumped away again. This response-stimulus interval corresponded to the foreperiod in this task. For half of the participants, the short foreperiod predicted a leftward movement of the carrot and the long foreperiod predicted a rightward movement, with 80% validity. For the other half, this relation was inverted. An error message was displayed after participants pressed the wrong key and the game was paused for 3 s (see Kunchulia *et al.* 2017, Kunchulia and Thomaschke 2016, Szameitat *et al.* 2009; Thomaschke *et al.* 2015). Each participant completed 150 trials.

The preparedness for an event (i.e. carrot's movement direction) at a fore period was a measure of expectancy. If participants formed time-based expectancies they would respond faster and more accurately to frequent combinations of fore period and direction than to infrequent combinations.

Median response time (RT) and mean error rates were each analyzed (Thomaschke and Dreisbach 2013, Volberg and Thomaschke 2017) with a mixed analysis of variance (ANOVA) with the between-subjects factor of Group (ASD vs. TD) and the within-subjects factor of Expectancy (expected vs. unexpected time-event combination). Error trials and trails following error trials were not considered in the RT analysis.

Experiment 2

The aim of Experiment 2 was to replicate findings that children with ASD are generally slower in simple response time than TD children. We compared performance between children with ASD and age-matched typically developing children by using a simple reaction time test.

Participants

Ten children with ASD and 10 TD children with ages ranging from 6–11 years participated. Eight out of the 10 children with ASD also took part in Experiment 1 (Table 1). All participants were right-handed.

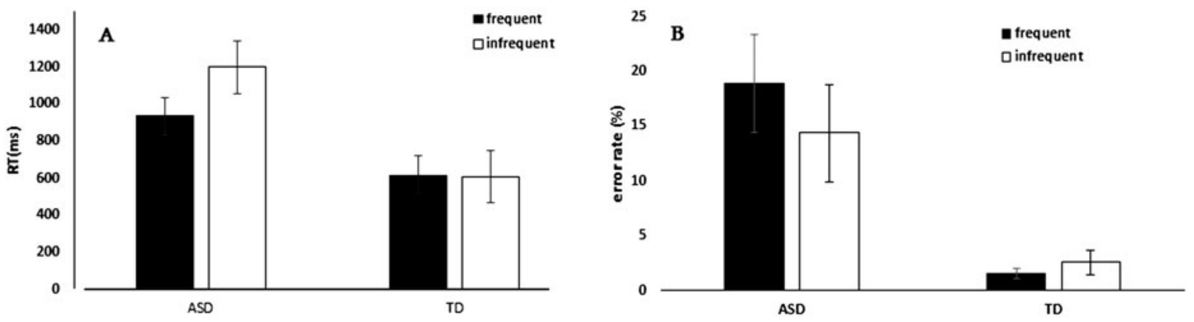

Figure 2 A choice response task. (A) Median response times (RT's) for groups. Error bars represent the standard error of the median. (B) Mean error rates for groups. Error bars represent the standard error of the mean

Apparatus

The apparatus was the same as in Experiment 1. For running the experiment and for collecting data Psychology Experiment Building Language (PEBL) version 0.14 (Mueller and Piper 2014) was used.

Procedure

In the simple reaction time test, the stimulus (symbol 'X') was presented on a black screen and the subject was required to respond as soon as possible when 'X' appeared by pressing on the 'X') button of the keyboard using the right index finger. The response times were analyzed. Each participant completed 100 trials.

Results

Experiment 1

Time-based expectancy

A mixed measures ANOVA with the between subjects factor 'Group' and the within-subjects factor 'Expectancy' and, with response times as the dependent variable, showed a significant main effect for 'group' (F (1,20)= 7.7, $p = 0.012$, η^2_p = 0.29) due to slower response times by ASD children (1066 ms, SD = 381), than by TD children (612ms, SD = 381). There was a marginally significant tendency for 'Expectancy' (F (1,20) = 4.14, $p = 0.055$, η^2_p = 0.17) due to faster response times for expected combinations of interval and direction (774 ms, SD= 242), than for unexpected combinations (904 ms, SD = 332.). Importantly, there was an interaction between 'Group and Expectancy' (F (1,20) = 4.67, $p = 0.043$, η^2_p = 0.19; Figure 2, Table 2). This interaction was due to a significant 'Expectancy' effect for ASD children (t(10) = −2.02, $p = 0.03$, Cohen's d = −0.63 (one-tailed)) but not for TD children (t(10) = 0.65, $p = 0.26$, Cohen's $d = 0.2$ (one-tailed)).

We did an analogous analysis on error rates. The main effect for 'Group' was again significant (F(1,20)= 11.23, $p = 0.003$, η^2_p = 0.36) due to higher error rates for ASD children (16.6%, SD = 10.2), than for TD children (2.05%, SD = 10.2). There was no main effect for 'Expectancy' (F(1,20) = 1.84, $p = 0.19$, η^2_p = 0.084) but there was an interaction between 'Group and Expectancy' (F (1,20)= 4.49, $p = 0.047$, η^2_p = 0.18).

Table 2 Results of the Experiment 1. Mixed ANOVA with the between-subjects factor of 'Group' (ASD vs. TD) and the within subjects factor of 'Expectancy' (expected vs. unexpected event combination)

	df RT Error rate						
		F	*p*	η^2	*F*	*p*	η^2
Expectancy	1.20	4.14	0.055	0.17	1.84	0.19	0.084
Group	1.20	7.7	0.012	0.29	11.23	0.003	0.36
Group × Expectancy	1.20	4.67	0.043	0.19	4.49	0.047	0.18

The interaction was due to a significant main 'Expectancy' effect for ASD children (t(10) = 1.85, $p = 0.047$, Cohen's $d = 0.56$ (one tailed)) but not for TD children (t(10) = −1.13, $p = 0.12$, Cohen's d = −0.34 (one tailed)). Yet, the marginal significant tendency for children with ASD points in the opposite direction, as expected: errors were more frequent in the expected combination (19.92%, SD = 14.9), than in unexpected combinations (14.35%, SD =14.6; Figure 2, Table 2).

A Pearson correlation showed a significant negative correlation between the expectancy effect magnitude on RT and the expectancy effect magnitude on error rate in the ASD group (r(11) = −0.66, p = 0.013 (one-tailed)) and in the TD group as well (r(11) = −0.59, $p = 0.029$ (one-tailed)).

Interval specific analysis

As a previous study with children with ASD showed time-based expectancy of different magnitude at different intervals (Kunchulia *et al.* 2017), we also conducted analogous ANOVAs including 'Interval' as a factor (short vs. long). However, the 'Group × Expectancy × Interval' interaction did not any attain significance, neither for response times (F(1,20) = 2, $p = 0.17$, $\eta^2 p = 0.09$, nor for error rates (F(1,20) = 0.04, $p = 0.83$, $\eta^2 p = 0.002$). These was a significant interaction between 'Group and Expectancy' (F(1,20) = 4.5, $p = 0.046$, $\eta^2 p = 0.18$) for error rates but not for RT (F(1,20) = 1.87, $p = 0.17$, $\eta^2 p = 0.086$). 'Expectancy × Interval' interaction was not significant neither for response times (F(1,20) = 0.97, $p = 0.34$, $\eta^2 p = 0.047$) nor for error rates (F(1,20) = 0.05, $p = 0.48$, $\eta^2 p = 0.025$).

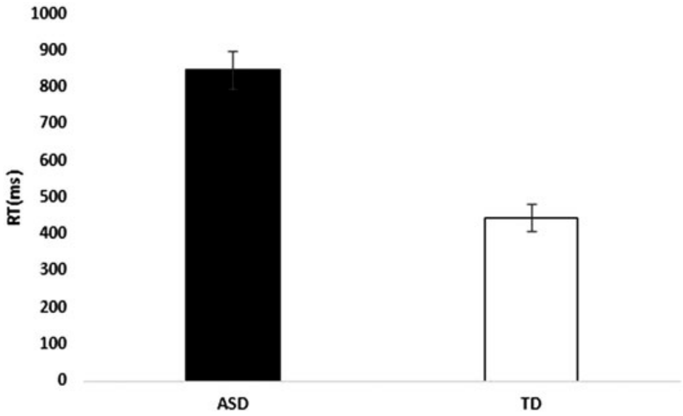

Figure 3 A simple reaction time test. Means of RT for children with ASD and TD children. Error bars represent the standard error of the mean

Experiment 2

Simple reaction time test

Mean response times were subjected to a t-test. Response times for ASD children (847 ms, SD = 161), were significantly longer than for TD children (444 ms, SD = 114; $t(18) = 6.42$, $p < 0.001$, Cohen's $d = 2.89$; see Figure 3).

Inter-experiment correlation

Eight out of the 11 children with ASD also participated in Experiment 2 (see 'Methods' section). Among these eight participants we conducted an exploratory correlational analysis between simple response time (Experiment 2), total choice response time (Experiment 1) and the magnitude of the time-based expectancy effect (Experiment 1). Total response times in Experiments 1 and 2 were not significantly correlated with each other, $r(8) = 0.42$, $p = 0.15$ (one-tailed). Simple response time in Experiment 2 was also not significantly correlated with effect magnitude in Experiment 1, $r(8) = 0.49$, $p = 0.11$ (one-tailed).

Discussion

We conducted Experiment 1 in order to test whether previously observed differences between children with ASD and TD children, with regard to time-based expectancy, would also be observable within a relatively long time range. We found that for a relatively long pair of intervals, 800 and 1400 ms, children with ASD showed a characteristic pattern of forming a time-based expectancy significantly different from TD children. While TD children were not affected by the correlation between interval and event, children with ASD were significantly sensitive to the regularity. Interestingly, they were faster for expected combinations of interval and event, as expected, but they were also less accurate for unexpected combinations. We conducted Experiment 2 to replicate findings that children with ASD are generally slower in simple response time than TD children and fully confirmed the hypothesis (see also Baisch *et al.* 2017).

The non-significant correlational analysis with simple response speed might suggest that the ability to form time-based expectancy in children with ASD maybe independent from their general response delay. These findings extend our knowledge about time-based expectancy in ASD in several ways.

First, like in the previous study (Kunchulia *et al.* 2017), children with ASD had significantly greater sensitivity towards time-based predictability than TD children. In fact, no evidence for any time-based expectancy was observed for TD children in this and our previous study. Yet, most importantly, time-based expectancy was contrary to the previous study (Kunchulia *et al.* 2017), not significantly modulated by interval for children with ASD. We conclude that the short interval in the previous study was probably just too short in general for the development of time-based expectancy, and the lack of time-based expectancy at that interval in the previous study was not due to that interval being the relatively shorter one of two. Thus, children with ASD are able to form time-based expectancies at relatively short as well as at relatively long intervals, given that the absolute duration is long enough. Our finding is in accordance with study by Tewolde *et al.* (2018), which found that general prediction abilities were not impaired in ASD children. It seems that continuous tracking and the coding of events at certain time points are not general impaired in ASD, but that individuals with ASD differ rather in how they balance out expectancy as a function of probability at each point in time.

Second, we found that the expectancy effect in children with ASD did not result in a general unequivocal performance improvement, but instead in a kind of speed-accuracy tradeoff. In expected conditions they were significantly faster, but also significantly less accurate. This pattern of an 'opposite' expectancy effect in error rates has previously been observed in older adults at an interval of 1200 ms (Kunchulia *et al.* 2018). However, it should be noted that older adults did not show any positive expectancy effect in response times in those studies. Young adults, on the contrary, often showed improved performance in response time as well as in error rates (Thomaschke *et al.* 2016, 2011a, 2011b). Thus, our findings suggest that children with ASD share some aspects of time-based expectancy with older adults (negative expectancy effect in error rates), but other aspects with young adults (positive effect in response times, not modulated by interval). However, those effects could also be explained by ASD related abnormalities. The negative expectancy effect in error rates may be related to higher impulsiveness (see for e.g. Aman *et al.* 2008) and abnormalities in motor control (see Gowen and Hamilton 2013, for a review). One might speculate that ASD children's typical deficits at the motor control level lead to erroneous responses, which are particularly frequent, when movements are initiated unusually fast in trial where the time-movement combinations was expected. This would explain why expected responses are faster but more error prone. The specific temporal sensitivity of children with ASD, may be due to that ASD children's general tendency to seek for patterns in the environment (e.g. Tomchek and Dunn 2007). Therefore, we recommend the future studies use eye-tracking to detect if the looking patterns are dependent on learned time-based expectancies.

Third, despite replicating earlier findings on generally delayed responses in children with ASD (Baisch *et al.* 2017), we suggest that this generally slowing in information processing might not be related to time-based expectancy. Interestingly, the decreased processing speed in children with ASD does not result in a disadvantage in the formation of time-based expectancy compared to their TD peer. However, developmental studies found positive correlations between development of time sensitivity and information processing speed (Droit-Volet and Zélanti 2013). It has been shown that general timing ability relies on absolute time representation (Creelman 1962, Treisman 1963, Gibbon 1977) while time-based expectancy relies on relative time representation (Thomaschke *et al.* 2015). Our finding also supports the claim that time expectancy and time-based expectancy draw on different internal timing mechanisms (Thomaschke *et al.* 2018, 2011b). On the other hand, this finding might be related to atypical developmental processes in children with ASD. For example, children with ASD, in contrast to TD children, show significantly different interdependence between alerting and executive control networks (Keehn *et al.* 2010), which might be differently involved in both tasks.

However, the methodological approach we used in Experiments 1 and 2 was different. For the study on time-based expectancy we used a gamification strategy that reduces any effect of motivation on performance, while for the study on perceptual-motor speed, the standard RT procedure without gamification was used. We suggest that future studies on general perceptual-motor speed and time-based expectancy in children with ASD, should compare performance under a standard RT task and a game-like RT task or alternatively using a volitional effort mobilization strategy (e.g. Steinborn *et al.* 2017). For future research, we also suggest to measure subjective stress state before and after the procedure, using questionnaires like for example the Dundee Stress State Questionnaire (Matthews *et al.* 2002, Langner *et al.* 2010) for evaluation of effect of motivation (task engagement) on performance.

However, the study has some limitations which should be pointed out. Sample size was small, especially for correlational analysis. Therefore, the data from the correlation analysis should be considered with caution and are difficult to interpret. In addition, in Experiment 1 we did not exclude the initial trials to keep the screening procedure exactly identical to previous experiments on this topic (see Kunchulia *et al.* 2017) making effect size more comparable to each other. However, this might lead to a systematic underestimation of the true effect size, as in the initial trials, participants could obviously not show the expectancy effect, because they could not have already adapted to it.

In general, we conclude that children with ASD are more sensitive to the predictive value of intervals than TD children and that this sensitivity is not restricted to the longer one of two intervals, and is also not related to previously investigated timing characteristics of children with ASD (Kunchulia *et al.* 2017). Yet the behavioral pattern of children with ASD is rather complex and needs further empirical investigation by more systematic approaches.

Disclosure statement

No potential conflict of interest was reported by the authors.

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