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Sequence Learning with Stochastic Feedback in a Cross-Cultural Sample of Boys in the Autistic Spectrum

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Abstract: The study investigated sequence learning from stochastic feedback in boys with Autistic Spectrum Disorder (ASD) and typically developed (TD) boys. We asked boys with ASD from Nigeria and the UK as well as age- and gender-matched controls (also males only) to deduce a sequence of four left and right button presses, LLRR, RRLL, LRLR, RLRL, LRRL and RLLR from a feedback signal. Results revealed no significant differences between the boys with ASD from Nigeria and the UK as both groups of boys improved during the task. Most interestingly, the ASD and TD group of boys learning differed for certainty, but not uncertainty of feedback. We concluded that further research is needed why boys with ASD did not benefit from true, logical and reliable feedback.

In recent years, researchers tried to find the underlying neurocognitive impairments to explain the symptoms of Autistic Spectrum Disorder (ASD) (Poljac & Bekkering, 2012). The symptoms of ASD as classified in the DSM-V comprise of persistent deficits in social communication and interaction across multiple contexts as well as restricted, repetitive patterns of behaviour, interests and activities (American Psychiatric Association, 2013). Because the severity and diversity of impairments varies across individuals, the term autistic spectrum disorder (ASD) was proposed (Poljac & Bekkering, 2012; Sheinkopf, 2005). There are low ability children, but also high-functioning (HF) children with ASD who can show extraordinary drawing, mathematical and/or memory abilities (Boucher & Bowler, 2008; Happé & Frith, 2010).

The current study investigates sequence learning in children with ASD who are of low to average ability. One of the first researchers examining sequence learning in children was Piaget (1952). He asked children to sort sticks of different lengths into a sequence according to size (seriation). Young children had no idea about seriation and would rather sort the sticks into aesthetic arrangements, while school-age children used strategies that were linked to their understanding of the concepts of dimension and scale. However, deductive sequence learning can also be drastically impaired in 8–11-year-old typically developing children when they encounter stochastic feedback (Lange-Küttner, Averbeck, Hirsch, Wiessner, & Lamba, 2012). We investigated this condition for sequence learning in autistic boys and age-matched control children in a within-subjects design. In the first half of the session, the sequence could be logically deduced from deterministic, correct feedback, while in the second half of the session, sequence learning needed mental estimation of the likelihood of feedback accuracy because it was randomly incorrect in 20% of the trials (stochastic feedback). We expected that boys with autism would be more dependent on deterministic feedback than neurotypical children. Furthermore, we compared boys with ASD from Nigeria and the United Kingdom in order to ascertain whether schooling experience and cultural socialization would ameliorate ASD-specific deficits.

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Executive Function and Sequence Learning

One core neurocognitive impairment that is related to deficits in ASD is executive dysfunction (Amaral, Collins, Bohache, & Kloos, 2012; Carr, 2006; Groen et al., 2008; Hill, 2004; Poljac & Bekkering, 2012; Rajendran & Mitchell, 2007). Executive function (EF) describes neuropsychological processes which enable physical, cognitive and emotional self-control and are necessary to maintain goal-directed behaviour (Corbett, Constantine, Hendren, Rocke, & Ozonoff, 2009). It is an umbrella term for various cognitive abilities such as sequencing, planning, impulse control, and inhibition that are involved in regulation and co-ordination of thoughts and actions (Amaral et al., 2012; Hill, 2004; Sheinkopf, 2005). EF is related to the Intelligence Quotient (IQ) (Liss et al., 2001).

Sequence learning can also occur when children have to deduce a sequence. For instance, if in a motor sequence task with left (L) and right (R) button presses, LRLR is the correct sequence, but the child pressed LLLR and would get the feedback correct, wrong, correct, correct, the child can deduct the correct sequence and adjust the second button press after the first round of feedback (Lange-Küttner et al., 2012). Lange-Küttner et al. compared sequence learning under certainty and uncertainty. This meant that one group of children always received correct feedback (deterministic feedback), while another group received just 85% correct feedback (stochastic feedback) and had to decide whether the feedback was trustworthy or not. Lange-Küttner et al. found that the group receiving stochastic feedback started on a significantly lower performance level compared to the control group receiving deterministic feedback, but became more confident and gradually increased performance. However, they did not reach the performance level of the group learning from deterministic feedback even when they repeated two rounds of six sequences.

The researchers also evaluated whether children learned more from positive or negative feedback and showed that the probability of learning was increased after positive feedback, whether it was correct or false. That is, they also learned from false positive feedback. Moreover, children found it especially hard to reject false negative feedback, that is, when the signal showed they were wrong when in fact they were right. This required a degree of self-assertion that this large sample of 8- to 11-year-old children could not yet master. This result showed that processing stochastic feedback also had a social aspect because it was agreeable for children when the computer feedback would praise them indiscriminately, but disturbed their learning when the critical feedback was unjustified.

Executive Function and Sequence Learning in Children with ASD

Learning of sequences is fundamental to human performance. It is used not only in mathematics, but also in a variety of everyday tasks, for example movements when getting dressed (Clegg, DiGirolamo, & Keele, 1998). This makes sequence learning also an important factor for low-ability children with ASD because they frequently fail in everyday tasks such as creating a shopping list (Charitos et al. 2000).

The theory of executive function can explain the behaviour problems of rigidity and perseveration seen in ASD by testing, for instance, the lack in initiation of new non-routine action and the tendency to be stuck in a given set (Hill, 2004). One aspect of this executive dysfunction is weak central coherence which is characterized as shifting attention from local elements to global patterns (Amaral et al., 2012; Happé & Frith, 2006). A critical review regarding the theory of executive dysfunction in children with ASD carried out by Hill (2004) showed that overall children with ASD tended to be impaired in planning, mental flexibility, which includes set-shifting and cognitive flexibility, inhibition and self-monitoring. Also, more recent studies confirmed that children with ASD showed impairments in planning, inhibition and self-monitoring (Corbett et al., 2009; Happé, Booth, Charlton, & Hughes, 2006; Robinson, Goddard, Dritschel, Wisley, & Howlin, 2009). However, when Robinson et al. controlled for age differences, she found age-related gains in mental flexibility, planning and the speed of response, but not in response inhibition and self-monitoring. Happé et al., (2006) also found that older children with ASD outperformed younger ones with ASD which indicates that executive function may increase with age despite the disability. However, in a longitudinal study by Ozonoff and McEvoy (1994) over three years, little improvement was seen in planning, working memory and cognitive flexibility.

Explicit learning is closely linked to executive function. It is intentional and requires the learner to think and relate to former knowledge (Gebauer & Mackintosh, 2007). Explicit learning correlates with IQ, while implicit learning does not (Gebauer & Mackintosh, 2007; Reber, Walkenfeld, & Hernstadt, 1991). Implicit learning occurs independent of chronological and mental age (Maybery, Taylor, & O'Brien-Malone, 1995; Meulemans & Van der Linden, 1998; Reber et al., 1991; Sloutsky & Fisher, 2008; Vinter & Perruchet, 2000, 2002; Weinert, 2009).

Implicit sequence learning takes place without awareness insofar as there is no explicit instruction or intention to learn (Brown, Aczel, Jiménez, Kaufmann, & Grant, 2010). However, Ferdinand, Mecklinger and Kray (2008) showed that sequence learning occurs irrespective of the learning condition because children learned equally when they were explicitly informed about the existence of a sequence they had to learn and when they were not informed.

So far, sequence learning in ASD has mainly been studied using the Serial Reaction Time (SRT) task. In this task, participants are asked to respond as quickly and accurately as possible to a black dot appearing in one of four locations on a screen by pressing four corresponding buttons. The locations of the dots are repeated in a particular sequence (Brown et al., 2010; Gordon & Stark, 2007). A variation of the SRT task is the Alternating Serial Reaction Time (ASRT) that uses a random dot appearance which hides the sequence better (Barnes et al., 2008). These studies tested whether implicit learning in children with ASD is impaired. The evidence on sequence learning is mixed: Some studies showed a difference in sequence learning between children with ASD and typically developed children (Gordon & Stark, 2007; Mostofsky, Goldberg, Landa, & Denckla, 2000), while others did not (Barnes et al., 2008; Brown et al., 2010; Nemeth et al., 2010).

These differences may be explained by different study designs. Brown et al. (2010) found no significant difference between children with ASD and typically developing children when using the SRT task, even though children were matched by IQ. Also Barnes et al. (2008) compared high-functioning individuals with ASD and Asperger who had an IQ in the normal range with typically developed children and matched them by chronological age. They used the ASRT task with three elements in a sequence and found no differences between the groups. Nemeth et al. (2010) also used the ASRT, but with eight elements and compared high functioning children with ASD to typically developing children matched for chronological age and IQ. They also did not find a difference between the two groups.

Mostofsky et al. (2000), however, did find a difference between individuals with ASD and typically developing individuals matched by age when using the SRT with still longer sequences, that is, ten elements.

Inui and Suzuki (1998) found that adolescents with ASD improved with practice in the SRT task. Gordon and Stark (2007) showed that low functioning 6- to 14-year-old children with ASD learned slower, made more errors and showed a greater variability. However, they still found significant learning progress in the first session with the four element sequence, suggesting that low functioning individuals with ASD are capable of learning a sequence with a lower cognitive load, respectively set size of the elements in the sequence.

The differences observed in these studies can be explained in different ways. One explanation could be the selection of participants. Individuals with ASD varied by age and severity of symptoms between studies, for instance, some studies just included high functioning children with ASD and Asperger. Furthermore, control groups of typically developed children might have been more likely to use explicit strategies. Moreover, the different procedures, such as the number and presentation timing of elements can contribute to differences. Hence, it appears that there is no consensus whether autistic children are just as good as age-matched controls when it comes to sequence learning. This is in line with Amaral et al., (2012) who stress that differences in age, severity of symptoms, co-morbidity with other disorders such as ADHD, or task integration of movements can have more or less of an impact on performance. Thus, so far no definite conclusion can be drawn from this review about the ability of sequence learning in children with ASD.

Feedback Processing in Individuals with ASD

The current study uses a task with a sequence of just four button presses, but with different types of feedback. Feedback processing implies information uptake for error correction which is yet another aspect of executive functioning (Bogte, Flamma, van der Meere, & van Engeland, 2007). The processing of feedback develops during childhood until early adulthood and is important for many learning situations. Ferdinand et al., (2008) report that children react stronger to external feedback than adolescents and adults and are less efficient in extracting the relevant information from the feedback. This means that with age the ability to shift from external to internal feedback monitoring and the relationship between error monitoring and behavioural adaptation seems to strengthen. Furthermore, Eppinger, Mock and Kray (2009) showed that children and adults have a similar accuracy when presented with valid feedback, but they could observe differences when a proportion of the feedback was invalid. However, it is important to distinguish between social and performance feedback (Lange-Küttner et al., 2012) to better understand the impairment of children with ASD.

Individuals with ASD are less motivated by social feedback (Ingersoll, Schreibmann, & Tran, 2003). For instance, they do not experience feedback information from emotional facial expression in the same way as typically developed individuals do (Stel, van den Heuvel, & Smeets, 2008). Although individuals with ASD have difficulties in processing the more subtle social feedback, in a study using a computer task with visual feedback they have been found to process external feedback similar to typically developed individuals (Larson, South, Krauskopf, Clawson, & Crowley, 2011).

With regards to performance feedback, Russell and Jarrold (1998) show that 6- to 16-year old children with ASD generally make more errors and a higher proportion remained uncorrected, that is they show poorer skills in error correction. Also Bogte et al. (2007) found that typically developed individuals slow down after making an error to adjust the behaviour, while high functioning individuals with ASD did not, thus more errors occurred.

Other studies support the notion that children with ASD process negative but also positive performance feedback differently from typically developed children. In the study of Groen et al. (2008), 10- to 12-year old children with ASD showed no feedback monitoring deficits in a probabilistic learning task which involved selective responses to pictures based on informative feedback or response-independent button presses. Children with ASD showed some affective flattening in the evaluation of negative feedback compared with TD control children. A similar observation was made by Broadbent and Stokes (2013) in a life-span study with individuals with ASD from age 14 to 70 and controls on the Wisconsin Card Sorting Test (WCST). In the WCST the participant is asked to sort the cards to certain criteria. The researcher gives feedback on the performance, but changes the sorting rule after some time without the knowledge of the participant. The test measures the perseverative responses and errors of the participant. Broadbent and Stokes (2013) found that children with ASD showed more perseveration as they stayed for longer with the first, initial card sorting strategy. Additionally, children with ASD performed significantly better without negative feedback (Broadbent and Stokes, 2013).

In the current study, we devised stochastic feedback (Lange-Küttner et al., 2012). This is different to the implicit feedback change in the WCST, because children are explicitly told that a percentage of the feedback is not correct. On the one hand, we expected the same selective uptake of positive feedback for sequence learning as the control children, but on the other hand, we presumed that children with ASD may be comparatively indifferent to the random false feedback as one hallmark of autism seems to be that adult individuals appear to follow their own agenda when learning (Bowler, Gaigg, & Gardiner, 2008).

The Influence of Culture on ASD

One aspect where still little is known is the difference between ASD in different countries, particularly African countries, and the influence of culture on the symptoms and cognitive processes on children with ASD (Ametepee & Chitiyo, 2009; Weru, 2005). Therefore, the aspect of culture is included in this study by not only looking at children with ASD from England, United Kingdom, but also from Nigeria, Africa.

Children in Africa started only in recent years to receive a diagnosis of ASD because for a long time ASD was thought to be a problem of Western industrialized countries with high technological development (Bakare & Munir, 2011a, Bakare & Munir, 2011b, Sanua, 1984, Lotter, 1978). The symptoms of ASD in African countries are similar to those in Western countries (Lotter, 1978, Dhadphale & Lukwago, 1982, Khan & Hombarume, 1996). Nevertheless, Lotter (1978) reported that ASD children in Africa showed less repetitive movements and less ritualistic activities involving objects compared to Western children in the autistic spectrum. A more recent cross-cultural study by Weru (2005) examined behavioural differences in autistic spectrum symptoms in African American children in the United States and children in Kenya. This study revealed that children with ASD in Kenya have more behavioural problems compared to African American children with ASD, with more severe problems of stereotyped behaviour, social interaction, social and self-help skills. Furthermore, they are more developmentally disturbed and have more communication problems. In particular, Weru (2005) found 13 Kenyans in the autistic spectrum to be entirely non-verbal compared to just one African American. The higher incidence of non-verbal cases in Africa is supported by other researchers (Bakare & Munir, 2011a, Lotter, 1980, Mankoski et al., 2006). Moreover, in African children, ASD has a comparatively higher impact on their intellectual ability (Bakare & Munir, 2011a, Lotter, 1980, Mankoski et al., 2006).

It remains unclear if the results of the studies really represent an objective picture of ASD in Africa, since most studies were conducted in poor urban environments. Access to professional health facilities is not guaranteed and specialist treatments often have to be paid for privately. The higher number of severe cases of ASD in Africa may be due to a sampling bias towards poor urban children. Furthermore only the very severe cases get reported in the first place (Bakare & Munir, 2011a). One reason for only reporting severe cases is that ASD often remains unrecognised by Nigerian healthcare workers (Bakare & Munir, 2011a) who often show a low level of knowledge and awareness about ASD (Bakare et al., 2009). This review highlights the fact that the research in the field of ASD in Africa is not yet very extensive. Especially in the field of cognition, it is not known whether African culture has an influence on ASD.

This current study aims to fill this gap in research by comparing Nigerian children in the autistic spectrum with British children in the autistic spectrum. The study only includes boys, as ASD is more common among boys than girls. In Western countries boys are four times more likely than girls to be in the autistic spectrum (Weru, 2005), and in Africa there is a similar male:female ratio of 3.8:1 (Ametepee & Chitiyo, 2009). Furthermore, pre-tests will be performed to assess the cognitive ability of the children from the UK and Nigeria with ASD in order to avoid differences in the cognitive ability as a confounding factor for differences in the sequence learning task.

Hence, this study will examine sequence learning from feedback under certainty (deterministic feedback) and uncertainty (stochastic feedback) in children with ASD to assess the influence of culture. It is expected that culture will have an influence on sequence learning insofar as UK children with ASD will perform better than children with ASD from Nigeria as previous studies showed that the children with ASD in Africa are more impaired than children in Western countries. Our review further suggests that children with ASD will be able to learn the given sequences, as they just contain four elements, however, the stochastic feedback should make the learning of these short series of button presses somewhat harder. Additionally, a difference in the processing of the positive and negative feedback between the children with ASD and the typically developed children is expected insofar as normally developing children may be more responsive to feedback.

Method

Participants

Twenty-two boys with ASD between 7 and 12 years of age received parental consent to participate in the study. The group from Nigeria consists of 13 boys with ASD, and the group from the UK consists of nine English boys with ASD. Six boys of this sample were excluded. Four boys were excluded from the study as they were not capable to perform the pretests (see Apparatus and Material) and two boys because of missing data in the button press task. Five of the six boys were in the Nigerian group and one was in the English group, which resulted in $N = 16$ participants, eight with ASD from Nigeria and eight with ASD from the UK. All 16 participants with ASD completed the sequence learning task under the deterministic feedback condition. Fourteen of these also finished the sequence learning under the condition of stochastic feedback, seven from the Nigerian group and seven from the UK group.

Typically developing (TD) children from western European countries were selected as control group matched for chronological age and gender from a study with a large sample (Lange-Küttner et al., 2012). In this study, the deterministic and stochastic feedback conditions were tested with a between-subjects design. Hence, for each participant in the current study, two control children were selected, one for the deterministic feedback and a second one for the stochastic feedback condition. Also the control children were boys only. The date of birth was matched for the exact month of birth in most cases, see Table 1. The Nigerian boys with ASD were significantly older than the English boys with ASD, $t(14) = -2.68$, $p = .018$, $d = .63$, because the diagnosis was made later. Hence, age was controlled in the analyses with age in months as a covariate.

Apparatus and Materials

Before starting with the sequence learning task, all boys with ASD completed three pretests to assess the cognitive ability: (1) Draw-A-Person (DAP) test from Naglieri (1988); (2) Colored Progressive Matrices (CPM) (Raven, Court, & Raven, 1990); and (3) The British Picture Vocabulary Scale (BPVS-III, third edition) (Dunn et al., 2009).

TABLE 1

Mean Age of the Boys with ASD and the Control Groups in both Feedback Condition (Years; Months with SD in brackets)

Condition	*N*	*Nationality*	*ASD Years; Months*	*Controls Years; Months*
Deterministic	16	Nigeria	11;5 (1;4)	11;5 (1;4)
Stochastic	14		11;5 (1;6)	11;6 (1;8)
Deterministic	16	UK	9;4 (1;6)	9;4 (1;6)
Stochastic	14		9;6 (1;7)	9;6 (1;4)

Draw-A-Person Test (DAP). The DAP test by Naglieri is a screening test for the cognitive developmental status. Children are asked to draw a man, a woman and the self. The scoring captures the amount of details in the figures and psychometric norms are available (Naglieri, 1988). It is one of the most widely internationally used screening tests and is assumed to be culturally fair because it does not draw on specific knowledge (Lange-Küttner, Küttner, & Chromekova, 2014; Naglieri, 1988).

Raven Coloured Progressive Matrices Test (Raven). Also this test minimizes the cultural influences and aims to measure spatial reasoning by asking the child to choose the correct piece from six picture fragments to complete a pattern (Raven et al., 1990; Raven, 2000). It is a nonverbal test with no time restrictions.

British Picture Vocabulary Scale. The BPVS III assesses receptive vocabulary of a child and allows to draw a conclusion about the cognitive development in the area of verbal intelligence (Dunn et al., 2009). In the test, the child is asked to select one from four pictures shown on a page that best fits the word that the researcher said.

Sequence learning task. The sequence learning task is a computer task developed with Matlab (MATHWORKS). The child learns a sequence of four left (L) and right (R) button presses in the absence of any visual or auditory stimulus. The four correct left and right but-

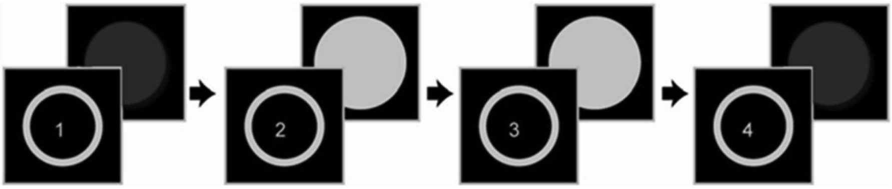

Figure 1. The figure shows a screenshots of the Sequence Learning Task. The screen in the front indicates the position of the next button press within the sequence, while the screen in the back shows the feedback after the button press. Reproduced with friendly permission of Seo et al. (2010).

ton presses had to be deduced from visual feedback (red/green) on the screen. The sequences were LLRR, RRLL, LRLR, RLRL, LRRL and RLLR. After each button press a circle appeared in red (wrong) or green (right) as feedback indicating if the child's action was right or wrong. Each feedback trial had a number 1, 2, 3 or 4 inside the circle which indicated the position of their button press in the sequence, see Figure 1.

If the child pressed the left button for the first position of the sequence and a green circle appeared the child knew that the first button press in this sequence had to be the left one. However, if the child pressed first the right button and the red circle appeared, the child could deduce from the feedback that the first button press of the sequence was not the one on the right side and it consequently had to press the left button in the next round.

In this study, participants performed the task three times (rounds). Each round contained the six different sequences. Before each round, the child was informed about the type of feedback. In the first round, children always received the correct, veridical feedback (deterministic feedback, 100% correct). In the second and third round the child received only 80% correct feedback with 20% randomly incorrect feedback (stochastic feedback). This means that even if the child pressed the right button, the feedback could have indicated that this was wrong. Conversely, if the child pressed the wrong button the feedback might have indicated that the response was correct. Stochastic feedback was more difficult to integrate than deterministic feedback since the child was required to integrate it over multiple response sets to determine the correct sequence.

After the child identified the correct sequence he was asked to repeat these button presses to show that the sequence was learned properly and that the first correct sequence was not a chance event. In the first round with the deterministic feedback the child had to repeat the sequence six times before moving on to a new sequence. In the second and third round with stochastic feedback, the child had to repeat the sequence four times before moving on. If the child failed to detect the correct sequence within 20 sets of button presses, the program automatically moved on to the next sequence. Before starting a new sequence the instruction: "You have a new sequence to learn" appeared on the screen to inform the child. There was no time constraint, the button-pressing task was self-paced and only the accuracy was measured which made it suitable for children with developmental and mental health difficulties.

Averbeck et al. (2011) developed a formal learning model, with two learning parameters, a positive and a negative learning parameter. The positive learning parameter measures how likely the child was to press the correct button in the next response set after receiving positive feedback. The negative learning parameter measures if negative feedback decreased the likelihood of learning to press the correct button in the next response set.

As mentioned before, the TD children were selected from the large sample of Lange-Küttner et al. (2012). Their task was minimally different from the current one. They used a between-subject design where children in the deterministic feedback group had to enter the sequence eight times, compared to the children with ASD in this study who just entered it six times. The stochastic feedback group had to enter the correct sequence six times, while the children with ASD in this study entered it just four times. Hence, we had lowered task demands for the children with ASD. The number of correct sequence repetitions was adjusted down for this study because we tested a clinical sample of medium to low ability. Moreover, the stochastic condition for the ASD children was 80% rather than as previously 85% stochastic feedback (Lange-Küttner et al., 2012), but this was only a very small difference.

Procedure

Approval was obtained from the London Metropolitan University ethical board as well as from the ethical committee from the Ministry of Health in Nigeria. In Nigeria, potential participants were identified with the service provider Playsmart. Playsmart sent out an information letter to schools with integrated children with ASD and centers working with children with ASD, whether they were aware of boys within the age range with ASD. If schools or centers agreed to support the study, a meeting between the first author and the person in charge of the school or center was arranged to explain the procedure. Afterwards, an information letter and a consent form were sent to the parents. Parents were also contacted directly at institutional meetings, where information was provided together with the information letter and consent form. If parents agreed for their sons to participate in the study, children were tested either in the school, or the center, or at the child's home. In all cases it was made sure that a known person to the child was present throughout data collection; this was either a therapist, psychologist, teacher, assistant, or the parent.

In the UK, special schools for children with ASD and organizations working with children with ASD were directly contacted with an information letter. When schools or organizations agreed to support the study, more information about the procedure was provided and an information letter and consent form was sent out to the parents who were known to have a child with ASD within the age range. Like in Nigeria, sessions took either place in the school or at the child's home, and in both cases it was made sure that either the teaching assistant or the parent was present.

The testing was distributed across two sessions. In the first session, the psychometric assessments were carried out. The time needed for the first session varied between 30 and 75 minutes. In the second session children performed the sequence learning task on a laptop. The time needed for this session varied between 40 and 100 minutes, since children could take breaks in between sets.

In the beginning the child would either read the instructions from the screen individually or the researcher would read them out loud, depending on the reading ability and preference of the child. The instructions for the deterministic feedback were depicted in several screenshots:

> *Welcome to the "Learn the 4 Button Press". You are given two buttons to press. You need to learn to press these buttons in a particular sequence, making a total of 4 button presses. For instance, Left, Right, Left, Right. Each time you press a button a GREEN or a RED circle will appear. The circle is like a streetlight which shows whether you pressed the right or wrong button. The computer always gives you the correct feedback. When you press the CORRECT button a green circle will appear. When you press the WRONG button a red circle will appear. After learning the correct 4 Button Presses repeat the same sequence six times and you will proceed to learn another new sequence.*

After finishing the deterministic feedback condition, the instruction for the stochastic feedback condition were given in several screenshots:

> *Welcome to "Learn the 4 Button Presses task". This task is the same task as before, except this time the computer will also give you wrong feedback 20 percent of the time. Even if you pressed the right button it may appear as false with a red circle. Even if you pressed the wrong button it may appear as right with a green circle. Therefore even if you think you know the sequence sometimes you may have to ignore the feedback. Are you ready?*

The researcher showed the child the two buttons. The left index finger was put on the "z" button and the right index finger on the "-" button on a UK/US keyboard layout. Both

TABLE 2

Psychometric Tests Scores for the Boys with ASD

					Independent Sample t-Test		
Test	*Children with ASD*	*n*	*Mean*	*SD*	*T*	*df*	*p-Value*
BPVS-III	Nigeria	8	79.63	23.48	1.29	14	.217
	UK	8	94.75	23.29			
CPM	Nigeria	8	23.38	8.16	1.10	9.79	.296
	UK	8	26.88	3.72			
DAP	Nigeria	7	58.86	20.25	1.16	13	.268
	UK	8	72.75	25.42			

Note. Degrees of freedom were adjusted when Levene's test for equality of variances was significant.

buttons were marked with a coloured sticker. The child was asked to keep the fingers on the keyboard during the task.

Results

The results are reported in two parts. In the first part, the boys with ASD from the two countries are compared, while in the second part they are compared as one group to the typically developing (TD) boys. When the Mauchley's Test of Sphericity was significant, degrees of freedom were adjusted according to Huynh-Feldt.

Results for Children with ASD

Pre-tests. The results of the three pre-tests assessing the cognitive ability of the boys with ASD from the two countries are listed in Table 2. For analyses of group differences, the raw scores were used because some participants scored outside the normative scale and no standard scores could be obtained. One boy could not draw a figure, but completed all other tests and hence was included in the analyses. There were no significant differences in any of the tests, $p_s > .217$. Nevertheless, the English boys with ASD scored higher in all three tests compared to the Nigerian boys with ASD, but because the standard deviations were high in both groups (indicating a wide range of ability in both groups), the t-tests did not reach significance.

Sequence learning. The first six response sets were averaged across the sequences LLRR, RRLL, LRLR, RLRL, LRRL and RLLR, in the deterministic feedback condition for one round, and in the stochastic feedback condition for both rounds.

A 6 (response sets) by 2 (feedback conditions) by 2 (country of origin) analysis of variance was run with repeated measures on the first two factors and country of origin as between-subject factor. There were no significant effects of the country of origin and feedback condition, $p_s > .313$. This showed that boys with ASD from both countries showed the same performance level and learned under both feedback conditions to a similar extent. Nevertheless, the analysis revealed a significant main effect of response sets, $F(3.36,16) = 8.92$, $p < .001$, $\eta^2 = .43$. Within-subjects contrasts (Difference) showed a significant increase of correct responses with almost every learning set, $F_s > 5.47$, $p_s < .033$.

When this analysis of variance was controlled with age as a covariate, the significant effect of learning set disappeared, $p > .970$, showing that age explained the learning effect. There was still no significant difference between the boys with ASD from Nigeria and the UK, $p > .432$. This result clearly demonstrated that sequence learning in boys with ASD was related to age and not to the country in which they lived.

Positive vs. negative feedback. The feedback-related learning parameters were analysed in a 2 (positive/negative feedback) by 2 (feedback condition) by 2 (countries of origin) analysis of variance with repeated measures on the first two factors and country of origin as

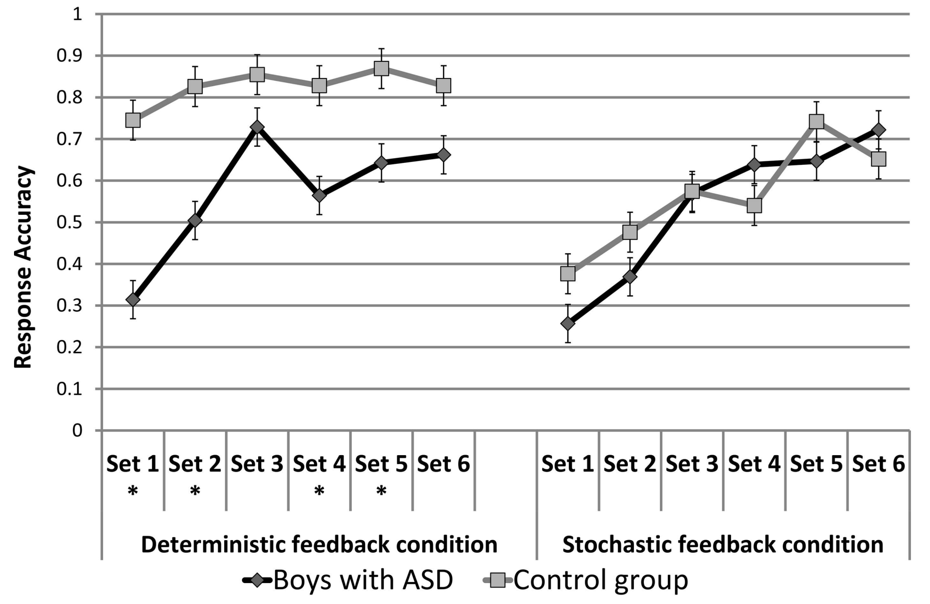

Figure 2. Sequence learning of ASD and TD boys in the deterministic (left) and stochastic (right) feedback condition. Significant differences in the sets between the boys with ASD and the control group are marked with a * in the respective section of the y-axes. Bars indicate the standard error.

between-subject factor. There were no significant statistical effects, $p_s > .206$, except for positive vs. negative feedback which had a very large effect size, $F(1,16) = 93.08$, $p < .001$, $\eta^2 = .89$. All boys with ASD learned significantly more from positive than from negative feedback in both the deterministic and the stochastic feedback condition. When this model was controlled for age, the feedback effect was reduced by more than half, but remained significant, $F(1,16) = 6.58$, $p = .026$, $\eta^2 = .37$. No other factor was significant, $p_s >$ .400.

Children with ASD and the TD Control Children

As it was found that there was no significant performance difference of the Nigerian and the English boys with ASD, their data were collapsed into one ASD group and compared with age- and gender-matched TD groups, one group for the deterministic feedback and one group for the stochastic feedback condition, because the TD boys were selected and matched from a sequence learning study with a between-subjects design (Lange-Küttner et al., 2012).

Sequence Learning

Deterministic feedback. A 6 (response sets) by 2 (ASD/TD group) analysis of variance was run with repeated measures on the first factor and group as between-subject factor. There was a significant main effect of groups, $F(1,30) = 16.89$, $p = .001$, $\eta^2 = .36$, indicating that the boys in the TD group learned on a significantly higher level compared to the boys with ASD, see Figure 2, left side. There was also a significant effect of sets, $F(4.41,30) = 6.94$, $p = .001$, $\eta^2 = .19$ and a significant interaction between groups and sets, $F(5,30) = 2.42$, $p = .04$, $\eta^2 = .08$). Even though the boys in the TD group performed significantly better, also the boys with ASD showed learning and narrowed the gap, see Figure 2, left side.

Stochastic feedback. The same analysis of variance for sequence learning with stochastic feedback. There was no significant difference between the TD group and the ASD group, $F(1,28) = 0.19$, $p = .670$, $\eta^2 = .01$. This means the boys in both groups showed a similar performance level. There was a significant main effect of response sets, $F(4.43,28) = 12.39$,

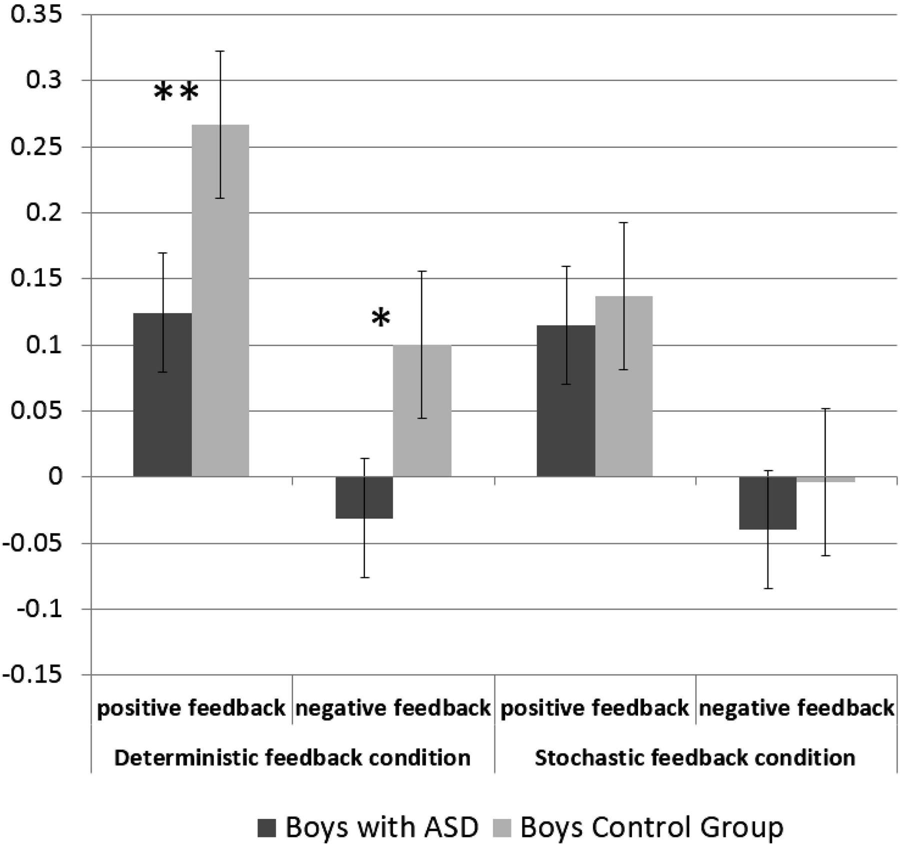

Figure 3. Learning from positive and negative feedback in ASD and TD boys in the deterministic (left) and stochastic (right) feedback condition. Bars indicate the standard error. **= p < .001; *= p < .05.

$p = .001$, $\eta^2 = .32$, see Figure 3, right. Within-subjects contrasts (Difference) showed a significant increase of correct responses with each learning set in both groups of boys, $F_s > 15.38$, $p_s < .03$.

Positive vs. Negative Feedback

Deterministic feedback. A 2 (positive/negative feedback) by 2 (ASD/TD group) analysis of variance was run with repeated measures on the first factor and group as between subject factor, group means are plotted in Figure 3, left. A significant effect of the feedback type $F(1,30) = 43.15$, $p < .001$, $\eta^2 = .59$, showed that all boys learned more from positive than from negative feedback. There was a significant difference, however, between the ASD and the TD boys, $F(1, 30) = 15.40$, $p < .001$, $\eta^2 = .34$. Independent sample t-tests showed that the TD boys learned significantly more from positive feedback than the boys with ASD, $t(30) = -5.11$, $p < .001$, and also from negative feedback $t(15.64) = -2.45$, $p = .026$. The interaction of feedback and group was not significant, $p = .830$.

Stochastic feedback. The same analysis of variance was run for feedback learning in the stochastic feedback condition, group means are plotted in Figure 3, right. There was an even larger significant effect of positive vs. negative feedback type in the stochastic condition, $F(1,26) = 126.72$, $p < .001$, $\eta^2 = .83$, as all boys in both groups learned more from positive than negative feedback. No other effects were significant, $p_s > .237$.

Discussion

Cultural Differences in Sequence Learning

In this study, we investigated whether sequence learning from feedback under certainty and uncertainty is impaired in boys with ASD and whether culture would have an influence. A comparison was made with a control group of typically developed boys matched for gender and month of birth. The study revealed no significant difference in the sequence learning task between the groups of boys with ASD from Nigeria and from the UK. Both ASD groups learned equally well after each set of button presses and processed the feedback in a similar fashion. This result indicates that sequence learning and the processing of feedback in boys with ASD is independent of schooling experience and culture. Therefore we would conclude that sequence learning in ASD is not influenced by cultural life circumstances. This result supports the findings that ASD is not just a problem of Western industrialized countries (Bakare & Munir, 2011a; Bakare & Munir, 2011b; Lotter, 1978; Sanua, 1984). However, cultural independence of sequence learning in boys with ASD is in contrast to the findings of Weru (2005) who found children with ASD from Kenya to be more impaired in general than children with ASD from the United States of America. However, in our study sequence learning in boys with ASD was related to age which suggests that also in the autistic mind there is a healthy core of executive functioning skills even if these do not reach the same level as in typically developed children (see also Happé et al., 2006; Ozonoff & McEvoy, 1994; Robinson et al., 2009).

Positive and Negative Feedback Processing and Sequence Learning

Feedback processing develops throughout the life-span (Störmer, Eppinger, & Li, 2014). Positive feedback is important in young children (Lange-Küttner et al., 2012), but still increases response consistency in adults (Störmer et al., 2014). However, also negative feedback processing gradually emerges in children (Crone, Bunge, Latenstein, & van der Molen, 2005; Lange-Küttner et al. 2012). The current study shows that typically developing boys not only learned more from feedback in the deterministic feedback condition, but they were even able to learn from negative feedback, while boys with ASD were not. This clearly shows that when learning a sequence, positive feedback is especially important for boys with ASD. The result is in line with findings of Broadbent and Stokes (2013) who found that children with ASD learned better when negative feedback was removed from a task. In the psychophysiological study of Groen et al. (2008) attention to negative feedback gradually decreased during their task in both ASD and TD children, but not in non-medicated children with ADHD. Likewise, children with ASD did not show deficits in error monitoring, but non-medicated children with ADHD did. In contrast, both non-medicated ADHD children and children with ASD showed strong anticipation of positive feedback, while there were no differences between the clinical groups and the TD children with respect to anticipation of negative feedback.

In short, the current study showed that typically developed boys recognize reliable feedback, whether it is positive or negative, while boys with ASD did not, as they seem to show an increased distrust of any feedback except if it is explicitly positive. Nevertheless, they were able to learn a sequence from stochastic feedback as well as normally developing boys. Our initial intuition was that English ASD boys should benefit from the advanced educational system and the reliable, deterministic feedback, but it seems that all that was needed was explicit positive reinforcement. This is not expensive to provide and thus can be delivered in any country. This means, schools and facilities as well as parents and other carers for children with ASD should focus more on praise and positive feedback when teaching and reduce the negative ones. Furthermore, tasks need to be adjusted insofar as the focus would be on achievable goals.

Deterministic and Stochastic Feedback

Surprisingly, in the stochastic feedback condition, differences in the processing of positive and negative feedback between the TD boys and boys with ASD were diminished and learning was the same (see Figure 3, right). We had expected that because TD boys find stochastic feedback processing difficult, boys with ASD should find it even more difficult, but this was not the case. It became very clear that there was no significant difference between sequence learning under certainty and uncertainty in the two groups of boys with ASD, while the control boys performed significantly better under deterministic feedback than the ones receiving stochastic feedback.

One reason could be that the group of boys with ASD in this study did both feedback conditions, starting off with the deterministic version. This means the boys with ASD had the advantage of knowing parts of the task already when starting to receive stochastic feedback and therefore did as well in this condition, because practice can have an impact in children with ASD (Inui & Suzuki, 1998), for instance in categorization (Groen et al., 2008). A practice effect in this logical deduction task would still be a remarkable learning effect in the boys with ASD.

Another explanation could be that an impairment in executive functions and therefore the lack of initiating new responses and actions (Hill, 2004), the need for sameness and strong tendency towards repetitive behaviour (Poljac & Bekkering, 2012), along with a lack of error correction (Russell & Jarrold, 1998) may have had an unexpected positive effect insofar as misleading feedback did not matter as much for ASD boys as for the control boys. It may be that children with ASD also follow their own agenda when learning - like adults with ASD (Bowler et al., 2008).

However, one could also turn this argument around and conclude that boys with ASD did not benefit as much as TD boys from true, deterministic feedback. This explanation is more straightforward as the boys always received the deterministic feedback first but still may have already distrusted this kind of feedback as much as the stochastic feedback even if it was veridical. This would mean that while typical developed children are more likely to trust and rely on information (Harris, 2012), children with ASD may base their decisions on their own autonomous ideas which may be one of basic mistrust, instead of socially guided information. Also parents of children with ASD show a high rate of social phobia suggesting that these parents would be more suspicious of feedback than parents of typical developing children (Piven & Palmer, 1999). Further children with ASD have many common as well as unusual fears and phobias, supporting their mistrust (Dickerson Mayes et al., 2013).

It is therefore also possible that the boys with ASD were suspicious of the truth of the feedback, even when there was no reason to be so. Adults with ASD were found not to benefit when memory stimuli are semantically related (Toichi & Kamio, 2002), even though they may have superior rote memory (DeLong, 2008). Likewise, in the current study, the boys with ASD did not benefit as much from feedback that is true and straightforward.

These are crucial findings, however, one limitation to the study is, that the ASD sample size was relatively small. However, we conducted a comprehensive assessment with a comparably long and computerized task which allowed us to control children's learning in a very fine-tuned way. We are currently carrying out further research on factors that may be responsible why low and average ability boys with ASD could not benefit as much from completely reliable feedback, yet learned so well under uncertainty.

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