Perceptual Style in High-Functioning Autism:

Implications from Pupillometry and Optical Illusion Susceptibility

Fredrik Svartdal Færevaag

Master of Philosophy in Psychology
Cognitive Neuroscience

UNIVERSITY OF OSLO

May 2015

Perceptual Style in High-Functioning Autism: Implications from Pupillometry and Optical Illusion Susceptibility

By Fredrik Svartdal Færevaag

Master of philosophy in psychology
Cognitive neuroscience
Department of psychology
University of Oslo

May 2015

2015

Perceptual style in high-functioning autism: implications from pupillometry and optical illusion susceptibility

Author: Fredrik Svartdal Færevaag

Supervisor: Bruno Laeng

Co-supervisor: Stephen von Tetzchner

http://www.duo.uio.no/

Abstract

Author: Fredrik Svartdal Færevaag

Title: Perceptual style in high-functioning autism: implications from pupillometry and optical illusion susceptibility

Supervisor: Bruno Laeng

Co-supervisor: Stephen von Tetzchner

Background: Several studies have shown a distinct perceptual style in individuals diagnosed with autism spectrum disorder. Results imply that people with autism have a bias for local over global processing, resulting in superior performance on local-based tasks, but at the same time demonstrate weakened processing of global context in stimuli. One believed consequence of this bias is that individuals with autism are not susceptible to optical illusions relying on an illusion-inducing context. However, studies have reported mixed results. **Objectives:** To determine if individuals diagnosed with autism are less susceptible to optical illusions or not, and to investigate differences in local-to-global integration in individuals with autism compared to controls. **Method:** 14 individuals diagnosed with high-functioning autism and 27 typically developed controls were recruited to participate in the study. All participants performed four different experiments; two designed to investigate performance dependent on local-to-global integration; and two investigating differences in illusion susceptibility between groups. By using a novel paradigm, we were able to detect illusion susceptibility through autonomous pupil reactions. While participants were solving each task, pupil sizes were recorded using an eye-tracking system. **Results:** Analyses of response accuracy and response times showed that participants in the autism group had no impairments perceiving globally compared to the control group. In addition, using pupillary dilation as index of cognitive workload, no differences in mental effort recruited in the task were observed between groups. However, accuracy results indicated that individuals with autism struggled with comparative judgments, as a large drop in performance was seen in a comparative task. Results also showed that the autism group did not experience illusions ‘as strongly’ as controls, given their significantly weaker pupillary constrictions to brightness illusions compared to the control group. However, when making explicit judgments about the same illusions, both groups succumbed to the illusion at equal rates. **Conclusion:** Perceptual style of individuals with high functioning autism seems to be biased for local over global processing, but at the same time seems highly sensitive to any task demands implying the need for global integration. When in need, individuals with autism can integrate objects equally well as typically developed individuals, without recruitment of extra cognitive effort. Individuals with autism seem less susceptible to optical illusions but only when viewing these passively. Making explicit judgments about the illusions may have caused a shift in the perceptual strategy used by individuals with autism, as both groups succumbed to the illusions at equal rates when they explicitly judged the stimuli.

Acknowledgements

I would like to thank my supervisors, Professor Bruno Laeng and Professor Stephen von Tetzchner, for giving me the opportunity to take part in this project. Thank you, Bruno, for your invaluable skills, feedback and support throughout the data collection and writing process. Your insights in the literature and methods, as well as your ability to answer all of my questions on a short notice have been of great help! Thank you, Stephen, for your rigorous comments and academic insight. Your expertise in the research field has been of great value to my learning process. I would like to thank Agata Bochyńska for her invaluable help with the design and analysis, and for helping with the controls' data collection. I could not have completed this project without your help and guidance. I would also like to thank Jarle Johannessen at *Autismeforeningen* i Norge (*The Norwegian Autism Organization)* for the help with recruiting participants for the study.

Contents

Perceptual Style in High-Functioning Autism:
Implications from Pupillometry and Optical Illusion Susceptibility

Autism Spectrum Disorder (ASD) is a neuro-developmental disorder with onset within the first three years of life. According to Diagnostic and Statistical Manual of Mental Disorders, fifth edition (DSM-5) the disorder is typically associated with persistent deficits in social communication and social interaction, and restricted, repetitive patterns of behaviors, interests and activities (APA, 2013). Compared to the previous editions of the manual, DSM-5 specifies that in addition to restricted behaviors and interests, individuals with autism can show hyper- or hyporeactivity to sensory inputs, such as excessive smelling or touching of objects and visual fascination with lights or movements. The severity of autism varies widely, as well as the severity of each symptom, making the disorder one of extreme heterogeneity (Happe, Ronald, & Plomin, 2006; Markram & Markram, 2010). For example, in one of the core-symptoms – impairments in communication – severity can range from a total absence of spoken language, to mild impairments, to hyper-linguism in some cases(Markram & Markram, 2010).

Due to the variation seen across autism cases and the complexity of the disorder, some researchers have stated that we cannot provide a universal account for the disorder (Happe et al., 2006). Consequently, several alternative models for the disorder have been presented. According to Baron-Cohen (2002), autism can be seen as a consequence of an “extreme male brain”, that is, traits of autism could be merely extreme manifestations of a normal male cognitive profile. According to Markram and Markram (2010), another explanation for traits seen in autism may be an effect of what they call an “extreme world syndrome”. They argue that autism arises because of hyper-functioning and hyper-plasticity of local neural circuits, mainly in the neo-cortex and amygdala. Though there are no fully agreed on accounts for autism spectrum disorders to this date, several researchers argue that genetic causes play a significant role in autism. The disorder is known as one of the most heritable (Markram & Markram, 2010; Persico & Bourgeron, 2006), with a 2-3% sibling recurrence risk, and a significantly higher concordance rate in monozygotic (60-91 %) than dizygotic twins (0-6 %) (Jamain et al., 2003). Also, researchers have hypothesized the possibility of autism spectrum disorders being predisposed by changes in the sex chromosomes, partially because of an observed 4:1 male-to-female prevalence ratio in autism, and an 8:1 ratio in Asperger syndrome prevalence (Jamain et al., 2003).

Perceptual Style in Autism Spectrum Disorder

A large body of research has investigated aspects of autism spectrum disorders and documented a variety of differences between ASD and typically-developed individuals. A significant amount of research has investigated visual perception in autism and showed replicable differences. Some of this research has focused on social stimuli, such as facial perception (Dalton et al., 2005; Schultz, 2005) but remarkably several studies have focused on low-level perceptual and attentional processes. These results indicate that individuals with autism can actually outperform controls in tasks that rely on focal attention to local features of the stimuli, such as pattern disembedding tasks, in which participants are asked to identify a simple figure that is embedded (hidden) within a more complex design (Happé & Frith, 2006) – see Figure 1.

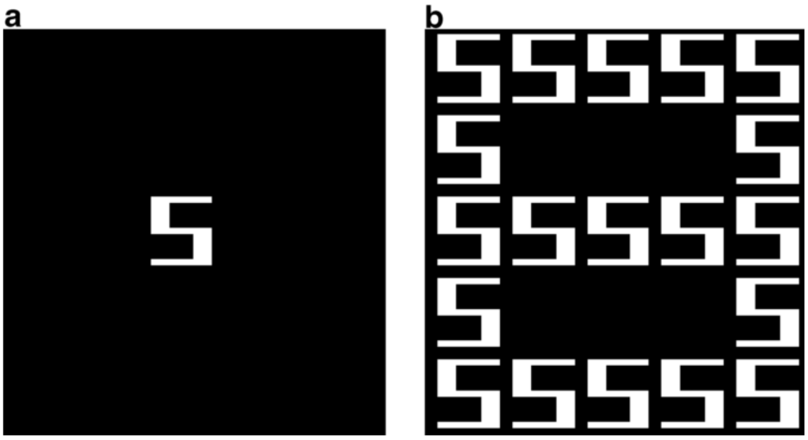


Figure 1. Isolated (a) and embedded figures (b). Used in Mottron et al. (2003) as an Embedded Figures Task.

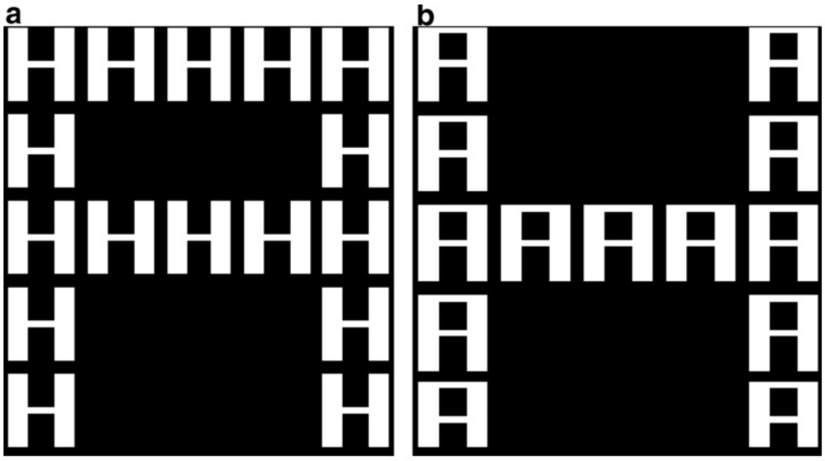


Figure 2. Examples of Navon’s hierarchical letter stimuli: a) the global letter ‘A’ consisting of the local letters ‘H’; b) the global letter ‘H’ consisting of local letters ‘A’. From Mottron et al. (2003).

Also, studies have shown that people with autism are better than matched controls in disregarding global, confounding stimuli, as shown through superior performance with Navon's hierarchical letter tasks, in which participants are asked to identify either a global or local letter in global letter figures made up of small, local letters – see Figure 2 (Brosnan, Scott, Fox, & Pye, 2004). Studies have also shown differences between autism and controls on other tests of spatial attention (for a review, see Ames & Fletcher-Watson, 2010).

One of the most prominent theories of the unique perceptual style seen in autism is the so-called theory of "weak central coherence" (Frith, 2003; Happé, 2005). The term 'central coherence' refers to a putative process of perception, where various information or elements within sight can be pulled together and processed in context, often at the expense of local details and resulting in a perceptual gestalt or global perceptual unit. By contrast, weak central coherence refers to the opposite tendency; that is, to attend to and remember the details or individual elements rather than the global percept derived from these elements (Frith, 2003). In other words, according to the weak central coherence theory, the perceptual style of autism is characterized by a bias for local over global processing, resulting in a failure to derive a contextual meaning from stimuli, but at the same time being more sensitive than normal to even minute details at a local level (Baron-Cohen, 2002; Frith, 2003)

Weak Central Coherence and Illusion Susceptibility

One believed consequence of a local processing bias in autism visual perception is a lowered susceptibility for optical illusions. Happé (1996) found that children with autism succumbed significantly less to optical illusions compared to typical developing (TD) children and children with mild learning disorders (MLD). In this study, children were shown different classical optical illusions, such as the Müller-Lyer illusion, the Ebbinghaus illusion (also referred to as the 'Titchener circles') and the Kanizsa triangle (see Figure 3). Each subject was presented with the illusion and a comparison figure consisting of target stimuli without the illusion inducing elements. For each picture, participants were asked about the size of an appropriate target object dependent on the picture shown (e.g., for the Ebbinghaus illusion: "Are the two circles of the same size or different?").

The results showed that only 28 % of the autistic children succumbed to three or more of the total six illusions, compared to 77 % in the MLD group and 95, 2 % in the TD group. Interestingly, one illusion showed deviant results from all the others: The Müller-Lyer illusion yielded no significant difference between groups, and the children with autism succumbed more to this illusion than any other group. This result may seem to challenge the notion that weak central coherence in autism perception leads to reduced illusion susceptibility. However, according to Happé (1996), this result can be interpreted compatibly with a local perceptual style in autism.

Weak central coherence, being a bias for local over global processing, should predict that children with autism would be less susceptible to illusions that relied on an illusion-inducing context. For example, the illusory effect in the Ebbinghaus illusion would arise as a result of integrating centered target disks and distractor disks, so that each target could be seen in comparison to the distractor. Thus, integrating the parts of the illusion into one whole could create an illusory context that children with autism would not succumb to. However, when an illusion does not rely on such an integration process of separate elements, differences between autism and control illusion susceptibility should not occur. According to Happé (1996), children with autism succumbed to the Müller-Lyer illusion because the illusion does not rely on an inducing context and cannot be split into separate parts. Whereas the target disks in the Ebbinghaus illusion are clearly isolated in space from the distractors, the spear-heads in the Müller Lyer-illusion are attached to the targets and part-and-parcel of a single object.

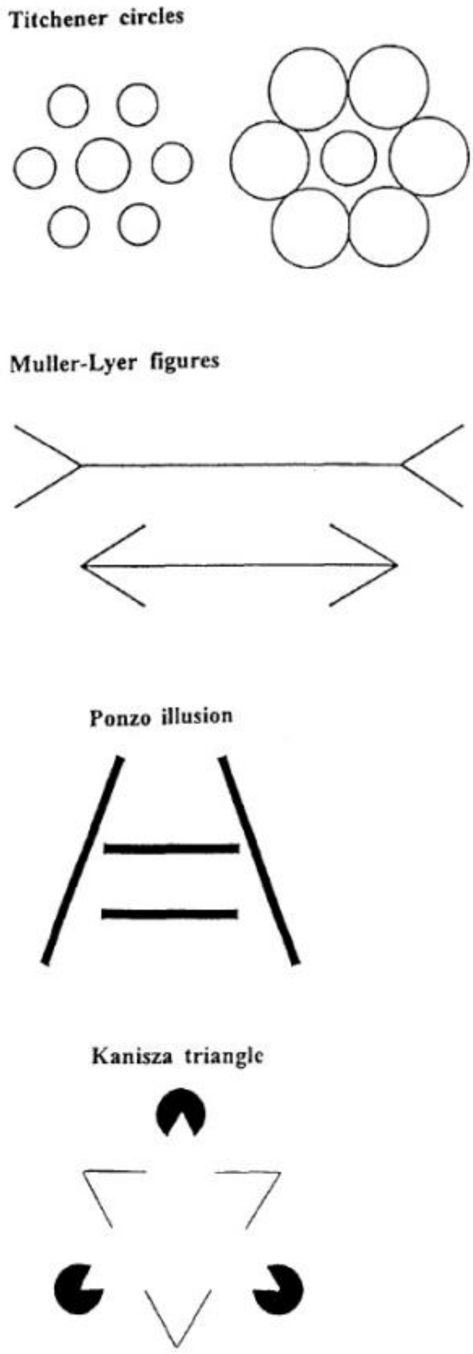


Figure 3. Examples of classical illusions, from Happé (1996).

Although the results from Happé (1996) seemed to indicate that individuals with autism have a distinct perceptual style, other studies have failed in replicating the effects. In a study by Ropar and Mitchell (1999), adolescents with autism, Asperger syndrome (a type of high-functioning autism), and moderate learning difficulties were shown four of the six illusions previously used in Happé (1996), and illusion susceptibility was compared to a group of typically developed adolescents. The study used a different, psychophysical, paradigm than the original study, in which participants were to adjust target object sizes to match ones of targets in illusions. Their results showed no significant difference in illusion susceptibility between groups. A similar finding was also shown in a second experiment, in which all participants were asked to make verbal judgments of the stimuli. In a follow-up study, Ropar and Mitchell (2001) sought to investigate whether individual differences in spatial ability of individuals included in different studies may have accounted for the failure to replicate the findings from Happé (1996). In their study, children with autism and Asperger syndrome were therefore compared to matched controls in their performance in a battery of visuospatial tasks thought to directly measure weak central coherence. Results showed that performance on the visuospatial tasks did not predict differences in illusion susceptibility in either group, and the authors argued that susceptibility to illusions and performance on visuospatial tasks may each rely on unrelated, perceptual mechanisms.

Seemingly, individuals with autism seem less susceptible to optical illusions relying on an illusion-inducing context due to a putative locally biased perceptual style.

Weak Central Coherence as a Bias in Perception

Happé (1996) argues for a direct effect of weak central coherence in autism children’s perceptual style. However, the above-mentioned problems with replicating these results in some other studies have raised the question whether there are differences in illusion susceptibility in individuals with autism or whether the mismatching results seen in different studies are due to population sampling biases or errors. As autism spectrum disorder is known as a heterogeneous disorder, one would think that illusion susceptibility could vary widely within the population along with severity in other traits.

Another facet that could explain the problems in replication – as noted by Happé and Frith (2006) and Mottron, Burack, Iarocci, Belleville and Enns (2003) – is that weak central coherence should be seen as a mere bias and not a clear-cut deficit of autism perception. They note that the global perceptual system is intact in individuals with autism, and that they can perceive at a global level if told to do so. The fact that individuals with autism are capable of global processing suggests that they are able to see illusions without succumbing to them, but as soon as the need for integration is made explicit as task demands, individuals with autism should succumb to illusions at the same rate as other people. This poses as a caveat for Ropar and Mitchell's (1999, 2001) attempts of replicating Happé's (1996) results. In Happé (1996), children with autism were asked directly about differences and similarities in target and control stimuli, whereas Ropar and Mitchell (1999, 2001) asked participants to adjust an object to match the target in an illusion. The two studies by Ropar and Mitchell thus seem to measure a different judgement than the original study by Happé (1996); that is, making relative judgments of stimuli versus performing adjustments of stimuli. The latter method may have encouraged a more global percept in the autism group, making them more susceptible to the illusions. Assuming that weak central coherence is only a bias in autism perception, in which global percepts can be achieved if demanded, differences in paradigms and tasks may lead to rather different perceptual judgments in individuals with autism. Thus, the relation between weak central coherence and illusion susceptibility is not straightforward.

Another important facet of the relation between weak central coherence and illusion susceptibility is the differentiation between *seeing* the illusory pattern and *succumbing to* the illusion. As noted by Scott, Brosnan and Weelwright (unpublished, as cited in Happé & Frith, 2006), asking participants if illusions and control figures *look* the same or *are* the same will lead to different outcomes of the judgment. They noted that participants in an autism group made more errors and succumbed more to illusory effects when asked whether target stimuli *appeared* as equal or different, whereas they gave more accurate responses when asked whether target stimuli *were* equal or different. This also highlights the sensitivity of weak central coherence. Asking autism participants if they can see an illusory effect may seem to communicate a need for a global percept, in which individuals with autism start seeking for a percept that fulfills the illusion in question, and consequently make less accurate judgments – i.e. succumb to illusions more frequently – than if they were asked to address actual differences in the stimuli.

Seeing that weak central coherence is only a bias in perception in individuals with autism, who will perceive at a global level if a need for integration is made explicit as task demands, future paradigms will need to isolate the illusory effects in order to clearly specify differences in perceptual processing style. This article presents one such paradigm, in which illusion susceptibility is measured through autonomous pupillary responses to illusory light, excluding the possibility of differences in task demands and (unintentional) communicated needs of integration.

Local-to-Global Integration

As mentioned, the relevant perceptual process that seems to be affected by a weak central coherence in autism perception is local-to-global integration. Normally, this is the process of deriving a gestalt through the interplay and integration of objects' parts (Prinzmetal, 1981; Treisman & Gelade, 1980). According to Treisman and Gelade's (1980) feature integration theory, features in visual stimuli are registered early and automatically – and in parallel – while objects as entities are identified separately and at a later stage requiring focused attention. Thus, when the eyes see an object, the visual system of the brain will first automatically detect the separate entities that make up the object, before these are integrated into the representation of the present object and become a conscious percept. This process calls for the ability to distinguish traits from objects; i.e. being able to perceive at a local *and* a global level in parallel. This is where the weak central coherence is believed to affect visual perception in people diagnosed with autism (Bernardino et al., 2012). In light of Treisman and Gelade's (1980) feature-integration theory of attention, people with autism should show a typical, automatic processing of features, as proposed in the theory, but they might fail to successfully integrate these into a whole gestalt. This is what Happé (1996) arguably showed with children diagnosed with autism, since they were not susceptible to those optical illusions that most relied on a local-to-global integration process. To conclude, the results combined suggest that the interaction between weak central coherence and local-to-global integration can cause a lowered susceptibility to (some) optical illusions caused by the inability in children with autism to derive a global, illusion-inducing context from these.

Pupillometry

Though Happé (1996) showed a direct effect of weak central coherence in autism perception, few studies have sought to investigate illusion susceptibility in autism since her seminal study. Apart from two unsuccessful replication attempts (Ropar & Mitchell; 1999; 2001), only a handful of studies in the past decade have investigated illusion susceptibility in autism spectrum disorder, primarily through other cognitive mechanisms than weak central coherence such as top-down processing (Mitchell, Mottron, Soulieres, & Ropar, 2010) and facial perception (Rouse, Donnelly, Hadwin, & Brown, 2004). The lack of recent research investigating the relation between weak central coherence and illusion susceptibility might seem to be due to the absence of novel paradigms and methods. The current study makes use of a novel neuro-physiological measurement that can be used to investigate illusion susceptibility in individuals at an autonomic level, without the need for explicit judgments or verbal reports, thus bypassing the possibility of a shift away from a local processing style in autism perception.

Measuring the diameter of the eye's pupil – called 'pupillometry' – is a measurement that extends beyond the eyes' responses to changes in light luminance. Research has established that pupil changes also occur due to cognitive processing, arousal (stress, sexual arousal), and emotional activation (Alnæs et al., 2014; Laeng, Sirois, & Gredebäck, 2012). By using infrared cameras attached to a stimulus screen, real-time pupillary measurements and scanpaths can be recorded at sampling rates normally ranging from 10Hz to 2000Hz (SMI, Teltow, Germany). One of the key-advantages of pupillometry as a neuro-physiological measurement is that pupil reflexes occur automatically and are difficult to control voluntarily. Pupil dilations may be voluntarily evoked indirectly – for example by imaging an object or scene that is arousing – but the pupil responses cannot be suppressed at will (Laeng et al., 2012; Laeng & Sulutvedt, 2014). Also, a study has shown that imagining objects that involve bright lights or bright objects will evoke pupil dilations or constrictions, respectively (Laeng & Sulutvedt, 2014) . Thus, the method gives an autonomous and continuous measure that gives insight to underlying processes in task performance and stimuli responses.

Pupillometry in autism spectrum disorders. Whereas a large body of research has investigated perceptual style in autism spectrum disorders (Happé & Frith, 2006), relatively few studies have investigated differences between people with autism and controls in their pupillary responses to visual stimuli. The need for paradigms that investigate underlying processing in perception seem evident in order to fully understand perceptual style in autism without the possibility of differences in task understanding and response biases. In one study using pupillometry to investigate perceptual style in autism spectrum disorder, Blaser, Eglington, Carter and Kaldy (2014) showed that autistic 2-year olds dramatically outperformed age-matched typically developing children on a set of visual search tasks. In addition, their results revealed differences in phasic pupillary changes in the autistic children as compared to neuro-typical controls. According to the authors, differences in phasic pupil sizes in children with autism gave evidence of greater attentional focus in autism perception compared to neuro-typical controls. They concluded that autistic children showed better performance in visual search tasks not due to differences in perceptual style, but because they searched *harder* compared to control participants.

The study by Blaser and colleagues (2014) highlights the need for new methodological approaches to the investigation of perceptual style in autism. Paradigms relying on judgment outcomes – e.g. if one illusory object differs from another – may fall short due to confounding variables such as task understanding and attentional shifts in autism perception. The addition of a neuro-physiological measurement in the study of autism illusion susceptibility may give valuable insight to underlying processes and autonomous responses that can explain why some studies have found that individuals with autism are less susceptible to optical illusions when other studies have failed to show the same.

Optical Illusions as Indicators of Perceptual Style

The use of optical illusions in the investigation of perceptual style seems useful, as some illusions offer clear indications of differences in perception through judgmental outcomes. As noted by Happé (1996), many of the classical optical illusions are devoid of higher level meaning, meaning that confound variables of participants' associations and semantic interpretation can be highly excluded from the perceptual processing. Optical illusions may also be good indicators of object-integration style; for example if a person does not indicate differences between two target disks in the Ebbinghaus illusion, this would indicate that the person sees the target disks isolated from the surrounding distractors, i.e. fails to integrate all aspects of the picture into a gestalt.

Though optical illusions give important insight to explicit judgments of stimuli, differences in stimuli judgments may also be due to differences in task understanding, and in the case of individuals with autism, due to shifts from local to global processing. However, a recent study by Laeng and Endestad (2012) offers a paradigm in which illusion susceptibility is measured through automatic and involuntary pupil reactions, thus showing illusion susceptibility without the need of explicit judgments that could differently affect the perceptual style. In the study, when shown illusions one at a time, participants showed pupil constrictions for pictures that induced an illusory perception of light, as compared to equiluminant pictures that did not share this increased brightness-induction. The results showed that the pupil does not react only to light but also to the *believed* presence of light.

Importantly, by presenting brightness illusions relying on the same illusory processes as the ones used in Happé (1996), the pupillary measurement promises to show differences in illusion susceptibility between groups without entirely relying on the explicit judgments made by participants.

In this study, we present results from four different experiments designed to investigate perceptual style in individuals diagnosed with autism. In Experiment 1a, we presented a group of autistic individuals and a control group with different types of letter stimuli. Letters from different experimental conditions needed to be integrated at a global level in order for participants to be able to identify them. In this experiment, we investigated the hypothesis that individuals with autism needed to recruit additional cognitive effort when integrating visual stimuli due to a weak central coherence in perception. In Experiment 1b, we used the same stimuli in a similar task, in which participants had to discriminate between two figures and identify which of the two represented a letter.

In Experiment 2a, we investigated differences in illusion susceptibility due to a weak central coherence in autism perception. By recording pupil sizes in participants as they perceived brightness illusions previously shown to cause pupil constrictions in participants (Laeng & Endestad, 2012), we could assess differences in illusion susceptibility without relying on participants' explicit judgments. In Experiment 2b, we used the same brightness illusions as in Experiment 2a, but here, participants were asked to explicitly evaluate the brightness of each illusion's middle. By comparing results from autonomic, neuro-physiological responses to illusions with results from explicit judgments, we could determine whether explicit judgments of stimuli caused a shift from a local to a more global percept in individuals with autism.

The Current Study

The main aim of the study was to investigate visual perceptual style in individuals diagnosed with autism spectrum disorders, mainly through differences in local-to-global integration and illusion susceptibility. In order to investigate perceptual style in autism spectrum disorders we presented two groups, the experimental group consisting of 14 individuals diagnosed with high-functioning autism, and a control group consisting of 27 participants, with two tasks involving novel letter stimuli that required different levels of integration. By differentiating between levels of integration needed in stimuli, we could investigate differences in required cognitive effort dependent on local-to-global integration through differences in tonic pupil sizes, and determine whether a weak central coherence in autism perception demands extra cognitive effort when integrating stimuli. Also, we presented participants with two tasks involving brightness illusions in which illusory effects relied on a successful local-to-global integration. We applied a novel paradigm for the investigation of illusion susceptibility in participants, in which the use of brightness illusions and pupillometry allowed us to investigate automatic neuro-physiological signatures of illusion susceptibility.

Overall Hypotheses

Due to a putative local preference in the perception of individuals with autism, we hypothesized that participants in the experimental group in general would show more sensitivity to local traits of stimuli, consequently overlooking the stimuli’s gestalt more frequently than participants in the control group. Derived from this, we present several specific hypotheses and predictions for each experiment.

Letter detection and discrimination tasks. We expected that participants in our experimental group would show difficulties in detecting and differentiating letter stimuli that required local-to-global integration. We hypothesized that the shift from local processing to a more global processing would demand extra cognitive effort in our experimental group; consequently, we expected that our experimental group would demonstrate larger tonic pupil changes than our control group when successfully detecting the presence of stimuli that required integration compared to stimuli that did not require such integration. Due to the forced shift from local to global processing, we also expected that our experimental group would demonstrate significantly longer response times and lowered response accuracy in object integration trials.

Brightness illusions. Following the above logic, if participants in our autism group had a tendency for local over global processing, they should not succumb to the brightness illusions at the same rate or to the same degree as control participants. As the brightness illusions rely on an illusory context – namely that the whole illusion must be integrated and seen as ‘one’ in order to create illusory light (e.g., as a flower-like pattern for the Asahi illusion) – we would expect participants in the experimental group to not show significant pupil constrictions in response to brightness illusions. However, when participants were asked to explicitly judge each brightness illusion and control figure, we expected the experimental group to show equal or same level of illusion susceptibility as the control group because of a shift from a local to a more global perception as a result of an increase in task demanded integration.

Materials and Methods

Participants

Due to large variation in cognitive impairments seen across autism spectrum disorders, we chose to narrow our experimental group to participants diagnosed with high-functioning autism or Asperger syndrome. Fourteen adults diagnosed with high-functioning autism were recruited for this study through contact with Autismeforeningen in Norway (*The Norwegian Autism Organization*). Clinical history was provided by the participants themselves – which diagnose they had received, when they received this, and by whom was registered for each participant. Control subjects were recruited from University of Oslo, mainly consisting of students from the Psychological Institute. Due to general difficulties in recruitment within a short period of time, control participants could not be matched with the experimental group on age, sex or educational level. Due to the restricted time schedule of this project, the total number of participants in the experimental group was quite low. However, twenty-seven university students were recruited as our control group.

All participants had normal or corrected-to-normal vision. Participants in the control group were paid NOK 200 for their participation, whereas participants in the experimental group were given NOK 300 for participating. One participant in the experimental group was excluded from the analysis due to poor calibration and consequent poor data recordings. In the brightness illusion experiment, recorded data from a previous pilot was included, increasing the number of control participants from 27 to 34. All participants completed Raven’s Progressive Matrices (Raven, 2003), Motor-Free Visual Perception Test, third edition (MVPT-3) (Colarusso & Hammill, 1972), and participants in the experimental group filled out the Autism Quotient Questionnaire (Baron-Cohen, Wheelwright, Skinner, Martin, & Clubley, 2001). Subject characteristics and test scores can be seen in Table 1.

Table 1. Subject characteristics and test scores. Maximum score achievable in the presented tests were: AQ: 50 points; MVPT-3: 50 points; and Raven's: 60 points.

Group	N		Age	AQ	MVPT-3	Raven's
ASD	13	Mean	36.31	33.50	42.15	38.54
		SD	13.00	8.39	4.36	9.40
Control	27	Mean	24.00	-	46.96	50.52
		SD	4.41	-	3.08	5.79

Ethics

Participants were informed that they would experience no advantages or disadvantages by participating in the study, but that the results from the study could contribute to the understanding of autism spectrum disorder. Participants were also informed about the anonymity of the study, in which participant data would be treated anonymously, in which individual performances could not be traced back to the individual participant. Written consent was received from all participants before testing, and the project was ethically approved by the Regional Committee for Medical and Health Research Ethics (REK Sør-Øst): Information letter is presented in appendix B.

Setup and Equipment

Throughout all sessions, participants' pupil diameters were measured at a sampling rate of 60 Hz using an SMI RED500 Eye-tracking device by SensoMotoric Instruments (SMI, Teltow, Germany). Pupil data was collected with the integrated iView 10 X Software provided by SMI. Pupil sizes were recorded in pixels, and all subsequent pupil size changes in this paper will be reported in pixels. All stimuli were presented through Experiment Center 3.2 – an integrated presentation software by SMI – and were shown on a Dell P2213 VGA LCD monitor. The size of the monitor was 18.5", measuring a diagonal length of 47 cm. The display resolution was set to 1680 x 1050 pixels, and was held constant throughout the procedure. All experiments were run on a Dell Latitude E6530 powered by an Intel i7-3520M CPU at 2.9 GHz. and 4 GB of RAM, running Windows 7 at 32 bit. All key press data were recorded with a Dell L30U keyboard. All participants were seated 55 cm from the computer screen and a chin rest was used in order to minimize head movements.

Procedure

Participants were tested in a quiet and dimly lighted room. At the beginning of each session, chair and chinrest height was adjusted to the height of the participant. Before each experiment, a calibration procedure was done in order to obtain as accurate pupillary recordings as possible. After each calibration, participants were asked to remain as static as possible. After each experiment, participants were given the opportunity to take a short break before continuing. Before each experiment, participants were shown an on-screen instruction slide telling them what their task was and what buttons to press in order to give their responses. Odd-numbered participants and even-numbered participants were presented with experiments in an ascending and descending fashion, respectively.

In all experiments, each trial started with a fixation cross presented in either corner of the screen, with an additional 500 MSEC fixation trigger (see Figure 4). After the trigger, a blank, luminance-matched baseline was presented. This was presented for 500 MSEC in the letter detection task, letter discrimination task and in the brightness comparison task. The baseline times were adjusted for the brightness illusion passive viewing experiment – from an initial 500 MSECs to 1500 MSECs.

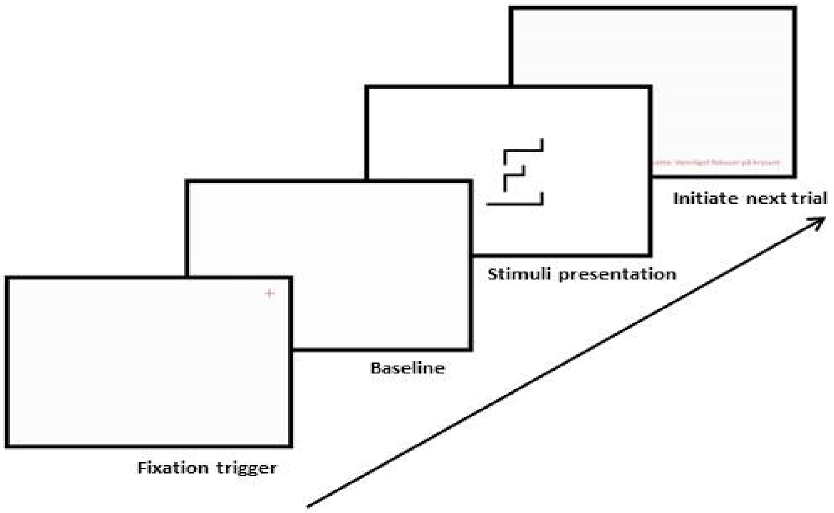


Figure 4. Example of a trial procedure taken from experiment 1a – letter detection. Participants were first shown a fixation cross in either corner of the screen that triggered the presentation of a 500MSEC luminance-matched baseline when looked at. After the baseline pupil-recording, an experimental stimulus was presented for four seconds. After that, a slide was presented prompting participants to press the spacebar to initiate the next trial.

After completing all experiments, participants were presented with two psychological tests; Raven’s progressive matrices (Raven, 2003), and Motor-Free Visual Perception Test, third edition (MVPT-3) (Colarusso & Hammill, 1972). Raven’s Progressive Matrices – a standardized IQ test with the maximum score of 60 points – consisted of 60 tasks of pattern recognition, in which participants had to select one of either six or eight alternative figures that would follow a pattern presented in the task. The test was presented on the stimulus monitor, and verbal responses were registered by the experiment leader. In motor-free test of visual perception – a standardized test of perceptual style and ability with a maximum score of 50 points – participants were shown different tasks on paper sheets. Participants had to detect one target stimulus for each trial, much similar to the procedure in the Raven’s test. In addition, participants in the experimental group were asked to fill out the Autism Quotient questionnaire (Baron-Cohen et al., 2001). The questionnaire consisted of 50 statements regarding traits and symptoms seen in autism spectrum disorder that participants had to report whether they fully or partially agreed or disagreed with.

Experiment 1: Letter Tasks

Stimuli

All stimuli used in the letter tasks – both letter detection and letter discrimination – were created by the author for this study. All figures were created in InkScape, Version 0.98 (2013), a vector-based graphics software.

Experiment 1a: letter detection. A set of 24 different letter stimuli was used. Each picture would represent one of four letter conditions used in the experiment: 1) Full letter – a bold, capital letter; 2) Shadow letter – a similar capital letter, but with some of its line missing, resulting in a perception of a three-dimensional letter when integrated to a gestalt; 3) Partial letter – similar to the shadow letter, but each line in the figure was replaced with dotted lines; and 4) Scrambled letter – a figure incapable of representing a letter, consisting of rotated elements from previous letter conditions (see Figure 5). Half of all stimuli – i.e. 12 pictures – represented a scrambled figure, whereas the remaining 12 pictures represented a letter. The 12 letter figures were equally distributed across three conditions.

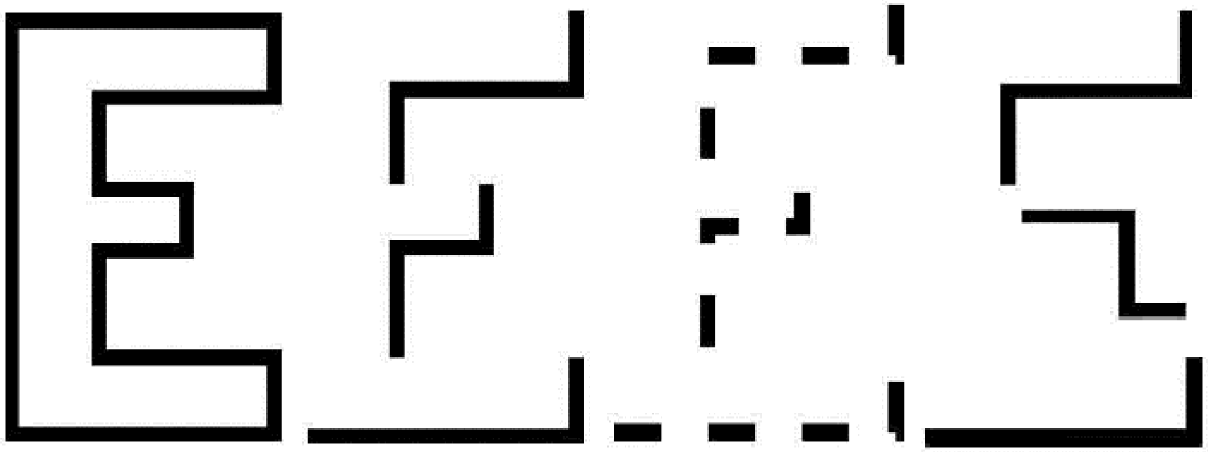


Figure 5. The different letter conditions used in the letter detection task: 1) Full letter; 2) Shadow letter; 3) Partial letter; 4) Scrambled letter. The complete set of images used in the experiment is presented in Appendix A.

Experiment 1b: letter discrimination. Equal letter stimuli were used in this experiment as in experiment 1a, but in this experiment pictures were presented in pairs. Letter-pairs consisted of one letter from either of the letter conditions (full letter, shadow letter or partial letter), and one scrambled letter. A total of six letter-pairs were used in the experiment, and spatial location of target was counterbalanced across trials. This resulted in three trials in which a letter appeared in the left hemi-field and three trials in which the letter appeared in the right hemi-field.

Procedure

Experiment 1a: letter detection. In the letter detection task, participants were told to press the green key on the keyboard if they saw a letter of the alphabet, or the red button if they believed no letter was presented. Response keys consisted of the two letters 'B' and 'N' on the keyboard, which were marked with a green and a red sticker. Participants would see the letter figure for a total of four seconds, and were asked to give their responses within this time-frame. All trials were presented in a randomized order.

Experiment 1b: letter discrimination. In the letter discrimination task, participants were asked to identify which out of two figures showed a letter. By using the same key press responses as in experiment 1a, participants would indicate if either right or left picture represented a letter by pressing the spatially corresponding button. In this case, that meant that the green button ('B'-key) would correspond with a letter being presented to the left, and the red button ('N'-key) corresponded with a letter presented to the right. Pictures stayed on-screen for four seconds, and participants were asked to give their responses within this time-frame.

Design and Analyses

In experiment 1a – Letter detection – the design was a 2x4 repeated measures factorial design, with group (ASD and Control) and letter conditions (Full, Shadow, Partial and Scrambled) as independent variables. In experiment 1b – letter discrimination – the design was a randomized post-test design with group (ASD and Control) as independent variables. Separate t-test analyses were done for each dependent variable; response accuracy, response times, and pupil changes. Pupil size and response time analyses were conducted for correct responses only in order to investigate differences in cognitive effort and processing time between groups for successful detection of integrated letters. As all t-tests were made on predicted mean comparisons, Bonferroni correction of the alpha level was not considered necessary.

Letter Tasks Predictions

As mentioned in the general predictions, we expected our experimental group to struggle with trials in which stimuli required local-to-global integration. Specifically, we predicted that the experimental group in the letter detection task would show 1) lowered accuracy for letter detection in the shadow and partial letter condition; 2) longer response times in the shadow and partial letter condition compared to controls; and 3) larger pupil sizes – as a consequence of more mental effort recruited in the task – for the shadow and partial letter conditions. In the letter discrimination tasks, we predicted that the experimental group in general would show lower accuracy rate, higher response times and larger average pupil sizes compared to controls, as both figures in the comparison task had to be integrated simultaneously in order for participants to make correct judgments.

Results: Experiment 1

Experiment 1a: Letter Detection. Results from the letter detection task showed performance on a similar level between groups. Contrary to our hypotheses, the experimental group showed no significant difference in accuracy or response times in comparison to the control group, including for trials in which object integration was necessary in order to make a correct response (see Table 2 and 3).

Table 2. Average response accuracy for the letter detection task (standard errors are reported within parentheses).

		Letter condition			
Group		Full	Shadow	Partial	Srambled
ASD	N=13	1 (0)	0.37 (0.11)	0.28 (0.11)	0.86 (0.05)
Control	N=27	1 (0)	0.44 (0.07)	0.36 (0.08)	0.86 (0.04)
t-test		0	*t*(37)=0.58	*t*(36)=0.57	*t*(38)=0.50

Table 3. Response times for correct responses in the letter detection task (standard errors are reported within parentheses).

		Letter condition			
Group		Full	Shadow	Partial	Scrambled
ASD	N=13	1666.95	1977.16	2163.51	2194.95
		(119.34)	(124.63)	(166.78)	(149.21)
Control	N=27	1339.80	2186.21	2244.06	1890.76
		(130.71)	(244.48)	(252.29)	(157.23)
t-test		*t*(36)=-1.63	*t*(32)=0.64	*t*(24)=0.27	*t*(38)=-1.22

Repeated measures ANOVAs showed no significant group by letter condition interaction on either response accuracy (*F*(3,33)=0,07, *p*=0,98) or response times (*F*(3,33)=0,88, *p*=0,47). Also, no significant group by letter condition interaction on pupil sizes (*F*(3,33)=0.07, *p*=0.98) was observed. No significant differences in pupil size was seen between groups, even for trials in which local-to-global integration was necessary in order to correctly identify a letter's presence (see Table 4 and Figure 6).

Table 4. Average pupil sizes for correct responses in the letter detection task (standard errors are reported within parentheses).

		Letter condition			
Group		Full	Shadow	Partial	Scrambled
ASD	N=13	0.88 (0.11)	0.87 (0.18)	0.98 (0.22)	0.62 (0.15)
Control	N=27	0.80 (0.09)	0.75 (0.11)	0.88 (0.12)	0.51 (0.80)
t-test		*t*(36)=-0.053	*t*(28)=-0.61	*t*(16)=-0.39	*t*(38)=-0.75

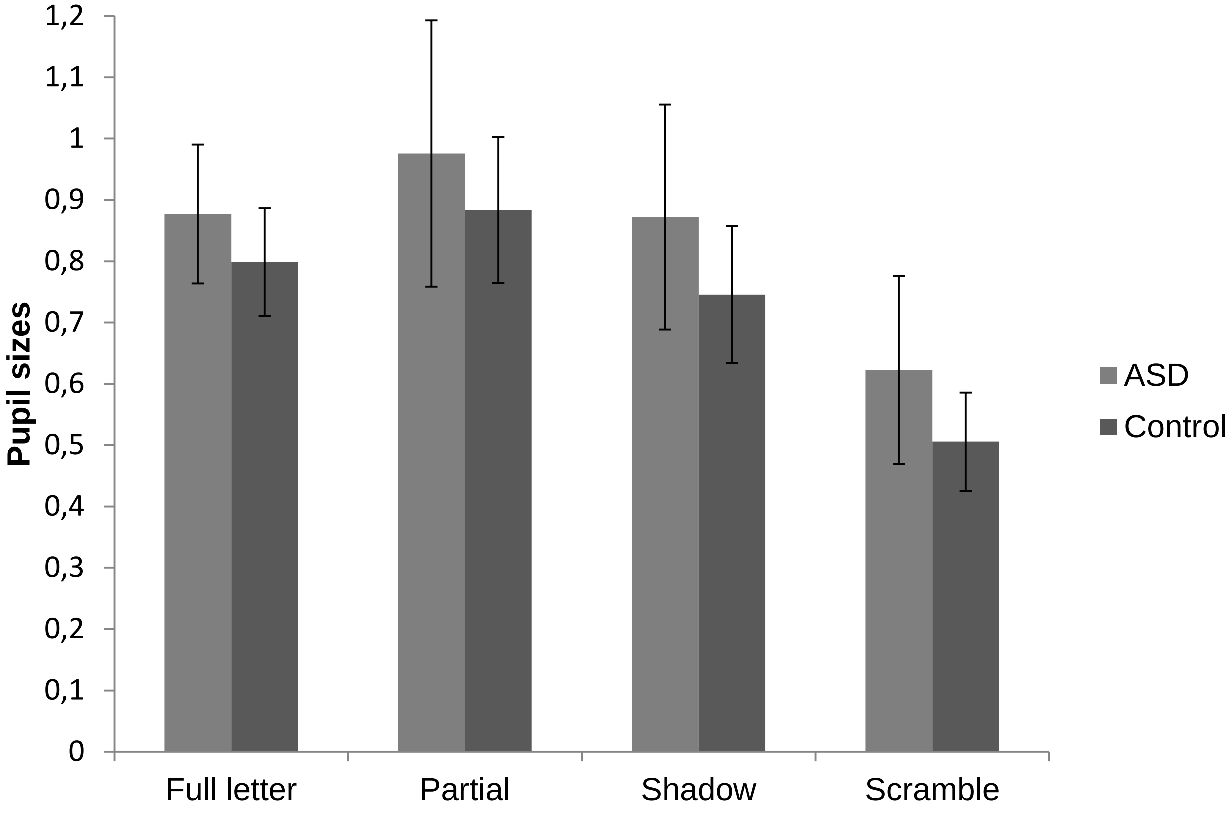


Figure 6. Baseline-corrected pupil sizes in pixels for the correct identification of letters in all conditions in the letter detection task. Error-bars indicate the standard error of the mean.

Experiment 1b: Letter Comparison. As predicted, the experimental group performed significantly poorer in the letter comparison task than compared to the control group (see Table 5). A Cohen's value (*d* = 1,350) suggested a large effect size. However, no corresponding differences in either pupil sizes or response times were observed between groups, indicating that recruitment of cognitive resources did not differ between the experimental group and controls.

Table 5. Average response accuracy, response times and pupil size changes in the letter comparison task (standard errors are reported within parentheses).

Group		**Response Accuracy**	**Response times**	**Pupil sizes**
ASD	N=13	0.45	2197.43	0.61
		(0.07)	(176.44)	(0.18)
Control	N=27	0.87	1850.87	0.67
		(0.04)	(115.63)	(0.09)
t-test		*t*(38)=4.49*	*t*(29)=-1.25	*t*(36)=0.33

*Significant at p<0.05

Experiment 2: Brightness Illusions

Stimuli

Experiment 2a: brightness illusions, passive viewing. The stimuli used in experiment 2a consisted of two different illusions, all previously used in Laeng and Endestad (2012). In the Kanizsa illusion (Kanizsa, 1976), surrounding objects appear in a non-randomly fashion, creating an illusion of a figure consisting of white, "negative space". This illusory figure is perceived as brighter than its equally white background, as it appears to be located in front of the other elements of the figure. The other flower-like shaped illusion, or Asahi illusion (Kitaoka, 2005), create the deception of a light glare in the figure's middle induced by the luminance gradients of the flower's "petals" (see Figure 7).

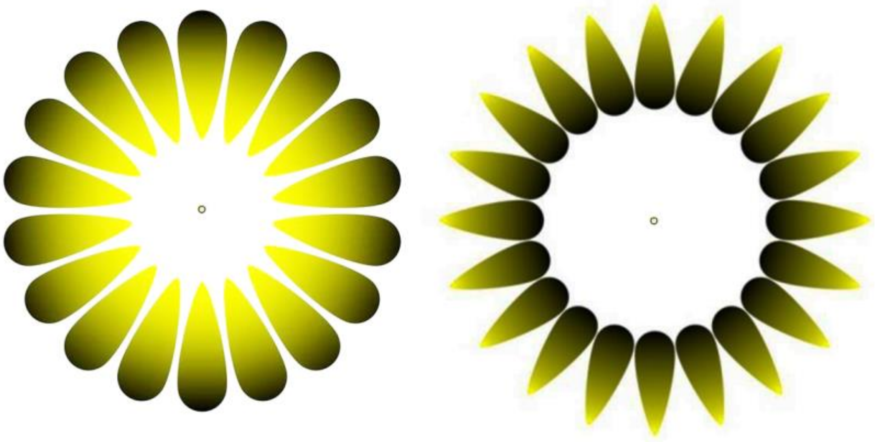


Figure 7. Example of one Asahi illusion and corresponding control figure – «Evening dusk» (from Laeng & Endestad, 2012) used in experiment 2a.

As a result, observers are tricked to believe that the middle of the flower is brighter than the equally bright background. All illusions were paired with control pictures, in which illusory-inducing elements were reversed in order to disrupt, or even reverse, the illusory effect (see "Evening Dusk" in Laeng & Endestad, 2012). In the middle of each pattern, there was a small fixation point.

Participants were presented with a total of seven different illusions – three kanizsa illusions, three Asahi illusions and a brightness illusion consisting of a cube pattern (see Laeng and Endestad, 2012) – with seven corresponding control figures, resulting in a total of 14 trials.

Experiment 2b: brightness comparison task. In experiment 2b, participants were presented with the Asahi-illusions from experiment 2a. All illusions were presented pair-wise with their corresponding control figure, as shown in Figure 7. Due to a low number of stimuli, all illusion-control pairs were presented twice; once in which the illusion appeared in the left hemi-field, once with the illusion in the right hemi-field, resulting in a total of six illusion-control pairs.

Procedure

Experiment 2a: brightness illusion passive viewing. In the passive viewing task, participants were told to fixate on the centered fixation point in each illusion. Also, participants were instructed to give no explicit responses to the stimuli; they were only to fixate on the fixation point throughout all trials. Stimuli were presented for four seconds before a slide appeared telling participants to press the spacebar to continue to the next trial. All trials were presented in a pseudo-randomized order, in which Kanizsa illusions and corresponding control figures were presented first, followed up with the Asahi illusions.

Experiment 2b: brightness comparison task. In experiment 2b, participants were presented with Asahi illusions paired with control figures. Participants were asked to identify if one of the figure’s middle was brighter compared to the other or if both were of equal luminance. If participants believed that there was a difference of luminance in either figure’s middle, they were asked to identify which of the two had the brightest middle. Responses were given verbally to the experiment leader who pressed corresponding response keys on the operating keyboard. Stimuli stayed on-screen until a response was registered.

Design and Analyses

In experiment 2a, pupillary changes dependent on illusion conditions were analyzed as a 2x2x7 repeated measures factorial design, with group (ASD and Control), condition (illusion on/off) and type of illusion as independent variables. In experiment 2b, behavioral responses were analyzed as a randomized post-test design, with group (ASD and Control) as independent variable. Mean pupil sizes for both conditions and groups were compared using a paired-samples t-test.

In experiment 2a, pupil differences dependent on group and illusion condition were analyzed using a repeated-measures ANOVA. According to Laeng and Endestad (2012), brightness illusions (e.g. the Asahi illusions) and lightness illusions (e.g., the Kanizsa illusions) have different effects on pupil sizes, in which brightness illusions have shown the strongest effects. Consequently, paired samples t-test analyses were conducted on pupil sizes dependent on all illusions and Asahi illusions alone across groups. In experiment 2b, response accuracy averages were compared using an independent samples t-test. As all t-tests were based on predicted changes in group means, the need for Bonferroni corrections of the alpha level were considered as not necessary.

Brightness Illusions Predictions

As mentioned in the general predictions, we expected our experimental group to show lesser susceptibility for the brightness illusions than compared to the control group or, in other words, weaker pupil constrictions in response to brightness illusions, and also weaker pupil dilations to the control figures with a reverse brightness effect, compared to controls. In contrast, in the brightness comparison task we expected that the experimental group would judge the illusions as having a brighter middle than control figures at the same rate as controls, as the need for integration is made more explicit as a task demand in the comparison task than the passive viewing task. Consequently, we expected the experimental group to show more susceptibility to the illusions when asked to explicitly judge their illusory effects.

Results: Experiment 2

Experiment 2a: Brightness Illusions, Passive Viewing. In experiment 2a, a significant effect of all brightness illusions on average pupil sizes was observed across groups (F(6,39)= 6,33, p=0,00). No significant interaction effect was observed (F(6,39)=0,569, p=0,75), indicating that the group variable did not significantly mediate the effects of all brightness illusions on pupil sizes. A paired samples t-test showed that none of the groups showed significant mean pupil size changes as an effect of the brightness illusions. As brightness illusions have shown to yield larger effects on pupil sizes than lightness illusions like the Kanizsa patterns (Laeng & Endestad, 2012), separate analyses were conducted for the Asahi illusions. A significant main effect of illusion on pupil sizes was observed across groups (F(2,43)= 14,27, p=0,00). Contrary to our prediction – that the effect of brightness illusions on pupil sizes would be mediated by the group variable – no significant interaction effect was observed for group and illusion on pupil sizes (F(2,43)=1,59, p=0,22). A paired-samples t-test yielded significantly different pupil averages in the control group dependent on condition (see Table 6); however, the pupil differences dependent on illusion condition did not reach significance in the experimental group.

Table 6. Mean pupil sizes in response for the Asahi illusions and control figures (standard errors are reported within parentheses).

		Condition		**T-test**
Group		Asahi Bright	Asahi control	t-value
ASD	N=13	-0.24 (0.14)	-0.10 (0.19)	*t*(11)=-1.95
Control	N=34	-0.29 (0.07)	0.13 (0.06)	*t*(32)=-6.62*

*Significant at p<0,05

Since half of the participants had seen the Asahi illusions before doing the passive viewing task – due to a reversed experiment order in half of the participants – separate analyses were conducted for participants who had not been presented with the brightness illusions prior to the passive viewing task. In order to investigate the pupillary responses in naïve participants, a repeated measures ANOVA was conducted for half of the participants. Importantly and in contrast to the above analysis, this time we found a significant interaction effect between groups and illusion condition for the Asahi illusions (*F*(2,21)=3,620, *p*=0,045). Also, additional t-tests on mean pupil sizes in response to Asahi illusions in naïve participants yielded a significant difference in pupil size in the control group but it was not significant for the experimental group (see Table 7 and Figure 8).

Table 7. Mean pupil sizes in response to Asahi brightness illusions and control figures for participants who had not seen the illusions beforehand (standard errors are reported within parentheses).

		Condition		**t-test**
Group		Asahi Bright	Asahi Control	t-value
ASD	N=7	-0.14 (0.25)	0.15 (0.27)	*t*(5)=-1.82
Control	N=18	-0.39 (0.10)	0.15 (0.08)	*t*(16)=-5.71*

*Significant at p<0.05

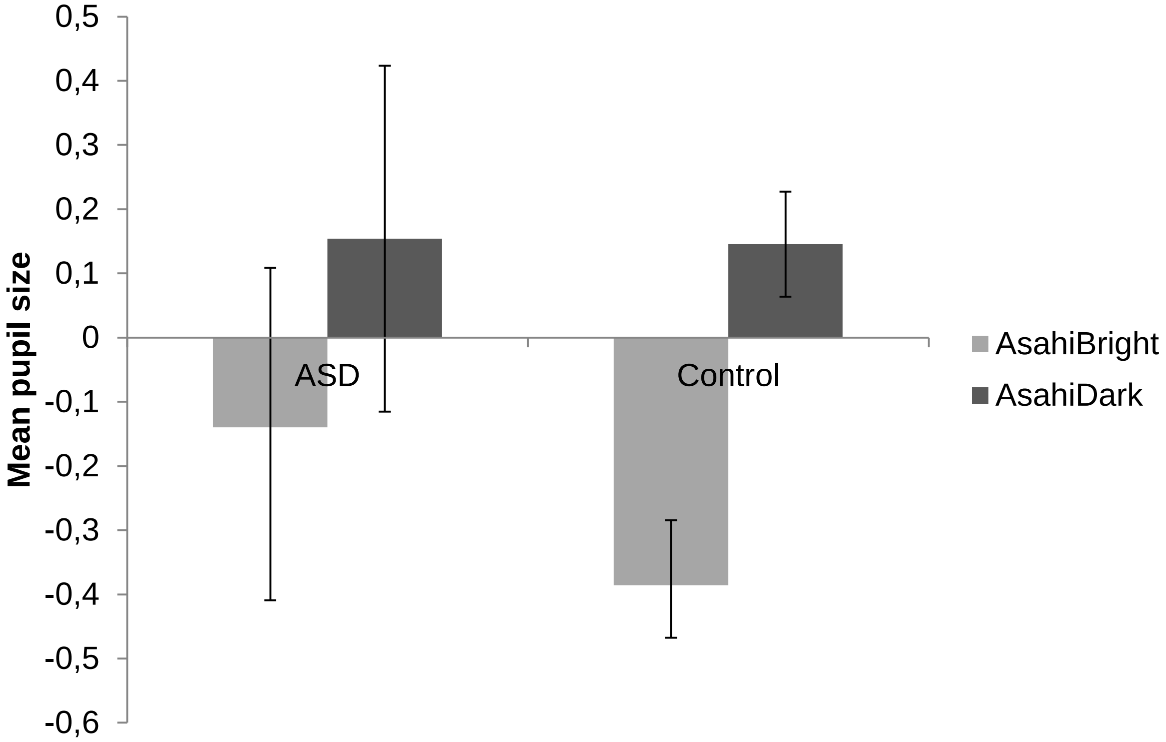


Figure 8. Mean pupil sizes reported in pixels to Asahi illusions and control figures in naïve participants who had not been presented with the illusion beforehand. Error bars indicate the standard error of the mean.

Experiment 2b: Brightness Illusions, Comparison Task. In concordance with our prediction, participants in both groups showed similar levels of illusion susceptibility when making explicit judgments of the brightness illusions. In the brightness comparison task, both groups made similar judgments of the illusion and control figure, as no significant group differences were seen for correct responses, responses indicating that the illusion was brighter in the middle, or response times between groups (see Table 8).

Table 8. Mean correct responses, illusion responses (responses indicating that one illusion had a brighter middle), and mean response times for both groups in the brightness comparison task. Standard errors are reported within parentheses.

Group		Correct response	Illusion response	Mean response time
ASD	N=13	0.06	0.82	4124.51
		(0.03)	(0.06)	(675.73)
Control	N=34	0.07	0.85	3799.69
		(0.04)	(0.06)	(352.12)
t-test		*t*(42)=0.17	*t*(42)=0.25	*t*(42)=-0.47

Correlational Analyses: Subject Characteristics

Participants in both groups completed the Raven’s Progressive Matrices and Motor-Free Visual Perception Test. In addition, participants in the autism group filled out the Autism Quotient questionnaire. Participant age correlated significantly with pupil differences – i.e., baseline-corrected pupil sizes recorded for all brightness illusions – *r*(39) = 0,33, *p*=0,04, indicating that participant age predicted a weaker effect of brightness illusions on participant pupil constrictions. Also, accuracy on the letter detection task *r*(39)=-0,31, *p*=0,050 yielded a significant correlation with participant’s age.

Raven’s progressive matrices scores correlated significantly with accuracy in the letter detection task *r*(39)=0,45, *p*=0,00. Scores on the Motor-Free Visual Perception Test correlated positively with pupil differences to the Asahi illusions across groups *r*(39)=-0,33, *p*=0,04 and accuracy on the letter detection task; *r*(39)=0,45, *p*=0,00. Scores on the Autism Quotient Questionnaire did not yield any significant correlations for subject performance in the autism group. For a complete overview of correlation analyses between subject characteristics, test scores and task performance, see Table 9.

Table 9. Correlation results between subject characteristics and test scores on task performance.

		All bright: pupil	Asahi: pupil	Bright Accuracy	Bright RT.	Letter Acc.	Letter Pupil	Letter RT
Age	Pearson r	0.33^{*}	0.10	-0.13	0.01	-0.31^{*}	-0.01	0.23
	P	0.04	0.52	0.43	0.96	0.05	0.95	0.18
	N	40	40	40	40	40	40	36
Raven's	Pearson r	-0.19	-0.13	0.01	0.10	0.45^{**}	-0.02	-0.09
	P	0.24	0.424	0.94	0.54	0.00	0.92	0.60
	N	40	40	40	40	40	40	36
MVPT-3	Pearson r	-0.26	-0.33^{*}	-0.01	-0.02	0.45^{**}	0.09	0.11
	P	0.11	0.04	0.95	0.93	0.00	0.60	0.54
	N	40	40	40	40	40	40	36
AQ	Pearson r	0.14	0.12	0.42	0.32	-0.20	-0.30	-0.12
	P	0.65	0.70	0.15	0.30	0.53	0.33	0.71
	N	13	13	13	13	13	13	13

**p<0.01 (2-tailed); *p<0.05 (2-tailed)

Discussion

The present study may be the first exploration of neurophysiological signatures to optical illusions in individuals diagnosed with high-functioning autism. The present results show that pupillary reactions to illusory light are weaker during passive viewing in individuals diagnosed with high-functioning autism than in a control group. However, when making explicit judgments about the same stimuli, both individuals with autism and control participants showed a close-to equal level of illusion susceptibility. In the letter detection task, when perceiving visual stimuli that needed to be integrated at a global level, results showed that individuals with autism did not show impairments in performance or neurophysiological signatures of extra cognitive effort recruited in the task compared to controls. However, when perceiving two such stimuli simultaneously, performance in the experimental group showed a significant drop compared to controls. This group difference was observed without any corresponding differences in response times or pupil sizes between groups, indicating that individuals with autism did not attempt to recruit more cognitive effort in the task than controls, while performing significantly poorer.

Previous studies have repeatedly reported a local preference in visual perception in individuals diagnosed with autism spectrum disorder, resulting in a perceptual style that over-looks global meaning in stimuli and instead focuses on minor details on a local level, called a weak central coherence(Frith, 2003; Happé, 2005). A believed consequence of this perceptual bias in autism is a reduced susceptibility to optical illusions, and superior performance on tasks relying on local processing – or the discrimination of confounding, global stimuli - compared to typically developed controls (Baron-Cohen, 2002; F. Happé, 1996; Ropar & Mitchell, 1999, 2001). Based on these previous findings, we sought to investigate two facets of autism perception: 1) if forced to perceive globally, do individuals with autism need to recruit extra cognitive effort in order to shift perceptual processing from a local to a global level?; and 2) by using a novel, neurophysiological measure, we investigated differences in illusion susceptibility between individuals diagnosed with high functioning autism and control participants.

Letter Detection and Letter Comparison Tasks

In the letter tasks we predicted that participants with autism would show impairments in performance – as indicated by lower accuracy scores and longer response times – when detecting and choosing stimuli that demanded local-to-global integration. Also, we expected that participants in the autism group would show larger tonic pupil sizes for trials in which stimuli demanded integration compared to controls. However, results did not show any impairments in letter detection in our experimental group compared to controls, as both groups performed on a similar level. In the letter comparison task, we predicted that accuracy in the experimental group would suffer due to a putative local preference in perception. In concordance with this hypothesis, participants with autism did struggle with the task – as indicated by a significantly lowered accuracy score compared to controls – but no corresponding differences in pupil sizes or response times was seen in the analysis.

By comparing pupillary changes between groups for the letter detection task, we could determine if level of integration needed would cause the recruitment of extra cognitive effort in the autism group. Our results showed that – contrary to a theorized local processing style in autism perception – there was no group difference in either response accuracy or pupil sizes was observed. These results suggest that individuals with autism can perceive at a global level when the need for integration is made explicit through task demands, and that a shift from a preferred local to a global level does not demand the recruitment of extra cognitive effort. Also worth mentioning, in Happé (1996), the comparison of two-dimensional and three-dimensional illusions showed that individuals with autism would succumb more to three-dimensional illusions compared to two-dimensional ones. The fact that the shadow letter condition, when integrated, results in the percept of a three-dimensional letter should therefore predict better performance in the autism group compared to trials with two-dimensional figures. Our results, however, showed no difference in performance according to spatial dimensions as both groups performed equally well on all tasks.

In the second task, we used a similar design in which participants were shown two pictures simultaneously – one being a letter, the other a control figure – and they were asked to identify which of the two represented a letter. In this task, the results showed a large drop in autism response accuracy compared to controls. However, no significant differences in pupil sizes or response times were observed. These results indicate that the autism group struggled with the task – responding with accuracy below chance level – without the recruitment of extra cognitive effort. This performance drop seems surprising, as both groups performed the detection task immediately before discrimination task on-set. The same stimuli were used in both experiments, causing participants in both groups to have experience with the task demands.

One possible explanation for the differences seen between groups in letter discrimination accuracy was likely due to the nature of the task. In the letter detection, participants were presented with a task in which absolute judgments were to be made; to decide whether a letter was present or not. In the discrimination task, however, participants were presented with a forced choice paradigm. This performance difference seems not likely attributable to a local preference in autism perception, as the comparison tasks did not require more integration than the previous trials in the detection task, in which participants in the autism group performed at the same level as controls.

Brightness Illusions: Passive Viewing and Comparison Tasks

We expected that participants in the autism group would show a lowered susceptibility to brightness and lightness illusions, as indicated through lesser pupil constrictions to illusory light in the experimental group compared to controls. Our results confirmed the expectation for the Asahi brightness illusions, since the control group showed a significant mean difference in pupil size dependent on illusion condition for the Asahi illusions whereas the experimental group showed no such differences. Also, a significant interaction effect of group on illusion on pupil sizes was observed for naïve participants. In a separate task, when making explicit judgments about each illusion’s brightness, we expected instead that both groups to show equal levels of susceptibility, as we hypothesized that explicit judgments would elicit more explicit demands of object integration. In concordance with our hypothesis, both groups did show similar susceptibility to illusions when judging these explicitly.

Previous research on illusion susceptibility in autism perception has demonstrated mixed results, in which one study has demonstrated that children with autism make significantly more accurate judgments when faced with optical illusions (Happé, 1996), whereas others have failed to demonstrate similar results (Ropar & Mitchell, 1999, 2001). We hypothesized that the mixed results showed in this research may be because explicit judgments of stimuli may prompt a shift from a local to a more global perceptual style in individuals with autism. By using optical illusions that rely on the same mechanism as illusions used in Happé (1996) – namely a global context – and the addition of an autonomous neurophysiological signature of illusion susceptibility, we were able to investigate illusion susceptibility in participants without relying solely on explicit judgments. Also, by asking participants to explicitly evaluate brightness in a set of illusions and control figures, we were able to determine if any explicit judgments about the stimuli actually would disrupt the theorized lowered illusion susceptibility in autism, or if illusion susceptibility would stay unaffected by explicit judgments.

There was a significant main effect of brightness illusions on pupil size across both groups. However, no significant interaction effect was yielded, and pair-wise t-tests showed that no significant difference between illusion and control pupil sizes was found in either group. When additional analyses were performed for the Asahi illusions alone, we observed a significant interaction effect between the two groups and illusion conditions for naïve participants, as well as a significant difference in mean pupil sizes between conditions for the control group but not for the autism group. This result shows that the brightness illusions had a stronger effect on pupil sizes in the control group as compared to the autism group, indicating that our group of individuals with autism did not succumb to the illusions “as much” as controls. This result indicates that there is lowered illusion susceptibility in individuals diagnosed with autism. However, when participants were shown Asahi illusions paired with control images and were asked to identify if one of the two had a brighter middle than the other, both groups showed an equal tendency for succumbing to the illusions.

These results combined support our hypotheses regarding illusion susceptibility in individuals with autism. Namely that, individuals with autism have a lowered susceptibility for optical illusions, but only at an early and autonomous level. When making explicit judgments of the illusions, an increase in task demands of integration will cause a shift in perceptual style in individuals with autism, making them as susceptible for the illusions as typically developed controls. The fact that any group differences in illusion susceptibility was diminished as soon as participants were asked to make explicit judgments of the stimuli, highlights the sensitivity of weak central coherence as a bias, and not a deficit, in autism perception.

Conclusions

The present results from four different experiments indicate that perceptual style in autism spectrum disorders may be more nuanced than previous research has indicated. In studies investigating illusion susceptibility in individuals with autism, paradigms have been heavily relying on explicit judgments of stimuli. By comparing results from explicit and autonomous reactions to illusory light, we have demonstrated that there are differences in illusion susceptibility amongst individuals with autism, but only when these illusions are viewed passively. Also, by manipulating level of integration needed in visual stimuli, we have demonstrated that individuals with autism can perceive at a global level equally well as controls, and that a shift from local to global processing style occurs automatically and without the recruitment of additional cognitive effort. This shows that paradigms investigating perceptual style in individuals with autism should not solely rely on explicit judgments of stimuli, as a shift from local to global perception can be initiated through demands of explicit judgments.

In our study, one surprising result in the letter discrimination task indicated that people with autism may be at disadvantage with comparative judgments compared to absolute judgments. Thus, research paradigms investigating perceptual style in autism through comparative judgments of stimuli may equally well show differences in task performance than perceptual differences, as individuals with autism seem to struggle with comparative tasks. As mentioned by Happé (2006) and further demonstrated in this study, weak central coherence in autism perception can easily be disrupted. Our results implicate that merely asking individuals with autism to make explicit judgments of visual stimuli may cause an automatic shift to a more globally oriented perceptual style, without the recruitment of extra cognitive resources.

Further Research

In the present study, two results stand out as particularly relevant for further research. First, our results indicate that individuals with autism do not succumb to optical illusions relying on an illusion-inducing context as much as controls when these are viewed passively. Previous research on autism illusion susceptibility has relied on the explicit judgment of illusions, but results have been mixed – both showing lowered and equal susceptibility to illusions. According to our results, explicit judgments may facilitate a global percept in individuals with autism; consequently causing them to succumb to illusions, despite results from a passive viewing task indicated a lowered susceptibility. Further research is needed to investigate if previous research paradigms involving explicit judgments of illusions – and other visual stimuli – have caused participants with autism to shift from a local to a more globally based perception. If this proves correct, previous research on the interaction between weak central coherence and illusion susceptibility may need to be revised. Moreover, a study by Walter, Dassonville and Bochsler (2009) suggested that a central trait in autism spectrum disorder, namely the need for systemization, may better predict differences in illusion susceptibility in autism than an autism diagnosis alone. Further research should therefore also investigate whether this trait will be a better predictor of pupil reactions to brightness illusions in individuals with autism than the social traits.

Second, in tasks involving comparative judgment and object integration, there was a large drop in performance accuracy in the experimental group. This performance drop seems unlikely to be attributable to weak central coherence, but might be due to impairment in task solving or decision making in individuals with autism. Further research needs to investigate whether people with autism struggle when performing comparative judgments, and investigate the possible explanations for this hypothesized deficiency.

Limitations

The study has several limitations. Primarily, the lack of age and education matched controls in the study weakens its empirical impact. In order to draw any conclusions about differences in perceptual style between individuals with autism and control participants, confounders such as age, sex and education need to be controlled for. The importance of matched controls was further highlighted in the correlational analyses between subject characteristics and task performance, in which scores on Raven’s test, Motor-free test of visual perception and participant ages showed significant correlations with performance in some tasks. Also, the number of participants was quite low (N=13 in the experimental group), resulting in large amounts of variance in the data. In order to demonstrate clear differences between groups, a larger sample will be needed.

General Conclusions

In this study we have shown that participants diagnosed with autism spectrum disorder do not succumb to optical illusions as much as control participants, as indicated through automatic pupillary responses. When participants are asked to make explicit judgments of the same stimuli, both typically developing controls and individuals with autism seem to succumb to the illusions in the same manners. Also, we have demonstrated that when stimuli calls for the integration of local traits to create a global percept, participants with autism shift from a local to a global processing style without the recruitment of extra cognitive effort. These results combined would suggest that individuals with autism may shift from a putative local preference in perception when making explicit judgments of stimuli. Thus, the existing views on perceptual style in autism spectrum disorder through explicit judgments may need revision. Finally, participants with autism seem to struggle when performing comparative, forced judgments of visual stimuli. There is at present no clear explanation for such a finding, and new theoretical approaches may be needed to explain the perceptual style of high-functioning individuals with autism.

References

Albert, M., Andler, J., Bah, T., Barbry-Blot, P., Barraud, J., & Baxter, B. (2013). Inkscape.

Alnæs, D., Sneve, M. H., Espeseth, T., Endestad, T., van de Pavert, S. H. P., & Laeng, B. (2014). Pupil size signals mental effort deployed during multiple object tracking and predicts brain activity in the dorsal attention network and the locus coeruleus. *Journal of vision, 14*(4), 1. doi: 10.1167/14.4.1

American Psychiatric Association. (2013). *Diagnostic and Statistical Manual of Mental Disorders: Dsm-5*: Amer Psychiatric Pub Incorporated.

Ames, C., & Fletcher-Watson, S. (2010). A review of methods in the study of attention in autism. *Developmental Review, 30*(1), 52-73. doi: 10.1016/j.dr.2009.12.003

Baron-Cohen, S. (2002). The extreme male brain theory of autism. *Trends Cogn Sci, 6*(6), 248-254. doi: 10.1016/S1364-6613(02)01904-6

Baron-Cohen, S., Wheelwright, S., Skinner, R., Martin, J., & Clubley, E. (2001). The Autism-spectrum Qquotient (AQ): Evidence from asperger syndrome/high-functioning autism, malesand females, scientists and mathematicians. *J Autism Dev Disord, 31*(1), 5-17. doi: 10.1023/A:1005653411471

Bernardino, I., Mouga, S., Almeida, J., van Asselen, M., Oliveira, G., & Castelo-Branco, M. (2012). A direct comparison of local-global integration in autism and other developmental disorders: implications for the central coherence hypothesis. *PLoS One, 7*(6), e39351. doi: 10.1371/journal.pone.0039351

Blaser, E., Eglington, L., Carter, A. S., & Kaldy, Z. (2014). Pupillometry reveals a mechanism for the Autism Spectrum Disorder (ASD) advantage in visual tasks. *Sci Rep, 4*, 4301. doi: 10.1038/srep04301

Brosnan, M. J., Scott, F. J., Fox, S., & Pye, J. (2004). Gestalt processing in autism: Failure to process perceptual relationships and the implications for contextual understanding.

Journal of Child Psychology and Psychiatry, 45(3), 459-469. doi: 10.1111/j.1469-7610.2004.00237.x

Colarusso, R. P., & Hammill, D. D. (1972). *Motor-Free Visual Perception Test*: Academic Therapy Pub.

Dalton, K. M., Nacewicz, B. M., Johnstone, T., Schaefer, H. S., Gernsbacher, M. A., Goldsmith, H., . . . Davidson, R. J. (2005). Gaze fixation and the neural circuitry of face processing in autism. *Nat Neurosci, 8*(4), 519-526. doi: 10.1038/nn1421

Frith, U. (2003). *Autism: Explaining the Enigma*. Hoboken, NJ, USA: Wiley.

Happé. (2005). The weak central coherence account of autism. *Handbook of Autism and Pervasive Developmental Disorders, Volume 1, Third Edition*, 640-649. doi: 10.1002/9780470939345.ch24

Happé, & Frith. (2006). The weak coherence account: detail-focused cognitive style in autism spectrum disorders. *J Autism Dev Disord, 36*(1), 5-25. doi: 10.1007/s10803-005-0039-0

Happé, F. (1996). Studying weak central coherence at low levels: children with autism do not succumb to visual illusions. A research note. *Journal of Child Psychology and Psychiatry, 37*(7), 873-877. doi: 10.1111/j.1469-7610.1996.tb01483.x

Happe, F., Ronald, A., & Plomin, R. (2006). Time to give up on a single explanation for autism. *Nat Neurosci, 9*(10), 1218-1220. doi: 10.1038/nn1770

Jamain, S., Quach, H., Betancur, C., Råstam, M., Colineaux, C., Gillberg, I. C., . . . Gillberg, C. (2003). Mutations of the X-linked genes encoding neuroligins NLGN3 and NLGN4 are associated with autism. *Nature genetics, 34*(1), 27-29. doi: 10.1038/ng1136

Kanizsa, G. (1976). Subjective contours. *Scientific American, 234*(4), 48-52. doi: 10.1038/scientificamerican0476-48

Kitaoka, A. (2005). *Trick Eyes*. New York, USA: Barnes & Noble.

Laeng, B., & Endestad, T. (2012). Bright illusions reduce the eye's pupil. *Proceedings of the National Academy of Sciences, 109*(6), 2162-2167.

Laeng, B., Sirois, S., & Gredebäck, G. (2012). Pupillometry A Window to the Preconscious? *Perspectives on psychological science, 7*(1), 18-27. doi: 10.1177/1745691611427305

Laeng, B., & Sulutvedt, U. (2014). The eye pupil adjusts to imaginary light. *Psychol Sci, 25*(1), 188-197. doi: 10.1177/0956797613503556

Markram, K., & Markram, H. (2010). The intense world theory - a unifying theory of the neurobiology of autism. *Front Hum Neurosci, 4,* 224. doi: 10.3389/fnhum.2010.00224

Mitchell, P., Mottron, L., Soulieres, I., & Ropar, D. (2010). Susceptibility to the Shepard illusion in participants with autism: reduced top-down influences within perception? *Autism Research, 3*(3), 113-119. doi: 10.1002/aur.130

Mottron, L., Burack, J. A., Iarocci, G., Belleville, S., & Enns, J. T. (2003). Locally oriented perception with intact global processing among adolescents with high-functioning autism: Evidence from multiple paradigms. *Journal of Child Psychology and Psychiatry, 44*(6), 904-913. doi: 10.1111/1469-7610.00174

Persico, A. M., & Bourgeron, T. (2006). Searching for ways out of the autism maze: genetic, epigenetic and environmental clues. *Trends in neurosciences, 29*(7), 349-358. doi: 10.1016/j.tins.2006.05.010

Prinzmetal, W. (1981). Principles of feature integration in visual perception. *Perception & Psychophysics, 30*(4), 330-340. doi: 10.3758/BF03206147

Raven, J. (2003). Raven progressive matrices *Handbook of nonverbal assessment* (pp. 223-237): Springer.

Ropar, D., & Mitchell, P. (1999). Are individuals with autism and Asperger's syndrome susceptible to visual illusions? *Journal of Child Psychology and Psychiatry, 40*(8), 1283-1293. doi: 10.1111/1469-7610.00544

Ropar, D., & Mitchell, P. (2001). Susceptibility to illusions and performance on visuospatial tasks in individuals with autism. *Journal of Child Psychology and Psychiatry, 42*(4), 539-549. doi: 10.1111/1469-7610.00748

Rouse, H., Donnelly, N., Hadwin, J. A., & Brown, T. (2004). Do children with autism perceive second-order relational features? The case of the Thatcher illusion. *Journal of Child Psychology and Psychiatry, 45*(7), 1246-1257. doi: 10.1111/j.1469-7610.2004.00317.x

Schultz, R. T. (2005). Developmental deficits in social perception in autism: the role of the amygdala and fusiform face area. *International Journal of Developmental Neuroscience, 23*(2), 125-141. doi: 10.1002/hbm.20283

Treisman, A., & Gelade, G. (1980). A feature-integration theory of attention. *Cognitive psychology, 12*(1), 97-136. doi: 10.1016/0010-0285(80)90005-5

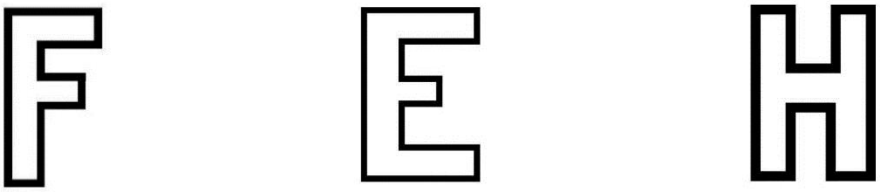
Walter, E., Dassonville, P., & Bochsler, T. M. (2009). A specific autistic trait that modulates visuospatial illusion susceptibility. *J Autism Dev Disord, 39*(2), 339-349. doi: 10.1007/s10803-008-0630-2

Appendices

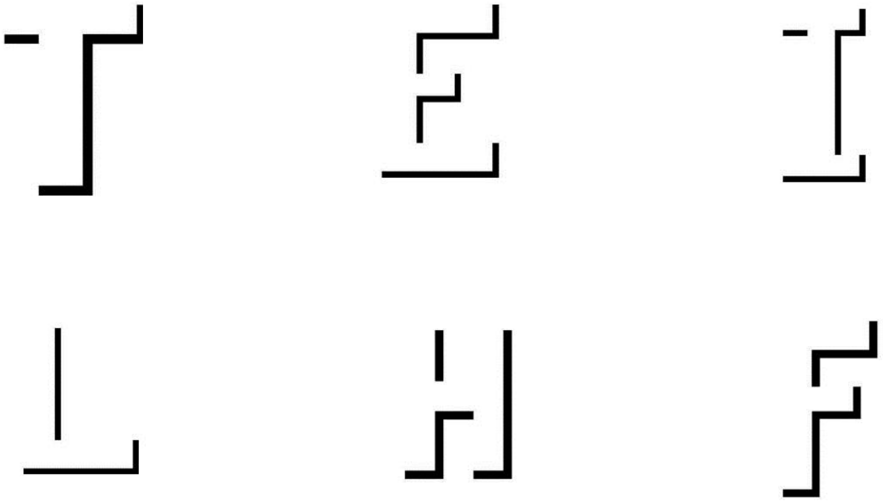
Appendix A

Letter stimuli from the letter detection and discrimination tasks.

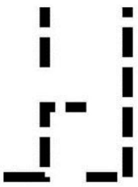
1. Full letters.

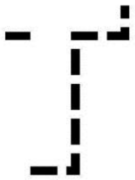


2. Shadow letters

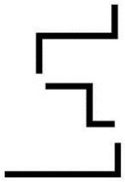


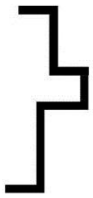
3. Partial letters

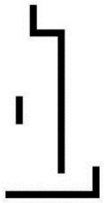


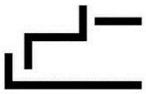


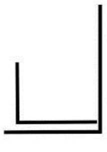
4. Scrambled letters

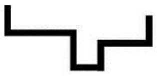


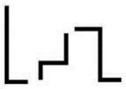


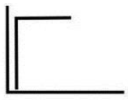


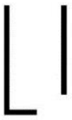






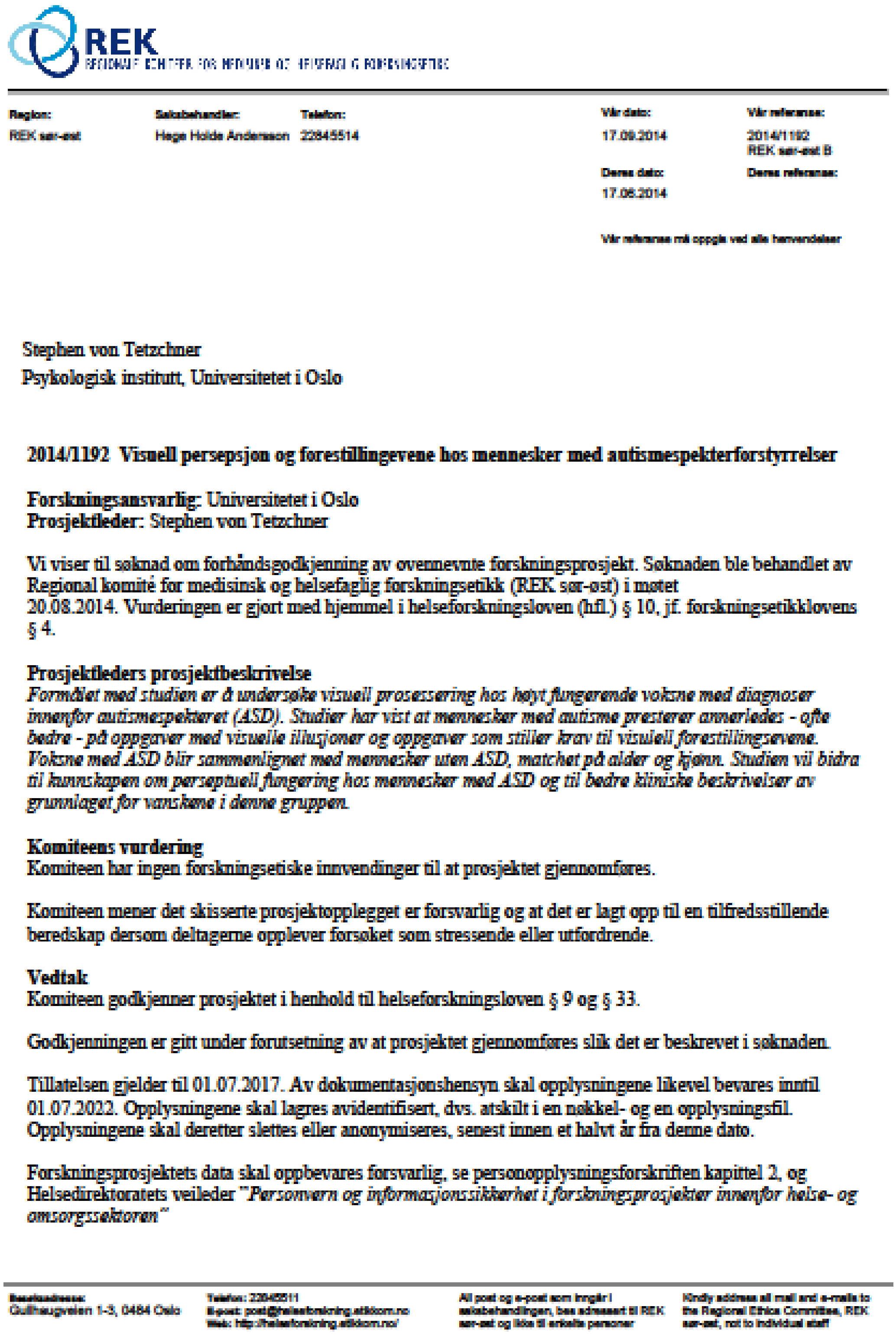






Appendix B

Letter of approval from the Regional Committees for Medical and Health Research Ethics (REK).



REK
REGIONALE KOMITEER FOR MEDISINSK OG HELSEFAGLIG FORSKNINGSETIKK

Region:	**Saksbehandler:**	**Telefon:**	**Vår dato:**	**Vår referanse:**
REK sør-øst	Hege Holde Andersson	22845514	17.09.2014	2014/1192 REK sør-øst B
			Deres dato:	**Deres referanse:**
			17.06.2014	

Vår referanse må oppgis ved alle henvendelser

Stephen von Tetzchner
Psykologisk institutt, Universitetet i Oslo

2014/1192 Visuell persepsjon og forestillingevene hos mennesker med autismespekterforstyrrelser

Forskningsansvarlig: Universitetet i Oslo
Prosjektleder: Stephen von Tetzchner

Vi viser til søknad om forhåndsgodkjenning av ovennevnte forskningsprosjekt. Søknaden ble behandlet av Regional komité for medisinsk og helsefaglig forskningsetikk (REK sør-øst) i møtet 20.08.2014. Vurderingen er gjort med hjemmel i helseforskningsloven (hfl.) § 10, jf. forskningsetikklovens § 4.

Prosjektleders prosjektbeskrivelse
Formålet med studien er å undersøke visuell prosessering hos høyt fungerende voksne med diagnoser innenfor autismespekteret (ASD). Studier har vist at mennesker med autisme presterer annerledes - ofte bedre - på oppgaver med visuelle illusjoner og oppgaver som stiller krav til visuelll forestillingsevene. Voksne med ASD blir sammenlignet med mennesker uten ASD, matchet på alder og kjønn. Studien vil bidra til kunnskapen om perseptuell fungering hos mennesker med ASD og til bedre kliniske beskrivelser av grunnlaget for vanskene i denne gruppen.

Komiteens vurdering
Komiteen har ingen forskningsetiske innvendinger til at prosjektet gjennomføres.

Komiteen mener det skisserte prosjektopplegget er forsvarlig og at det er lagt opp til en tilfredsstillende beredskap dersom deltagerne opplever forsøket som stressende eller utfordrende.

Vedtak
Komiteen godkjenner prosjektet i henhold til helseforskningsloven § 9 og § 33.

Godkjenningen er gitt under forutsetning av at prosjektet gjennomføres slik det er beskrevet i søknaden.

Tillatelsen gjelder til 01.07.2017. Av dokumentasjonshensyn skal opplysningene likevel bevares inntil 01.07.2022. Opplysningene skal lagres avidentifisert, dvs. atskilt i en nøkkel- og en opplysningsfil. Opplysningene skal deretter slettes eller anonymiseres, senest innen et halvt år fra denne dato.

Forskningsprosjektets data skal oppbevares forsvarlig, se personopplysningsforskriften kapittel 2, og Helsedirektoratets veileder "*Personvern og informasjonssikkerhet i forskningsprosjekter innenfor helse- og omsorgssektoren*"