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WCC Theory, Change Blindness, and Facial Processing in Adolescents Diagnosed with ASD

by

Karolina Štětinová

A thesis

submitted in partial fulfillment

of the requirements for the degree of

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To the Graduate Faculty:

The members of the committee appointed to examine the thesis of KAROLINA ŠTĚTINOVÁ find it satisfactory and recommend that it be accepted.

Robert Rieske
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April 1, 2019

Robert Rieske
Psychology
MS 8112

RE: regarding study number IRB-FY2018-315 : Attention, Perception, and Facial Processing in ASD, ADHD, and NT populations utilizing eye-tracking

Dear Dr. Rieske:

Thank you for your responses to a full-board review of the study listed above. Your responses are eligible for expedited review under FDA and DHHS (OHRP) regulations. This is to confirm that I have approved your application.

Notify the HSC of any adverse events. Serious, unexpected adverse events must be reported in writing within 10 business days.

You may conduct your study as described in your application effective immediately. The study is subject to renewal on or before March 31, 2020, unless closed before that date.

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Sincerely,

Ralph Baergen, PhD, MPH, CIP
Human Subjects Chair

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WCC Theory, Change Blindness, and Facial Processing in Adolescents Diagnosed with ASD

Thesis Abstract – Idaho State University (2020)

The current study investigated differences in change detection ability between two groups of adolescents, typically developing (TD) and those diagnosed with autism spectrum disorder (ASD). Past research suggested that, compared to their TD peers, individuals diagnosed with ASD are faster and more accurate when detecting small details in complex pictures because they show a preference for local rather than holistic processing (i.e. Weak Central Coherence theory). Individuals diagnosed with ASD may also experience difficulties detecting changes in facial expressions because human faces typically require holistic processing. For this reason, the current study evaluated the differences in response time, response accuracy, and labeling accuracy, asking the ASD and TD participants to detect and label emotional and physical changes presented on pictures of human faces. The current study included five matched pairs. The results did not support the research hypotheses but indicated that participants diagnosed with ASD struggled when labeling emotional expressions.

Key Words: weak central coherence, facial processing, change blindness, ASD, autism

Introduction

ASD and Weak Central Coherence Theory (WCC)

The fifth edition of the Diagnostic and Statistical Manual of Mental Disorders (DSM-5) introduced a diagnosis of autism spectrum disorder (ASD), which was designed to describe neurodevelopmental symptoms including repetitive and rigid behaviors, limited interests, and difficulties with social interaction (American Psychiatric Association, 2013). ASD is also often co-morbid with intellectual disability (ID), but a below average IQ score is not a part of the diagnostic criteria for ASD as formulated by the DSM-5 (American Psychiatric Association, 2013). As a result of these commonly observed cognitive differences, a great body of research has been conducted in order to more closely examine cognitive functioning and information processing in the population of those diagnosed with ASD. However, much of the extant literature reported mixed findings, leading to controversy and disagreement about the reliability of the observed abnormalities in cognitive functioning for individuals diagnosed with ASD.

One of the greatest controversies in the field of ASD research and cognitive processing is related to the performance of individuals diagnosed with ASD on tasks involving visuospatial processing (Happé & Frith, 2006). Many studies have reported that people diagnosed with ASD outperform their typically developing peers in the ability to notice a detail and orient in space (Jolliffe & Baron-Cohen, 1997; Ropar & Mitchell, 2001; Shah & Frith, 1983). One of the theories that aims to explain this enhanced ability in visuospatial processing tasks is the Weak Central Coherence (WCC) theory. This theory suggests that the reported cognitive abnormalities are caused by a restricted ability of individuals diagnosed with ASD to perceive objects holistically and understand their context (Happé, 1999). According to the WCC theory, people diagnosed with ASD show a preference for local stimuli (i.e. details and parts), which then results in poorer global processing of the whole object but superior performance on tasks which require local processing of the individual parts and details (White & Saldana, 2011).

One of the first studies investigating this assumption was the study of Shah and Frith (1983). In this study, children with autism were administered the Children's Embedded Figures Test (CEFT), which required the participants to find a simple target figure camouflaged in a complex picture. This task prioritizes local over global processing and thus, building on the ideas of the WCC theory individuals diagnosed with ASD should show enhanced performance compared to their typically developing (TD) peers. The results of this study supported this view, such that the ASD group was more accurate in locating the target figure compared to the groups of TD children and those with the diagnosis of mild ID (Shah & Frith, 1983).

A similar study tested individuals with a diagnosis of autism or Asperger’s syndrome by administering the Embedded Figures Test (EFT), an adult version of the CEFT (Jolliffe & Baron-Cohen, 1997). They found that individuals with autism and Asperger’s syndrome had significantly shorter response times compared to their TD peers. Nonetheless, the accuracy of the responses for the autism, Asperger’s, and TD groups did not differ significantly, which was consistent with later findings of Ozonoff, Pennington, and Rogers (1991). There is no clear explanation for why the accuracy scores did not yield significant differences between the ASD and TD groups while the response times did, but in theory, individuals diagnosed with ASD could be quicker when noticing the presence of the target stimuli but demonstrate difficulty with expressing it since such task requires comprehension of the context.

Ropar and Mitchell (2001) also investigated performance on visuospatial processing tasks including EFT and Block Design in groups of children diagnosed with autism and Asperger’s syndrome, children diagnosed with mild learning disabilities, and two control groups of TD children (8-year-olds and 11-year-olds). Consistent with prior research, children with autism and Asperger's syndrome were significantly faster in their response times on the EFT compared to all the other groups. Interestingly, on the Block Design task, children with autism and Asperger's syndrome on average achieved significantly higher scores than the other groups, with means closest to the group of typically developing 11-year-olds (Ropar & Mitchell, 2001).

Furthermore, the study of Brian and Bryson (1996) sought to find differences in scores between the autistic/pervasive developmental disorder (PDD) group and a group of TD children in relation to the meaningfulness of the presented figures. However, they failed to replicate the findings of the previously mentioned studies. It could be argued that inclusion of the PDD participants in the autistic group could have confounded the results since, as other studies have suggested, the performance of individuals with autism on those tasks significantly differs from performance of participants diagnosed with other disorders or intellectual disabilities (Ropar & Mitchell, 2001; Shah & Frith,1983). The researchers, however, reported to conduct the same analyses solely for participants who met the autistic diagnostic criteria, but the analyses did not yield a significant difference between the groups in either the accuracy or the response times in the EFT task (Brian & Bryson, 1996).

In support of those findings, Ozonoff, Pennington, and Rogers (1991) developed a study measuring various cognitive processing skills in children with autism and compared them to their TD peers matched on age and sex. Despite the fact that the study showed interesting results in the form of deficits in tasks involving executive functioning and theory of mind, there was no significant difference in the accuracy between autistic children and their TD peers on visuospatial tasks like CEFT or Block Design (Ozonoff et al., 1991).

Interestingly, more recent studies like the one of White and Saldana (2011), which involved measuring accuracy, reaction time on correctly answered items, and reaction time on all answered items, have not shown any significant difference between the ASD and TD groups on the EFT task. Similarly, in a study conducted by Brundson et al. (2015), the ASD group did not significantly outperform the TD group on tasks such as Block Design and EFT where local processing is advantageous, but, in concordance with the WCC theory, the ASD group showed poorer performance on tasks such as Homographs Reading Test, Planning Drawing Task, and the Sentence Completion Task which involve global processing (Brundson et al., 2015).

Such findings undermine the idea that individuals diagnosed with ASD show a greater preference for local stimuli during information processing. For this reason, all of the studies researching whether individuals diagnosed with ASD have an enhanced ability to notice minute details on visuospatial tasks as well as other tasks related to the WCC theory were reviewed by Happé and Frith (2006). In their meta-analysis, Happé and Frith (2006) confirmed that there are mixed findings in this area, especially since newer studies often fail to replicate WCC-supportive findings of older studies. In agreement with White and Saldana (2011), they also suggested that the discrepancy between the findings of the individual studies completed on this topic could be due to methodological differences in the matching procedures, diagnostic criteria for ASD, and administration techniques. For example, test question wording may be an important variable for test administration in research involving the individuals with ASD, since even a slight modification in wording can result in misunderstanding by this group (Happé & Frith, 2006). The controversy about the enhanced performance of individuals diagnosed with ASD on visuospatial tasks where local processing is advantageous, therefore, calls for a greater amount of research on this topic together with employment of more rigorous methodology.

WCC and Change Blindness

WCC theory could be applied to other areas of research evaluating cognitive processing of individuals diagnosed with ASD. Since WCC is commonly understood as a tendency to notice small details and react to unapparent changes in the environment, and since some of the previously mentioned studies found that ASD samples showed enhanced performance in some areas of visuospatial processing, it is possible that such preference for local stimuli could be exhibited in tasks involving change blindness. However, in order to study the WCC theory in the context of change blindness, several factors related to visuospatial processing need to be considered. The first factor is the contextuality and location of the modification. Typically, change blindness studies differentiate between contextually central changes made in the location of most interest which is a subject of most visual attention and contextually marginal changes that are less likely to be attended to. It was found that humans have the tendency to notice central changes with less difficulty than the marginal changes (Rensink, O'Regan, & Clark, 1997; Utochkin, 2011). For example, in the study of Rensink et al. (1997) which used a flicker task, the participants were, on average, two times slower when noticing marginal changes compared to the central changes.

Since individuals diagnosed with ASD are thought to be less influenced by the contextuality of the stimuli and show preference for details, it would be reasonable to assume that, if the ideas of the WCC theory were correct, individuals diagnosed with ASD would show smaller than typical differences between their performances when noticing central versus marginal changes. This hypothesis was supported by the findings of Smith and Milne (2009) who presented two groups of participants, ASD and TD, with short video clips where continuity errors such as sudden change of color of the actor’s trousers between scenes were introduced.

The researchers found the ASD group was, overall, better than the TD group at noticing continuity errors. Both groups followed a similar pattern and were more accurate in noticing central errors compared to the marginal ones, but importantly, the gap between the central and marginal error-noticing accuracy was smaller for the ASD group, which suggests that the ASD group was not as influenced by the centrality of the change as the TD group (Smith & Milne, 2009).

Nakahachi et al. (2008) compared ASD and TD adults on their ability to notice a change on drawings portraying different social situations. The researchers found that the TD participants were better at detecting changes that were contextually central and meaningful compared to participants diagnosed with ASD. Loth, Gomez, and Happé (2008) also researched the impact of context on change detection in individuals diagnosed with ASD. Even though there was no significant difference in the overall reaction times and accuracy between the two groups consisting of TD and ASD adults, the TD group performed significantly better than the ASD group when noticing changes made on objects that contextually did not fit in the presented scene.

Similarly, Ashwin, Wheelwright, and Baron-Cohen (2017) conducted a study where they presented ASD and TD groups with pictures of real-life scenes. Those pictures were also modified for the re-exposure by introducing changes in color, location, or object removal. The participants were asked to identify the individual changes. The ASD group was found to perform equally to the TD group when the changes were central but better when identifying the marginal changes (Ashwin et al., 2017).

In contrast, other studies have not found individuals diagnosed with ASD to be less susceptible to change blindness based on contextuality and marginality. For example, Burack et al. (2009) administered modified pictures of objects with marginal and central changes to ASD and TD children. The results did not show any significant deviation from the typical pattern in the children diagnosed with ASD, and both groups performed better when detecting central versus marginal changes (Burack et al., 2009).

Fletcher-Watson et al. (2012) tried to replicate the study of Burack et al. (2009), with slight modifications to the methodology. In this study, the researchers substituted pictures of isolated objects with complex scenes in order to more closely simulate the real-life experience. This study also involved asking the participants open-ended questions about the location of the change rather than presenting them with forced choice questions. Even though the group composed of children diagnosed with ASD had significantly shorter reaction times compared to the groups of TD children and adults, they did not outperform any of the TD groups in either the central changes condition or the marginal changes condition (Fletcher-Watson et al., 2012). In fact, the accuracy of the ASD group for the central changes was similar to the accuracy of the TD groups and the ASD group was significantly less accurate when detecting the marginal changes in comparison to both TD groups (Fletcher-Watson et al., 2012).

Fletcher-Watson, Leekam, Turner, and Moxon (2006) found that adults and adolescents diagnosed with ASD follow patterns of change detection similar to the TD population. In this study, the ability to detect a change by both ASD and TD group was dependent on the location of the change on the picture, central vs. marginal, as well as the extent to which the change was in coherence with the context of the picture. Overall, it was more difficult for both groups to detect marginal changes compared to the central ones, but the ASD group was significantly slower in detecting the marginal changes than the TD group. Such finding is inconsistent with the finding of the previously mentioned studies of Smith and Milne (2009), Loth, Gomez, and Happé (2008), and Ashwin et al. (2017). Fletcher-Watson et al. (2006) also found that the groups did not differ on the ability to detect changes based on the context appropriateness, which is inconsistent with the WCC idea that individuals diagnosed with ASD have difficulty with processing stimuli in relation to its environment and context.

Another factor which needs to be considered when researching the WCC theory in relation to change blindness is the processing approach itself. It is still unclear which type of processing (i.e. holistic vs. local) is, in general, a greater advantage in change blindness tasks. However, some studies have indicated that a holistic approach is more beneficial when processing changes in faces while local processing is more useful when processing changes made on objects (Tanaka & Farah, 1993; Macrae & Lewis, 2002; Perfect, Dennis, & Snell, 2007). For example, a study of Wilford and Wells (2010) looked at the human ability to detect changes made on pictures of faces and houses. The researchers were interested in the human ability to notice a modification of the original picture and the ability to locate the change. Wilford and Wells (2010) hypothesized that the participants will be more likely to notice a modification in pictures of faces compared to pictures of objects because faces are processed in a more holistic way. Nonetheless, according to the researchers, the ability to locate the modification should be better for the pictures of objects since they are processed in a more localized manner than faces. The results of the study supported this hypothesis; participants more accurately determined if a modification was present on pictures of faces compared to pictures of houses, but when asked to locate and describe the modification, the participants performed more accurately on pictures of houses (Wilford & Wells, 2010).

Similar results were reported by Ro, Russell, and Lavie (2001) who used a flicker task to examine the difference in the ability to detect a change in pictures of faces and objects. In this study, the participants were presented with a set of six pictures at once, one of them always being a human face while others were various objects like pieces of clothes or fruit. After the initial exposure to the original set of pictures, the participants were then presented with a new set of pictures from which one may have been switched for a different picture from the same category (a picture of the original face was switched for a picture of a different face). The results showed that the participants noticed the switch with greater accuracy when done on pictures of faces compared to the pictures of other objects (Ro et al., 2001). These results imply that humans, in general, are better at noticing changes in faces compared to changes in objects because they process them more holistically.

Based on those generalized findings, individuals diagnosed with ASD could possibly show deficits in performance on areas of change blindness tasks which involve holistic processing (e.g. upright face), but superior performance where local processing is an advantage (e.g. an object). Even though no study directly investigated such difference in processing and compared the object and face processing in relation to the WCC theory, several studies have investigated the processing style of individuals diagnosed with ASD in relation to faces.

For example, Nakahachi et al. (2008) studied change blindness in relation to facial processing. In this experiment, participants in the ASD and the TD groups were presented with photographs of female faces which were either unmodified, thatcherized (i.e. inverted mouth and eyes), or fully inverted. Since previous studies found that the inverted faces are not processed as holistically as the upright faces (Kirita & Endo, 1995), the researchers expected that the ASD group would not be as affected by the inversion as the TD group. The results supported their hypothesis, showing that the ASD participants had slower response times when processing the upright and thatcherized photographs, but there was not a difference in response times between the groups when processing the inverted photograph (Nakahachi et al., 2008). This finding supports the WCC theory and suggests that individuals diagnosed with ASD do not process the human faces holistically.

Kikuchi, Senju, Tojo, Osanai, and Hasegawa (2009) used a change blindness task to test whether individuals diagnosed with ASD follow the same pattern of preference for social and non-social stimuli as their TD peers. Their study compared TD children to children diagnosed with ASD on a change blindness task involving colored photographs of natural scenes including human figures. For the re-exposure, each of these original photographs was modified, and a change in the human head, object, or background was introduced. Change in the head was created by switching the original head for a head of a different person of the same gender. For the modifications done on the background or object in the photographs, either a change in color, deletion, or substitution was used. Both groups of children were presented with the original photographs first, and then after a short period of a blank screen, they were exposed to the modified version of the photographs. Interestingly, the sequence was repeated until the modification was detected by the participants or until the participants ran out of time. Both groups were then asked to identify the modification through verbal or nonverbal communication.

The results of this study only partially supported the ideas of the WCC theory. First, the TD group had overall faster response times compared to the ASD group, but the difference in performance was greatest when detecting changes on faces (Kikuchi et al., 2009). This comparatively lower performance of the ASD group on the condition involving facial changes is consistent with the idea that upright faces are processed more holistically, supporting the expectation that such tasks should be more challenging for this population. Nonetheless, since individuals diagnosed with ASD are thought to have an advantage in tasks involving local processing, it was expected that the ASD group would outperform in the condition involving changes in background and objects compared to the TD group. However, this expectation was not supported by the results of this study as no significant difference in the response times of the ASD group between conditions involving changes in faces and objects was found (Kikuchi et al., 2009).

WCC and Facial and Emotional Processing

Once again, the findings of the above-mentioned studies are hardly interpretable from the perspective of the WCC theory in relation to the claim that individuals diagnosed with ASD have an advantage when detecting changes done on objects due to the preference for local stimuli. Nonetheless, the studies altogether indicate that there is something special about the way they process human figures and faces, which may be a key for disentangling the controversial findings of the WCC theory. The observation that individuals with ASD show deficits in facial processing is not new and has been widely studied. For example, Langdell (1978) found that while TD children mostly focused on the upper regions including eyes for facial recognition, children with autism were better at recognizing faces based on lower facial regions such as the mouth.

Similarly, Joseph and Tanaka (2003) investigated the ability to recognize facial parts (eyes and mouths) on pictures of whole faces or isolated facial areas. They found that children diagnosed with ASD were better at recognizing mouths on pictures portraying whole faces than in isolation, outperforming the control group composed of TD children. When recognizing the eyes, the ASD group had more difficulties with the pictures portraying the whole faces than in isolation and was outperformed by the TD group (Joseph & Tanaka, 2003).

Furthermore, the study of Deruelle, Rondan, Gepner, and Tardif (2004) compared children with autism and Asperger’s syndrome to two control groups of TD children on tasks assessing facial processing. The task involved matching photographs of children's faces based on various relationships (identity, emotional expression, gender, the direction of gaze, and lip reading). The participants were presented with three photographs of faces at the same time and asked to choose which one of the two faces was related to the primary face of interest. The results showed that children diagnosed with autism and Asperger's syndrome had more difficulties in all conditions compared to the TD groups. The ASD group showed significantly poorer performance in conditions involving matching faces through emotional expression, the direction of gaze, gender, and lip-reading (Deruelle et al., 2004).

Such results suggest that even though faces were generally found to be processed in a holistic manner by the previously mentioned studies, there are particular facial features which seem to be more problematic when processed by individuals diagnosed with ASD than by those that are typically developing. This notion can be critical for proper understanding and interpretation of the reported abnormalities in facial processing exhibited by individuals diagnosed with ASD in relation to the WCC theory. More specifically, the general finding seems to be that individuals diagnosed with ASD have more difficulties when processing the eye region whereas their ability to process the mouth region may not differ significantly from the TD individuals. Also, since Deruelle et al. (2004) showed that the ASD group was mainly struggling when identifying changes in emotions, it may be appropriate to investigate the significance of this facial modification more closely.

For example, a study of Hobson, Ousten, and Lee (1988) investigated the significance of individual facial features in emotional recognition. Two groups of ASD adolescents and adolescents with mild ID were asked to recognize identity and emotions from pictures of human faces that were either fully visible or partially blacked out. The blacked-out regions of the faces included the mouth and forehead including eyebrows. The results showed that the ASD participants performed poorer than the participants with mild ID when asked to recognize both the identity and the emotion in a condition which included blanked out mouth and forehead regions. However, the ASD participants performed similarly to the participants diagnosed with mild ID when recognizing the identity from full-face pictures, and they performed significantly better than the participants with mild ID when recognizing emotions from the full-face pictures (Hobson, Ousten, & Lee, 1988).

Krebs et al. (2011) further aimed to study the relationship between facial identity and emotional recognition. The researchers, therefore, developed a task in which two groups of children, ASD and TD, evaluated both the identity and the emotional expression on pictures of human faces. As hypothesized, the TD group was not affected by the variation of emotional expression during the identity recognition task, but their recognition of emotional expressions was processed in interaction with identity. In contrast, no such interaction was found in the ASD group. Therefore, the researchers concluded that the ASD participants process emotional expressions and identity separately (Krebs et al., 2011).

There are also several eye-tracking studies which examined facial and emotional processing in individuals diagnosed with ASD. One of them is the study of Pelphrey et al. (2002) who used an infrared corneal reflection technique to measure facial and emotional processing in individuals diagnosed with ASD. Their results showed that the processing pattern of the ASD participants significantly differed from the processing pattern of the TD participants on both the non-emotional and emotional faces conditions. More specifically, the ASD participants processed the faces in a disorganized manner focusing only on one or two facial features such as ear or chin, while the TD participants showed facial processing in a shape of a triangle including eyes and mouth. This difference between groups was also visible while processing a variety of emotional expressions.

Another study of Wagner, Hirsch, Vogel-Farley, Redcay, and Nelson (2013) compared the visual processing of ASD and TD adolescents on a task involving angry, fearful, and neutral facial expressions and photographs of houses. The goal of the study was to examine the duration and fixation of gaze as well as differences in pupil dilation. Interestingly, the results showed only a subtle difference between the groups. For example, both groups spent a longer time scanning the eye region compared to the mouth region and there were no differences in pupil diameter when looking at emotional faces (Wagner et al., 2013).

Tsang (2018) also explored fixation duration and scan paths in individuals with high-functioning autism when identifying emotional expressions. This study showed significant differences between the ASD and TD groups in gaze fixation and accuracy in emotion identification. Not only did the TD group spend twice as much time scanning the facial regions than the ASD group, but they were also more accurate when identifying more complex emotional expressions (Tsang, 2018).

Lastly, Spezio, Adolphs, Hurley, and Piven (2007) used eye-tracking technology in combination with the “bubble” method, a technique commonly used in recognition tasks, to judge how large of an area of a face has to be uncovered before individuals diagnosed with ASD accurately identify the presented emotional expression. The results revealed that the ASD participants relied on different facial areas for emotion identification than their TD peers. More specifically, the ASD group relied significantly more on the mouth region and less on the eye region (Spezio et al., 2007).

The idea that individuals diagnosed with ASD process facial features and emotional expressions differently from their TD peers has empirical support in neuroscience as well. According to Nomi and Uddin (2015), facial processing in TD individuals can be described in two neural pathways (subcortical and cortical) including areas of the brain such as the amygdala, superior colliculus, fusiform gyrus, and inferior occipital gyrus. Those pathways were found to be responsible for processing both unchangeable facial features (e.g. identity) as well as the changeable ones including facial expressions (Nomi & Uddin, 2015). In the TD sample, the fusiform gyrus was also found to be more active when looking at images of human faces compared to objects (Kanwisher & Yovel, 2006). Such results were, however, not found for individuals with ASD. In fact, the results of a study where TD and ASD groups were compared when identifying fearful emotion in blurred pictures indicated abnormalities in the subcortical pathway of the ASD group, including hypoactivation in the fusiform gyrus, amygdala, and superior colliculus (Kleinhans et al., 2011).

Furthermore, Aoki, Cortese, and Tansella (2015) created a meta-analysis of fMRI studies investigating emotional face processing in individuals with ASD. The meta-analysis compared the results of 13 studies examining differences in regional activation of the brain during tasks involving non-face, neutral face, and emotional face conditions. The overall results of the meta-analysis indicated that compared to their TD peers, participants diagnosed with ASD experienced hyperactivation in the bilateral thalamus, bilateral caudate nucleus, left cingulate gyrus, and right precuneus as well as hypoactivation in the hypothalamus (Aoki, Cortese & Tansella, 2015). Since both the thalamus and caudate nucleus were previously linked to automatic emotional-face processing (Aoki, Cortese & Tansella, 2015; Tamietto & Gelder, 2010; Sun et al., 2015), the finding of this meta-analysis supports the idea that disturbances in emotional processing in ASD individuals have a neural basis.

In summary, Weak Central Coherence (WCC) theory suggests that individuals diagnosed with autism spectrum disorder (ASD) have enhanced abilities when noticing minute details and changes in their surroundings. However, the research investigating this theory shows ambiguous findings, only partially supporting the WCC ideology. One of the factors possibly contributing to the discrepancy in these finding is the visual processing style. While objects are thought to be processed locally (focusing on individual parts and characteristics), human faces and emotional expressions were found to be processed holistically (focusing on the constellation of the parts and characteristics). This could mean that individuals diagnosed with ASD may not show the expected enhanced ability to detect minute details as formulated by the WCC theory on a change blindness task involving human faces and emotional expressions.

Our study aims to investigate this possibility and explore how adolescents diagnosed with ASD recognize physical and emotional changes made on pictures of human faces. No study to date has synthesized the ideology of the WCC theory with research investigating the performance of individuals diagnosed with ASD on tasks involving change blindness and facial and emotional processing. For this reason, the proposed study strives to compare the performance of ASD participants to the performance of their TD peers, in order to evaluate whether or not the groups differ in visual-spatial processing.

Methods

Participants

In the current study, participants were recruited for two groups, ASD and TD. The proposed sample size was derived from a power analysis for a two-way ANOVA (α = 0.05, power = 0.80) using the G*power statistical software (Faul, Erdfelder, Lang, & Buchner, 2007), which indicated that approximately 37 participants will be needed in total to obtain a large effect size of 0.48. This effect size was reported in a study completed by Shah, Bird, and Cook (2016) which investigated differences in facial processing between ASD and TD groups and is expected to be similar to the effects being investigated in the current study. Therefore, our initial goal was to collect 20 participants aging between 8 to 17 years for each group (N = 40). However, due to challenges connected to data collection, the current study did not meet the proposed sample size. Altogether, data were collected from 17 participants (M_{age} = 11.1, SD_{age} = 2.3; M_{IQ} = 98.5, SD_{IQ} = 17.5). Participants who met the Autism Diagnostic Observation Schedule – 2nd Edition (ADOS-2; Lord et al., 2012) criteria for autism spectrum disorder were assigned to the ASD group. Specifically, participants with a minimum score of 7 on the ADOS-2 Modules 3 or 4 were assigned to the ASD group. Participants who did not meet the diagnostic criteria were assigned to the TD group. This resulted in an all-male sample of 8 ASD participants (M_{age} = 11.6, SD_{age} = 2.7; M_{IQ} = 89.8, SD_{IQ} = 19.0) and 9 TD participants (gender = 6 males, 3 females; M_{age} = 10.6, SD_{age} = 1.7; M_{IQ} = 106.2, SD_{IQ} = 11.5). The average ADOS-2 score for the ASD sample was 11 (range: 7-18), and the average ADOS-2 score for the TD sample was 3.4 (range: 0-5).

The initial goal of this study was to have the average age, IQ scores, and gender approximately equal across the two groups. However, due to the limited sample size and significant discrepancy between the mean IQ scores of the individual samples, 10 participants were selected from the sample and matched between the groups (ASD and TD) based on age and IQ. Such approach allows for reduction in the error caused by individual differences, leading to an increase in power (Lammers & Badia, 2005). Specifically, a power analysis for a repeated-measures analysis of variance (RM-ANOVA; α = 0.05, power = 0.80) using the G*power statistical software (Faul, Erdfelder, Lang, & Buchner, 2007) indicated that the total obtained sample of 10 participants is needed to obtain a large effect size of 0.51, approaching the originally proposed large effect size of 0.48.

The final sample used within the study thus consisted of 5 matched pairs, including an all-male sample of 5 ASD participants (M_{age} = 10.8, SD_{age} = 2.7; M_{IQ} = 102.2, SD_{IQ} = 12.5) and 5 TD participants (gender = 2 males, 3 females; M_{age} = 10.8, SD_{age} = 1.8; M_{IQ} = 101.6, SD_{IQ} = 11.6). The average ADOS-2 score for the ASD sample was 9.2 (range: 7-16), and the average ADOS-2 score for the TD sample was 2.4 (range: 0-5).

The primary investigator collaborated with the supervising investigator on the matching procedure. During the selection of the pairs, the priority was given to balancing IQ scores and ages of the participants. The remaining participants (*n* = 7) whose IQ scores and ages were not compatible for matching across groups were excluded from the current study.

Table 1

Age and IQ Scores of Participants Included in the Matched Pairs

Pair Number	Group Membership	Gender	IQ score	Age (year: month)
1	TD	F	112	8:1
	ASD	M	113	9:0
2	TD	F	111	12:2
	ASD	M	109	15:5
3	TD	M	97	13:2
	ASD	M	97	12:2
4	TD	F	107	10:11
	ASD	M	112	8:5
5	TD	M	81	10:2
	ASD	M	80	8:9

Materials

This study utilized several assessment and diagnostic measures including:

1. The Differential Ability Scales-II (DAS-II) is a standardized examination used to measure intelligence (IQ; Elliott, 2007). This measure was used to evaluate the cognitive abilities of the participants in both groups. The participants were matched between the groups by their General Conceptual Ability (GCA) score obtained on this measure, also referenced as the "IQ score." The average internal reliability of DAS-II school-age GCA (7:0 – 17:11 years) is r = .96, test-retest reliability is r = .90, and criterion validity in relation to the Weschler Intelligence Scale for Children, 4th edition (WISC-IV) Full Scale IQ is r = .84 (Elliott, 2007).
2. Autism Diagnostic Observation Schedule – 2nd Edition (ADOS-2) is used for assessment of ASD across age, developmental level, and language skills (Lord et al., 2012). ADOS-2 was administered to all participants in order to evaluate whether they met the autism spectrum classification. The overall interrater reliability of ADOS-2 Module 3 was r = .94 and r = .94 for Module 4 (Lord et al., 2012). The sensitivity and specificity for Module 3 was r = .91 and r =.84, respectively (Lord et al., 2012). For Module 4, the sensitivity was r = .87 and the specificity was r = .76 (Lord et al., 2012).
3. Conners Continuous Performance Test - 3rd Edition (Conners CPT 3) is a standardized task-oriented computerized assessment of attention-related problems (Conners, 2014). This measure was administered to participants in both groups in order to evaluate their attention span. The Conners CPT 3 split-half reliability ranges between r = .92 - .95, test-retest stability r = .67, and discriminative validity ranging from Cohen's d = .10 - .49 across all samples (Conners, 2014).

The experimental phase included the presentation of 36 pictures portraying human faces in color, which were selected by the researcher from the Radboud Faces Database (Langner et al. 2010). The pictures were used in their original and modified versions (see Appendix A). The modifications of the pictures were created using GNU Image Manipulation Program (GIMP).The experiment was presented to the participants using an eye-tracking system (Eye Link 1000 Plus Eye Tracker from SR Research).

Procedure

The participants were recruited on campus through the SONA Systems subject pool-software, student-announcement emails, and flyers posted around the campus. Participant recruitment was also conducted online using flyers posted on social media and websites collaborating with individuals diagnosed with ASD. Additional flyers were handed out to the community during events organized for individuals with disabilities (i.e. Trunk or Treating), and flyers were also distributed to local organizations providing services to individuals diagnosed with ASD (e.g. disability agencies, pediatric centers).

The study took place at Idaho State University in the Integrated Research Center. Before any procedure or experiment was conducted, the participants were familiarized with the purpose of the study and asked to sign the informed consent form. Participants wearing make-up were also asked to remove any eye make-up, as it could interfere with the accuracy of the eye-tracking technology. All participants then completed several procedures which were split into two sessions due to the concerns about participant exhaustion. The first testing session involved administration of the DAS-II and ADOS-2. The second testing session included administration of Conners CPT 3 as well as the change-blindness task, which was administered using the eye-tracking system. The procedures of both phases were the same for both groups, ASD and TD.

First testing session. Once the participants signed the informed consent and were familiarized with the purpose of the experiment they were then asked to complete the assessment phase where two different clinical measures were administered. The first measure administered to the participant was the DAS-II. The second measure administered to the participant was the ADOS-2. The measures were administered by graduate-level researchers who received supervised training focused on administration and scoring of the utilized measures prior to the beginning of the study. All of the researchers involved in the data-collection also showed a minimum of 80% inter-rater reliability on ADOS-2 scoring algorithm with the supervising investigator who completed the ADOS-2 Research Reliability Training 2019. For administration of both DAS-II and ADOS-2, the researchers used standardized materials and followed the administration protocols. Altogether, the first testing session lasted approximately 90-120 minutes.

Second testing session. During the second testing session, which occurred on a different day than the first testing session, the participants first completed the Conners CPT 3, which was administered via computer using a standardized program and equipment (Conners, 2014). Upon the competition of the Conners CPT 3, participants were asked to sit down by the eye-tracking system through which the change-blindness task was administered. Participants first underwent eye-tracking calibration procedures completed by the researcher, followed by a teaching trial. This teaching trial procedure imitated the actual change-blindness task, but included step-by-step instructions presented visually on the screen and verbally by the researcher. During the teaching trial, the participants were also queried by the researcher to ensure that the participants understood the instructions. The teaching trial involved two picture pairs, each composed of an “original” and “modified” picture of a face. The “modified” pictures portrayed the same picture of a face as the original picture but included some additional modification (EMOTIONAL or PHYSICAL) in order to familiarize the participant with both possible outcomes. All participants were provided with feedback from the researcher regarding their performance on the teaching trial. In case that the participants selected incorrect response during the questioning sequence of the teaching trial (e.g. selected that an “ANGRY” emotional modification was present instead of selecting the “HAPPY” emotional modification), they were asked to provide verbal reasoning for their selection. Participants who demonstrated comprehension of the task procedure were allowed to move on to the change-blindness tasks even if an incorrect answer was provided on the teaching trial.

The change-blindness task consisted of a series of picture pairs which were presented to the participant. In total, 36 picture pairs were presented to the participant in a randomized order. Each picture pair involved an "original" picture presented first and a "modified" picture that was presented second. The original picture from a picture pair always portrayed one of the selected human faces with neutral facial expression exactly as provided in the database. The modified picture from the picture pair portrayed the same human face as the original picture from the picture pair, but it also involved a modification created by the researcher. Such modifications were either physical (eye color, shape of a nose, shape of chin, hairstyle, freckles, shape of ears) or emotional (happy, angry, sad, surprised, disgusted, fearful). Eighteen pictures involved physical modification, and eighteen pictures involved emotional modification. There was an equal number of female (9) and male (9) faces in each category (physical modification, emotional modification).

The sequence of the picture pair presentations was as follows: The original picture appeared on the screen in front of the participant for 4s and stayed on the screen for the full length of time. After the 4s of original picture exposure, a blank white screen appeared for 2s and stayed on the screen for the full length of time. The blank screen exposure was followed by the presentation of the manipulated picture from the picture pair. This modified picture stayed on the screen in front of the participant for up to 10s. The participants were instructed to press the left PC mouse button anytime during the 10s presence of the modified picture once the modification was detected. The presence of the modified picture was terminated immediately after pressing the button or once the time (10s) elapsed. The time taken by the participant to detect the change and respond by pressing the button was measured. The maximum time taken by the participant was 10s. Immediately after the termination of exposure to the modified picture, the participant was presented with a set of written questions on the computer screen.

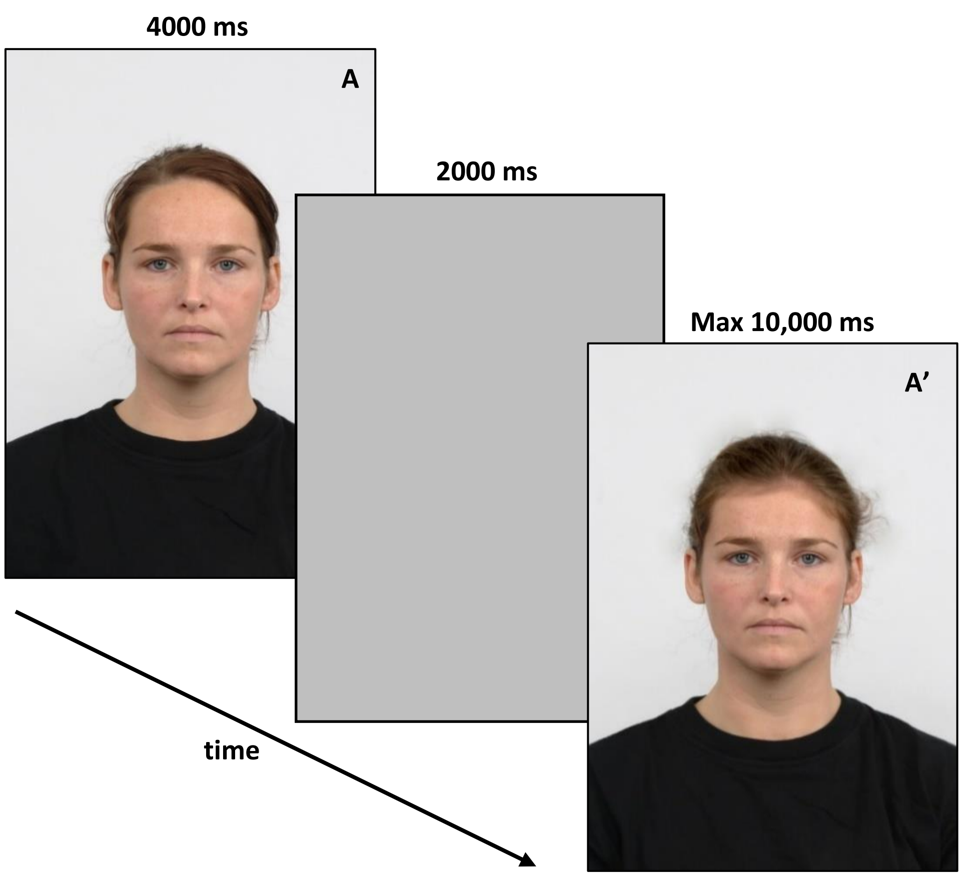

Figure 1. Schematic diagram of the picture pair sequence.

Participants were first presented with a question asking about the type of modification that was presented on the second picture from the picture pair. The participant could select from two answer choices (PHYSICAL and EMOTIONAL). This question was presented to all the participants after every trial. Based on the selected answer on the first question, two possible scenarios could have taken place.

If the participant selected the choice "PHYSICAL," indicating that a physical feature of the face was modified on the second picture of the picture pair, the participant was presented with a second question asking the participant to select the specific modification that was present as well as a list of facial features that could have been modified. This list contained eight items (EYES, HAIR, NOSE, EAR, FRECKLES, CHIN, LIPS, WRINKLES). The two items (LIPS and WRINKLES) served as distractors. After the selection of one of the available physical features, a screen containing text “Get ready for the next one!” appeared in front of the participant for 2s, indicating the end of this trial sequence and start of the next trial sequence.

If the participant selected the choice "EMOTIONAL," indicating that an emotional expression on the face was modified on the second picture of the picture pair, the participant was presented with a second question asking the participant to select the specific modification that was present as well as a list of emotional expressions that could have been modified. This list contained eight items (HAPPY, SAD, ANGRY, DISGUSTED, SURPRISED, FEARFUL, BORED, CONFUSED). The two items (BORED and CONFUSED) served as distractors. After the selection of one of the available emotional expressions, a screen containing text “Get ready for the next one!” appeared in front of the participant for 2s, indicating the end of this trial sequence and start of the next trial sequence.

Once the participants completed the 36 trials of the change-blindness tasks, they were debriefed and informed that the study was finished. Altogether, the second testing session lasted approximately 40-50 minutes. Upon competition of the second session, the participants were provided the incentive for participation in form of a $10 gift card and an option to sign up for a chance to win one of two $50 gift cards. Smaller insensitive in form of stickers, candy, and small toys were given to the participants throughout the testing during both sessions in order to promote motivation and engagement in the tasks consistent with standardized protocols.

Hypotheses and Analyses

Response Times

Table 2

Response Time Hypotheses

Hypothesis 1	The TD group will have slower response times than the ASD group when detecting the physical modifications.
Hypothesis 2	The TD group will have faster response times than the ASD group when detecting the emotional modifications.
Hypothesis 3	The ASD group will have slower response times when detecting the emotional modifications compared to the physical modifications.
Hypothesis 4	There will be a smaller difference in response times between the emotional and physical modifications in the TD group compared to the ASD group.

The Statistical Package for the Social Sciences (SPSS) program was used for statistical analyses (IBM Corporation, 2017). The proposed analysis for hypotheses 1-4 was a two-way analysis of variance (ANOVA), where the group membership (TD, ASD) and the type of modification (physical, emotional) were the predictors and the response time was the outcome variable. However, due to the limited sample size, hypotheses 1-4 were analyzed using the two-way RM-ANOVA, where the group membership (TD, ASD) and the type of modification (physical, emotional) were the factors and the response time was the outcome variable. The response time was measured in milliseconds (ms). Participant trials which reached the maximum of 10000ms were not excluded from the analyses in order to minimize data attrition.

RM-ANOVA is a type of hypothesis-driven statistical method used to determine if there is a statistically significant interaction effect between two within-subject factors on a continuous dependent variable (Laerd Statistics, 2015). This method is appropriate for matched-pair study designs where participants are matched between groups based on certain characteristic (e.g. IQ, age, gender), and their scores are compared to each other (Lammers & Badia, 2005; Salkind, 2010). RM-ANOVA is based on three assumptions, including 1) a lack of significant outliers in any cell of the design, 2) normal distribution of the dependent variable, and 3) equality of the variance of the differences between levels (i.e. sphericity; Laerd Statistics, 2015).

Traditionally, Mauchly's tests are conducted prior to running RM-ANOVA in order to assess for sphericity. However, the assumption of sphericity does not apply to analyses where the within-subject factor (i.e. type of modification) only has two categories (i.e. physical and emotional; Laerd Statistics, 2015). The results of a two-way RM-ANOVA provide main effects of group membership and type of modification as well as the interaction term between these two factors (Laerd Statistics, 2015). A significant interaction term of a two-way RM-ANOVA analysis needs to be followed-up with a series of post-hoc t-tests which evaluate the differences among individual levels and produce simple main effects (Laerd Statistics, 2015). The Bonferroni correction, simplest and most conservative approach for lowering α values, is traditionally used to compensate for increased chances of committing Type I error when running multiple t-tests (Cabin & Mitchell, 2000).

Response and Labeling Accuracy

Table 3

Accuracy Hypotheses

Hypothesis 5	The TD group will be less accurate than the ASD group when recognizing the physical modifications.
Hypothesis 6	The TD group will be more accurate than the ASD group when recognizing the emotional modifications.
Hypothesis 7	The ASD group will be more accurate when labeling the physical modifications than the emotional modifications.

It was proposed that the “accuracy” hypotheses 5-7 will also be analyzed with two-way ANOVAs, where the group membership (TD, ASD) and the type of modification (physical, emotional) were the factors and the participant’s response accuracy scores (i.e. percentage of accurate responses to Q1 - What type of change did you see?) or labeling accuracy scores (i.e. percentage of accurate responses to Q2 – What changed?) were the outcome variables. However, similar to hypotheses 1-4, hypotheses 5-7 were also analyzed using two-way RM-ANOVAs with matched-pairs due to the limited sample size. The individual accuracy scores were calculated by dividing the number of participant’s correct responses to either physical or emotional modifications by the number of total physical or emotional trials, which resulted in a percentage of “accurate answers” for each participant. This procedure was completed for both response (Q1) and labeling (Q2) accuracies. It is important to note that, despite being analyzed separately, the labeling accuracy scores were dependent on the response accuracy scores. This is due to the questioning logic utilized within the current study, which provided participants with different answer choice options on Q2 depending on the participant’s answer on Q1.

Results

Response Times

A two-way RM-ANOVA was run to determine the effects of type of modification and group membership on response times. Analysis of the studentized residuals showed that there was normality, as assessed by the Shapiro-Wilk test of normality ($p > .05$) and no outliers, as assessed by no studentized residuals greater than ± 3 standard deviations. For directional hypotheses, the provided *p*-values are one-tailed.

There was not a statistically significant two-way interaction between the type of modification and group membership in response time, $F(1, 4) = 0.69$ $p = .227$, $\eta_p^2 = .147$. The main effect of type of modification showed a statistically significant difference in response time between the physical ($M = 4179.50$, $SD = 218.20$) and emotional ($M = 1723.80$, $SD = 214.81$) modifications, $F(1,4) = 241.60$, $p < .001$, $\eta_p^2 = .984$, where the mean difference between the response times on physical and emotional modifications regardless of the group membership was 2455.70ms, 95%CI [-2894.35, -2017.05]. The main effect of group membership showed that there was not a statistically significant difference in response times between the TD ($M = 3277.90$, $SD = 384.27$) and ASD ($M = 2625.40$, $SD = 341.07$) groups, $F(1,4) = 1.165$, $p = .171$, $\eta_p^2 = .226$, where the mean difference between the response times for the TD and ASD groups regardless of the type of modification was 652.50ms, 95%CI [-1025.89, 2330.89].

Table 4

Response Time Group Means in Relation to Type of Modifications

	Emotional Modifications		Physical Modifications	
	n	*M (SD)*	*n*	*M (SD)*
TD	5	1889.60 (821.48)	5	4666.20 (1015.21)
ASD	5	1558.00 (318.63)	5	3692.80 (1305.49)

Note. The provided values are in milliseconds (ms).

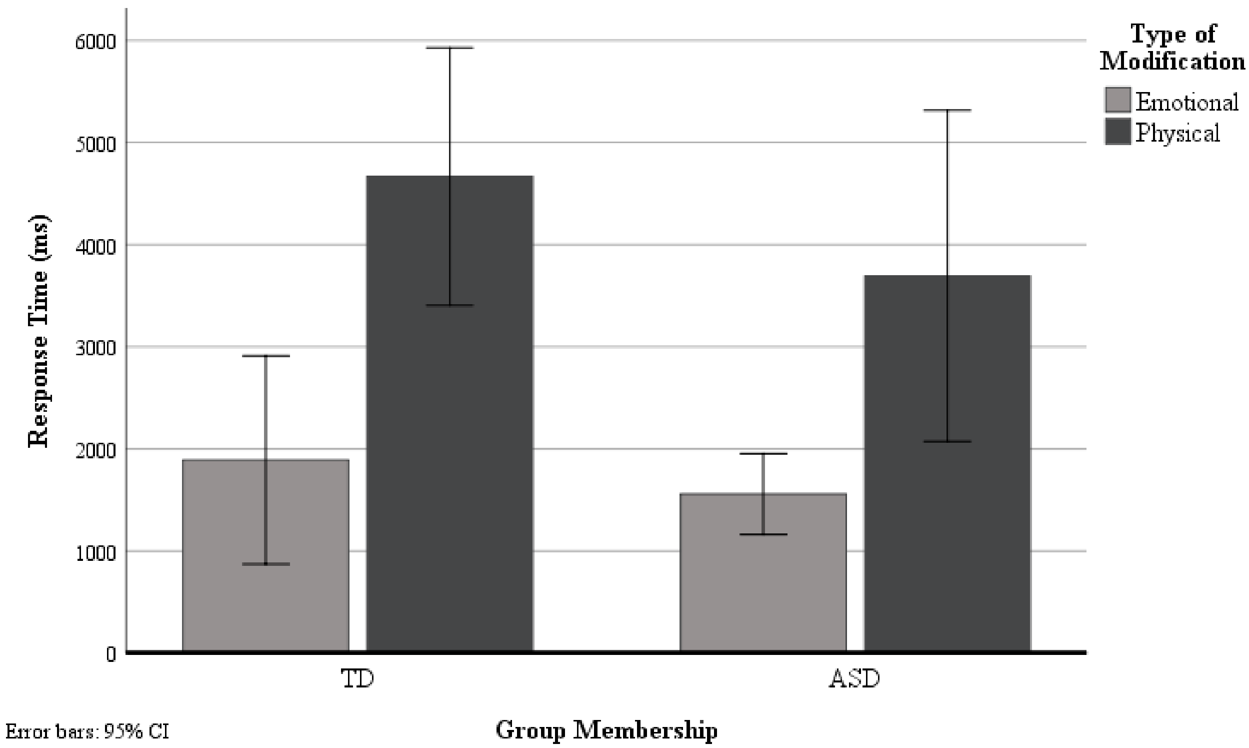

Figure 2. Group differences in response time based on type of modification.

Response Accuracy

A two-way RM-ANOVA was run to determine the effects of type of modification and group membership on response accuracy. Analysis of the studentized residuals showed that there were no outliers, as assessed by no studentized residuals greater than ± 3 standard deviations. Response accuracy scores were normally distributed ($p > .05$) except for scores of the ASD group on physical modifications ($p = .042$), as assessed by Shapiro-Wilk's test of normality on the studentized residuals. Further analyses indicated that the distribution of response accuracy scores of the ASD group on physical modifications was moderately negatively skewed (-0.86, *SE* = 0.91) with kurtosis of -1.75 (*SE* = 2.00). Absolute Z-scores computed for both skewness (Z = 0.97) and kurtosis (Z = -0.87) indicated that the distribution of response accuracy scores of the ASD group on physical modifications can be considered normal when using the Z-test with recommended alpha level of .05 (±1.96) for small samples (n < 50; Ghasemi & Zahediasl, 2012; Kim, 2013). The decision to carry on with analyses without transforming the response accuracy scores was made following the consideration that ANOVAs are thought to be fairly robust of normality violations (Laerd Statistics, 2015) and transformation of all response accuracy scores would be required, likely resulting in overall distribution changes that make interpretation of the results more challenging. For directional hypotheses, the provided *p*-values are one-tailed.

There was not a statistically significant two-way interaction between the type of modification and group membership in response accuracy, $F(1, 4) = 1.96$, $p = .117$, $\eta_p^2 = .329$. The main effect of type of modification did not show a statistically significant difference in response accuracy between the physical ($M = 85.55$, $SD = 6.11$) and emotional ($M = 92.78$, $SD = 1.88$) modifications, $F(1,4) = 0.95$, $p = .193$, $\eta_p^2 = .191$, where the mean difference between the response accuracy scores on physical and emotional modifications regardless of the group membership was 7.22%, 95%CI [-13.42, 27.86]. The main effect of group membership did not show a statistically significant difference in response accuracy between the TD ($M = 84.44$, $SD = 4.62$) and ASD ($M = 93.89$, $SD = 1.36$) groups, $F(1,4) = 4.52$, $p = .051$, $\eta_p^2 = .530$, where the mean difference between the response accuracy for the TD and ASD groups regardless of the type of modification was 9.45%, 95%CI [-21.79, 2.90].

Table 5

Response Accuracy Group Means in Relation to Type of Modifications

	Emotional Modifications		Physical Modifications	
	n	*M (SD)*	*n*	*M (SD)*
TD	5	92.22 (8.43)	5	76.66 (22.70)
ASD	5	93.33 (6.09)	5	94.44 (7.86)

Note. The provided values are in percentages (%).

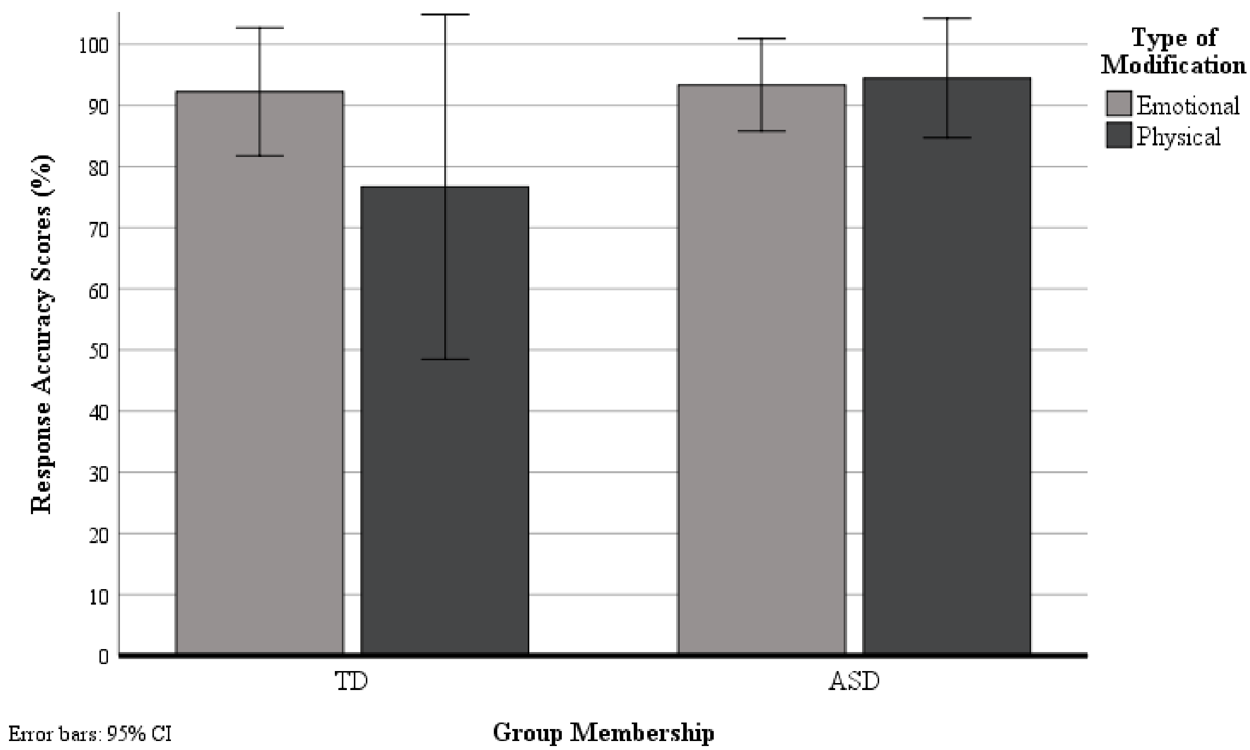

Figure 3. Group differences in response accuracy based on type of modification.

Labeling Accuracy

A two-way RM-ANOVA was run to determine the effects of type of modification and group membership on labeling accuracy. Analysis of the studentized residuals showed that there were no outliers, as assessed by no studentized residuals greater than ± 3 standard deviations. Labeling accuracy scores were normally distributed ($p > .05$) except for scores of TD group on emotional modification ($p = .006$), as assessed by Shapiro-Wilk's test of normality on the studentized residuals. Further analyses indicated that the distribution of response accuracy scores of the TD group on emotional modifications is moderately positively skewed (0.61, *SE* = 0.91) with kurtosis of -3.33 (*SE* = 2.00). Absolute Z-scores computed for both skewness (*Z* = 0.67) and kurtosis (*Z* = -1.67) indicated that the distribution of response accuracy scores of the TD group on emotional modifications can be considered normal when using the Z-test with recommended alpha level of .05 (±1.96) for small samples (n < 50; Ghasemi & Zahediasl, 2012; Kim, 2013). Similar to response accuracy scores, the decision to carry on with analyses without transforming the labeling accuracy scores was made following the consideration that ANOVAs are thought to be fairly robust of normality violations (Laerd Statistics, 2015) and transformation of all labeling accuracy scores would be required. For directional hypotheses, the provided *p*-values are one-tailed.

There was a statistically significant two-way interaction between the type of modification and group membership in labeling accuracy, $F(1, 4) = 11.15$, $p = .029$, $\eta_p^2 = .736$. Therefore, simple main effects were run. The simple main effect of type of modification showed a statistically significant difference in labeling accuracy between the physical (*M* = 39.90, *SD* = 4.84) and emotional (*M* = 87.77, *SD* = 2.72) modifications in the TD group, $F(1,4) = 85.05$, $p = .001$, $\eta_p^2 = .955$, where the mean difference between the labeling accuracy scores on physical and emotional modifications was 47.87%, 95%CI [33.46, 62.29]. The simple main effect of type of modification showed a statistically significant difference in labeling accuracy between the physical (*M* = 32.22, *SD* = 6.90) and emotional (*M* = 61.11, *SD* = 6.80) modifications in the ASD group, $F(1,4) = 50.07$, $p = .002$, $\eta_p^2 = .926$, where the mean difference between the labeling accuracy scores on physical and emotional modifications was 28.89%, 95%CI [17.55, 40.22].

The direction of this relationship was, however, opposite from what was expected in hypothesis 7.

The simple main effect of group membership showed that there was a statistically significant difference in labeling accuracy between the TD (*M* = 87.77, *SD* = 2.72) and ASD (*M* = 61.11, *SD* = 6.80) groups on emotional modifications, $F(1,4) = 10.77$, $p = .03$, $\eta_p^2 = .729$, where the mean difference between the labeling accuracy scores for the TD and ASD groups was 26.66%, 95%CI [4.10, 49.23]. The simple main effect of group membership showed that there was not a statistically significant difference in labeling accuracy between the TD (*M* = 39.90, *SD* = 4.84) and ASD (*M* = 32.22, *SD* = 6.90) groups on physical modifications, $F(1,4) = 3.44$, $p = .137$, $\eta_p^2 = .462$, where the mean difference between the labeling accuracy scores for the TD and ASD groups was 7.68%, 95%CI [-3.81, 19.17].

Table 6

Labeling Accuracy Group Means in Relation to Type of Modifications

	Emotional Modifications		Physical Modifications	
	n	*M (SD)*	*n*	*M (SD)*
TD	5	87.77 (6.09)	5	39.90 (10.83)
ASD	5	61.11 (15.21)	5	32.22 (15.42)

Note. The provided values are in percentages (%).

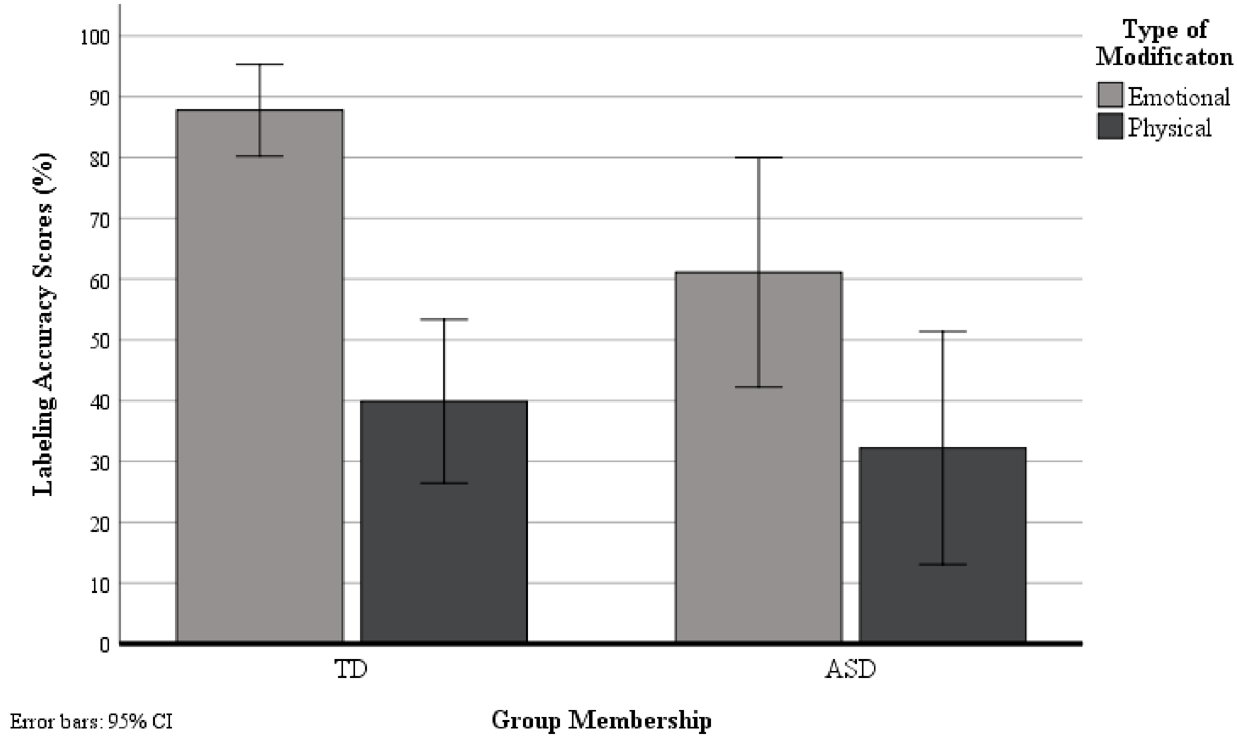

Figure 4. Group differences in labeling accuracy based on type of modification.

Discussion

The current study examined the differences between typically developing (TD) participants and those diagnosed with autism spectrum disorder (ASD) in the ability to detect and label changes made on pictures of human faces. Previous studies suggested that, compared to their TD peers, individuals diagnosed with ASD have an enhanced ability to notice details and changes in complex images and their surrounding (Jolliffe & Baron-Cohen, 1997, Ropar & Mitchell, 2001, Shah & Frith, 1983). Weak Central Coherence (WCC) theory aims to explain this discrepancy in performance by proposing that individuals diagnosed with ASD have restricted ability to perceive objects holistically (Happé, 1999), which is why they show a preference for local processing of minute details. Multiple studies have attempted to investigate the WCC theory, exploring differences between the ASD and TD groups in both response time and accuracy on tasks requiring detail detection (Jolliffe & Baron-Cohen, 1997; Ropar &

Mitchell, 2001; Shah & Frith, 1983). However, these studies are showing inconsistent findings, which may be due to methodological differences, changes in diagnostic criteria for ASD, or administration techniques (Happé & Frith, 2006).

It was also theorized that the inconsistency in findings of previous studies investigating WCC in relation to detail and change detection may be caused by variations in contextuality/location of the modification (i.e. central changes are made in the location of most interest while marginal changes are less likely to be attended to; Utochkin, 2011) as well as the processing approach itself (i.e. tendency to employ holistic vs. local processing depending on the perceived image). For example, several studies suggested that holistic processing is more beneficial when detecting changes made on human faces whereas local processing is more beneficial when detecting changes made on objects (Tanaka & Farah, 1993, Macrae & Lewis, 2002; Perfect, Dennis, & Snell, 2007). This was further supported by the finding that individuals diagnosed with ASD struggle with evaluating emotional expressions, which typically require holistic processing as they involve simultaneous changes in multiple areas of the human face (Deruelle et al., 2004). Since, up to date, no study has specifically looked at the differences between ASD and TD samples when detecting changes on human faces in relation to WCC theory and processing style, the current study attempted to do so by asking the participants to detect and label physical and emotional changes made on images of human faces. Hypotheses about the group differences in response times, response accuracy, and labeling accuracy were formulated in accordance with the literature available on this topic.

Response Time

Since previous studies suggested that individuals with ASD may be faster when noticing local stimuli than their TD peers (Jolliffe & Baron-Cohen, 1997), we hypothesized that the ASD participants in the current study would be faster than their matched TD peers when detecting physical modifications made on human faces (i.e. Hypothesis 1) because physical modifications such as change in eye color may require less holistic processing than emotional modifications. Similarly, we expected the TD group to show a superior performance in response times when detecting the emotional modifications compared to the ASD group (i.e. Hypothesis 2) as it was thought that emotional modifications may require more holistic processing that, based on the WCC theory, may provide an advantage for the TD group. The results of the current study did not support these hypotheses, showing non-significant difference between the groups regardless of the type of modification. Nonetheless, though the difference was non-significant, the ASD group showed slightly faster average response times on both types of modification (i.e. emotional and physical) than the TD group. Such finding does not fit the WCC theory in relation to processing style, but it is consistent with the results of Ropar and Mitchell (2001) and Jolliffe & Baron-Cohen (1997), who found that ASD participants had faster reaction times than their TD peers when detecting details using Embedded Figures Test (EFT).

Furthermore, the ASD group was expected to show slower response times when detecting the emotional compared to physical modifications (i.e. Hypothesis 3). Even though a significant main effect of type of modification was found, both the ASD and TD groups showed faster average response times on emotional compared to physical modifications. This is likely due to the large visual differences between the emotional and physical modifications. While the physical modifications consist of a change in one facial feature (i.e. shape of nose, eye color, style of hair), the emotional modifications are composed of both macro and micro changes occurring across multiple facial regions, predominantly mouth and eye (Guarnera, Hichy, Cascio, & Carrubba, 2015).

Another possible factor that may have influenced the reason why emotional modifications were more easily detectable for both groups in the current study is related to contextuality. As mentioned earlier, contextually central modifications that are made in the main location of most visual attention were found to be more easily detectable than contextually marginal changes made in locations of lower visual interest (Rensink, O'Regan, & Clark, 1997; Utochkin, 2011). Even though some studies found that individuals diagnosed with ASD tend to be less influenced by contextuality than their TD peers (Smith & Milne, 2009), it is likely that the contextuality differences between emotional and physical modifications in the current task were too profound to be disregarded by the ASD group.

Whereas emotional modifications are contextually central as they are primarily located in the triangular region between the eyes and mouth that was previously identified to be the primary area of visual interest and fixation in TD samples (Belle, Ramon, Lefèvre, & Rossion, 2010; Bindemann, Scheepers, & Burton, 2009; Hsiao & Cottrell, 2008; Orban de Xivry, Ramon, Lefèvre, & Rossion, 2008), with some abnormalities found in the ASD sample (Pelphrey et al., 2002), the physical modifications utilized within this study were ranging between contextually central (i.e. changes in the eye color, shape of nose, and addition of freckles to the center of face) and contextually marginal (e.g. change in the shape of ears, chin, and hair style). There was an attempt to balance the number of contextually central and marginal physical changes within the study, but the inclusion of contextually marginal changes in the physical modification conditions and a lack of contextually marginal changes in the emotional modification conditions likely made detection of physical modifications more challenging overall, hence the statistically significant discrepancy in reaction times between physical and emotional modifications across both groups. Therefore, rather than replicating the findings of Smith and Milne (2009) in terms of contextuality, the results of the current study were more consistent with findings of Burack et al. (2009) and Fletcher-Watson et al. (2012), who showed that both ASD and TD groups had shorter response times when detecting central versus marginal changes.

Lastly, we hypothesized that there will be a smaller difference in the response times between the emotional and physical changes in the TD group compared to the ASD group (i.e. Hypothesis 4). This hypothesis built on the assumptions of WCC theory as reflected by Hypotheses 1 and 2, predicting that participants diagnosed with ASD will show greater extremes in their performance (i.e. faster reaction times on physical modification and slower reaction times on emotional modifications) than the TD participants. The results did not support this hypothesis, showing non-significant interaction between the groups and types of modification. In contrast with the hypothesis, the TD group showed a larger difference in response times between the emotional and physical modifications than the ASD group. Such finding is not consistent with studies demonstrating that individuals with ASD tend to show slower response times when simultaneously processing multiple features of human faces (Kikuchi et al., 2009; Nakahachi et al., 2008) and studies suggesting that individuals with ASD show faster response times when detecting simple forms in complex backgrounds (Jolliffe & Baron-Cohen, 1997; Ropar & Mitchell, 2001). It is unclear why the current study failed to show the predicted interaction between the group membership and the type of modification, but there is a possibility that the profound differences in study designs utilized by the past research might have resulted in inaccurate interpretation of the findings in relation to the current study.

Nonetheless, even though the difference in response times between the groups was non-significant, the finding that the TD group showed slower response times on both emotional and physical modification was unexpected. One of the possible explanations for this finding is presented by Tsang (2018), who suggested that TD individuals may be trading speed for accuracy when scanning facial regions.

Response Accuracy

Previous studies investigating differences in accuracy between ASD and TD samples on tasks requiring change detection also showed mixed findings, but, based on the ideology proposed by WCC theory, individuals diagnosed with ASD are expected to be more accurate when noticing smaller local details that require local processing than their TD peers. For this reason, when asked to determine whether physical or emotional modification was present on the picture pair, we hypothesized that the TD group would be less accurate when recognizing the physical modifications compared to the ASD group (i.e. Hypothesis 5). Similarly, we expected to see the opposite direction for the emotional modifications, hypothesizing that the TD group would be more accurate than the ASD group when recognizing the emotional changes (i.e. Hypothesis 6).

The results did not show significant interaction or main effects for either of the response accuracy hypotheses, indicating that there was neither a statistically significant difference between the groups in the ability to accurately determine which modification was presented on the picture pair nor was there a difference in accuracy depending on the type of modification. It is, however, important to note that the findings exhibited an unexpected pattern of responding for both groups. Not only was the ASD group, on average, more accurate than the TD group when recognizing both physical and emotional changes, but there was also a greater discrepancy in the response accuracy on physical modification between the groups compared to emotional modifications. The current study thus provided promising findings for Hypothesis 5, showing a possibility that, with a larger sample size, we may be able to see a significant effect of group membership in relation to response accuracy of physical changes. Such finding would be consistent with the idea of WCC theory proposing that individuals diagnosed with ASD show enhanced ability to recognize minute details in complex backgrounds as, for example, demonstrated by Shah and Frith (1983) but possibly also with the finding of Joseph and Tanaka (2003), who indicated that individuals diagnosed with ASD are better at processing and recognizing certain facial features (e.g. mouth).

Labeling Accuracy

Lastly, the current study included one hypothesis related to the "labeling accuracy," defined as the ability of participants to accurately label what specific modification they were presented with beyond determining if the modification was emotional or physical. As described in the method section, depending on their answer on Question 1, the participants in the current study were presented with a second question asking them to select one of the eight answer choices, determining what modifications they saw. These choices were "EYES, HAIR, NOSE, EAR, FRECKLES, CHIN, LIPS, and WRINKLES" for physical modifications and "HAPPY, SAD, ANGRY, DISGUSTED, SURPRISED, FEARFUL, BORED, CONFUSED" for emotional modifications, where LIPS, WRINKLES, BORED, and CONFUSED answer choices served as distractors.

Since there is limited research investigating differences in labeling accuracy performance between the individuals diagnosed with ASD and those that are typically developing utilizing the methodology of the current study, a single hypothesis investigating within-group differences was formulated. Specifically, we predicted that the ASD group would be more accurate when labeling the physical changes compared to emotional changes (i.e. Hypothesis 7). This expectation was based on the WCC theory stating that individuals diagnosed with ASD should show higher accuracy when recognizing minute details (e.g. change in eye-color), as well as past research findings suggesting that individuals with ASD struggle when recognizing different emotional expressions (Deruelle et al., 2004; Tsang, 2018).

Even though the results of RM-ANOVA showed significant interaction and simple main effects of group and type of modification in relation to labeling accuracy, the significant findings did not match the proposed direction of Hypothesis 7 as the ASD group showed higher labeling accuracy on emotional compared to physical modifications. Since the TD group showed the similar pattern of responding, it is likely that both groups found it easier to label the individual emotional modifications (e.g. happy, angry) than the physical modifications (e.g. eye-color, shape of chin).

Nonetheless, the results of RM-ANOVA showed other interesting findings beyond Hypothesis 7. Even though the current study did not include any predictions regarding group differences in labeling accuracy, the results suggested that there was a significant difference between the TD and ASD groups in their ability to accurately label emotional modifications. Specifically, the TD group was found to have significantly higher labeling accuracy scores on emotional modifications compared to the ASD group. This finding is even more intriguing when contrasted with the performance of the ASD participants on response accuracy task. While the ASD participants in the current study did not show significant difference from their TD peers on response accuracy in relation to emotional modifications, their labeling accuracy scores for emotional modifications were found to be significantly lower. Therefore, while the ability to decide whether the presented change was emotional or physical appears to be comparable between the ASD and TD adolescents, the ability of the ASD sample to determine what emotional expression they saw appears to be much lower. This finding is consistent with findings of previous studies that showed that individuals diagnosed with ASD experience more difficulties accurately recognizing different emotional expressions than their TD peers (Deruelle et al., 2004; Tsang, 2018).

Furthermore, the fact that the current study did not show a statistically significant difference between groups on labeling accuracy of physical modifications indicates that the there is something special about the way participants with ASD process changes in emotional expressions compared to the typically developing sample, but these abnormalities do not apply to physical changes. These results thus suggest that, in relation to labeling accuracy, the ASD sample may be struggling with holistic processing required for recognition of facial expressions, without necessarily showing enhanced performance when recognizing physical changes, a task requiring local processing of a minute detail. Unfortunately, there are no previous studies with similar methodology that could effectively explain the current findings. However, several past studies indicated that individuals with ASD do not always outperform their TD peers on tasks where local processing is thought to be advantageous (Brundson et al., 2015; White & Saldana, 2011).

Implications and Limitations

The current study expanded on the available literature combining the ideas of the WCC theory with change blindness and facial and emotional processing in individuals diagnosed with ASD. Similar to the past literature investigating the WCC theory, the findings of the current study are mixed and hardly interpretable in relation to contextuality and processing style. Nonetheless, even though we were unable to find statistical significance for any of the formulated hypotheses, the current study showed several surprising findings, mainly related to group differences in labeling accuracy on emotional modifications and response accuracy on physical modifications. Analyses of the eye-tracking data collected by the current study may also further broaden our understanding of this topic and provide additional information about the ways the ASD and TD groups detect and label physical and emotional modification on pictures of human faces. Nevertheless, several limitations of the current study should also be noted.

First, the sample size included in the current study is limited. Despite the efforts to accelerate the recruitment by including incentive for participation and advertising the study to both students of Idaho State University and the local community, the originally proposed sample size was not reached even after 6 months of intensive participant recruitment. One of the possible reasons for the recruitment difficulties present in the current study is the relatively small size of the community in which the study took place as well as its rural location, as these two factors limit the number of potential participants that meet the inclusion criteria. In addition, the current study was designed to recruit adolescents diagnosed with ASD, which is a population known to face unique challenges that may create participation in research studies difficult (Russell et al., 2019; Woodall, Morgan, Sloan, & Howard, 2010). The study further targeted individuals with average cognitive abilities who are able to follow instructions and provide assent to participate, posing additional recruitment challenges due to the high comorbidity of ASD and ID diagnoses (Charman et al., 2011)

There was an effort to minimize the negative impact that a small sample size may have on the quality and generalizability of the study results by utilizing match-paired sample and RM-ANOVAs instead of the originally proposed between-group analyses. Such approach allowed for reduction in the error caused by individual differences, leading to an increase in power (Lammers & Badia, 2005).

Another limitation related to the sample of the current study is the lack of female participants in the ASD sample. This is a common limitation of research studies that recruit participants with ASD diagnosis as the male:female ratio of individuals diagnosed with ASD in the general population is 4:1 (Fombonne, 2009), making recruitment of female participants diagnosed with ASD more challenging.

Furthermore, when comparing the full samples for TD and ASD groups, there was a significant discrepancy between the average IQ scores (ASD = 89.8; TD = 106.2). In addition, IQ scores of two participants in the ASD group were more than 2 *SDs* below the mean. This discrepancy was effectively addressed in the current study by matching participants between the groups, but inconsistency in IQ scores may pose a potential challenge in the future once the originally proposed sample is collected and between-group analyses will be conducted. Individuals diagnosed with ASD also tend to present with fractured subscale profiles on intelligence measures (Charman et al. 2011; Mayes & Calhoun, 2007; Oliveras-Rentas, Kenworthy, Roberson, Martin & Wallace, 2012). For this reason, matching between groups based on overall IQ score may not be the most effective method as it may mask some of the group differences in cognitive abilities.

It is also important to note that, even though the participants were evaluated for attentional difficulties using the Conners CPT-3, the current study did not use these scores for matching or exclusion purposes due to the limited sample size. Since previous studies found that attention plays an important role in change blindness tasks (Eimer & Mazza, 2005; Schankin, Bergmann, Schubert, & Hagemann, 2017; Taya & Mogi, 2006), abnormalities in the participants' attentional abilities should be addressed once the originally proposed sample size is reached.

As previously mentioned, the sample also comes from a small, rural, intermountain community with a predominantly white population in terms of ethnic identity. For this reason, the generalizability of the findings to general US population is likely limited. Future research would, therefore, benefit from expanding to more diverse populations as well as inclusion of individuals diagnosed with ASD with comorbid IDs and low verbal abilities, minimizing the selection bias described by Russell et al. (2019).

In terms of methodology, one of the limitations of the current study is the profound difference between emotional and physical modifications. Even though the primary goal of the current study was to evaluate the interaction between group membership and type of modification rather than investigate the sole differences in response times, response accuracy, and labeling accuracy between the types of modification, it is important to consider how such differences might have influenced the study findings.

As previously discussed, emotional modifications inherently include changes in multiple facial areas and features, whereas physical modifications included in this study were more localized. In terms of contextuality, it was also theorized that all 36 emotional modifications included in the current study were contextually central, whereas only 18 of the physical modifications were contextually central and 18 were contextually marginal. In theory, it is also believed that there was a greater within-group variability among physical modification compared to emotional modification. For example, a change in a hair style is likely to be perceived as more profound modification than the addition of freckles. For these reasons, results regarding group differences in performance between the physical and emotional modifications should be interpreted with caution, and future studies should strive to further explore what effects can differences in within-group variance and contextuality among physical and emotional modifications have in relation to WCC theory.

Lastly, it is important to note that the analyses included participants' response times on all 36 trials, regardless of whether the ceiling time of 10s was reached or not. It is, therefore, possible that the ceiling time for exposure to the modified picture could have negatively impacted the results of the current study. A lack of standard guidelines and agreement within the field about the procedures and timing of change blindness tasks make interpretation of the possible impact of the 10s ceiling time challenging. However, in general, not providing the participants with enough time to detect the modification may arbitrarily diminish the between-group differences. Considering that the overall average response time was approximately 3000ms, it would appear that the participants in the current study were provided with enough time to detect the presented modifications. Nonetheless, future research should consider whether extending the time of exposure to the modified picture could result in greater variability in individual response times.

Future Directions

Several of the above-mentioned limitations of the current study may be effectively addressed by future research. Collecting additional participants will allow for increased power, enhancing the likelihood that potential differences between the TD and ASD group performance on the change blindness task will be detected. Specifically, it is expected that a significant main effect of group membership may be seen between the TD and ASD groups on the response accuracy, as the current results approached significance and showed a large effect size.

In addition to collecting more participants, the future research should include additional analyses that could provide richer information about the interaction between the group membership and type of modification. For example, the interaction between response time and accuracy may be analyzed using Linear Integrated Speed-Accuracy Scores (LISAS). LISAS were found to have high sensitivity (*d'*), small effect size variability, and seem to be ideal for measurement of efficiency because compared to Rate Correct Scores (RCS) and Inverse Efficiency Scores (IES), these scores could be used with error proportions above 0.10 (Vandierendonck, 2018). The results of efficiency analysis using LISAS may then be contrasted to the results of the response time analysis. Although no outcome predictions about response efficiency were formulated within the current study, this comparison may help to uncover whether the response times between the groups are significantly influenced by their accuracy.

Analysis of the eye-tracking data collected by the current study may also provide additional information about the ways ASD and TD participants engaged with the presented pictures of human faces. Based on prior research of facial processing, it is expected that the ASD participants will spend less time looking at the triangular area of interest located between the eyes and mouth regions of the face (Tsang, 2018). However, considering that the current study was the first to synthesize the ideas of WCC theory with change blindness and facial/emotional processing, it is likely that the results of the eye-tracking analyses will provide exploratory findings and further research will be needed to provide greater clarity about the differences in visual processing between ASD and TD individuals.

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Appendix

Examples of Images with Emotional and Physical Modifications

Emotional Modification Pair - Happy

Physical Modification Pair - Freckles