THE IMPACT OF AUDITORY DISTRACTORS ON VISUAL SEARCH PERFORMANCE IN INDIVIDUALS WITH AUTISM SPECTRUM DISORDER

by

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Dedicated to my family, who have supported me unwaveringly through the best and worst times

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ABSTRACT

Enrollment in post-secondary education for individuals with autism spectrum disorder (ASD) is increasing; however, students with ASD are less likely to complete a degree than students with other disabilities. Classroom performance requires attending to course-related information while filtering distractions. These attentional functions are critical for academic achievement. However, ASD is associated with pervasive impairments in attentional filtering. The present study used visual search, a task in which individuals with ASD excel, to investigate filtering of irrelevant social and non-social auditory information in college students with and without ASD. Results of the present study suggest a filtering deficit for individuals with ASD and indicate that this filtering impairment is present for both social and non-social information. Importantly, these deficits are present on a task in which individuals with ASD excel. Our findings suggest that irrelevant social and non-social sounds may adversely affect performance in college-aged students with high-functioning ASD and highlight the importance of minimizing competing background noise for these students.

INTRODUCTION

Since 2000, the prevalence of ASD has increased from 1 in 150 to 1 in 54 children (as of 2016) (Maenner et al., 2020) with a growing percentage of those diagnosed with ASD having average or above average intelligence (about 27% to 44%) (Baio et al., 2018). This increase in prevalence and shift in ability level has led to increased enrollment in post-secondary education for individuals with ASD (White et al., 2011). As this trend continues, larger cohorts of individuals with ASD will be entering post-secondary education. However, findings from previous studies have shown that, in general, individuals with ASD are less likely to complete a degree than individuals with other disabilities (e.g., learning disabilities, speech/language impairment, hearing impairment, visual impairment, orthopedic impairments, other health impairment, and traumatic brain injury) (Wei et al., 2013). Thus, it is critical to understand the factors that may contribute to this lower post-secondary completion rate so that interventions and/or accommodations can be generated to increase the graduation rates of students with ASD.

For those that enter post-secondary education, students with ASD often enroll in majors within science, technology, engineering and mathematics (STEM) fields (Wei et al., 2014; Wei et al., 2013). Students with ASD may gravitate towards these majors due to the rule-based system that is prevalent in STEM-related fields (Baron-Cohen et al., 2007). However, STEM courses have begun to transition from traditional passive, lecture-based instruction to more active learning environments, which require students to participate in collaborative hands-on learning (Smith et al., 2005). Given that ASD is a developmental condition diagnosed on the basis of impairments in social interaction and verbal and nonverbal communication, as well as atypical restricted and repetitive behaviors including atypical sensory responsivity (American Psychiatric Association, 2013), these changing classroom environments may present further challenges for students on the autism spectrum (Pilotte & Bairaktarova, 2016).

LITERATURE REVIEW

ASD and Attention

Successfully navigating a classroom environment requires adaptive allocation of attention. For example, students need to select important sources of information (e.g., instructor, presentation slides) while ignoring distracting information (e.g., peers browsing social media, loud air conditioning noise). Further, students must be able to flexibly shift their attention from their notes to the instructor or presentation. Together, effective academic performance requires the selection of relevant course-related agents or information, while filtering irrelevant components of the classroom environment. These attentional functions have also been associated with academic achievement (Breslau et al., 2009; Steele et al., 2012). For example, Rabiner and colleagues (2000) conducted a longitudinal study with over 300 students from kindergarten to fifth grade comparing standardized attentional-problem measurements with reading achievement and found a strong correlation between attentional deficits and reading difficulties. These attentional demands are further increased in active learning situations, which are likely to be more dynamic and chaotic. Given that individuals with ASD exhibit pervasive impairments in attention (Keehn et al., 2013), on-task classroom behavior in these more difficult environments may be particularly challenging.

Previous research findings have shown that individuals with ASD exhibit weaknesses in filtering irrelevant information. Specifically when trying to maintain attention of a task-relevant stimulus, individuals with ASD show difficulty ignoring behaviorally-irrelevant distractors (Adams & Jarrold, 2012; Keehn et al., 2019; Keith et al., 2019; Murphy et al., 2014; Ohta et al., 2012), including both visual and auditory information. Since individuals with ASD demonstrate difficulty filtering irrelevant information, they are more likely to process this distracting information in a classroom setting. In other words, they may be unable to "tune-out" distractions of any modality. In particular, previous studies have found hearing to be the main modality that results in sensory issues for students with ASD, and may lead to anxiety, frustration or discomfort (Ashburner et al., 2008; Howe & Stagg, 2016; Kanakri, Shepley, Varni, et al., 2017). Based on these findings, many studies have suggested limiting background noise in classrooms to help address this difficulty (Kanakri, Shepley, Varni, et al., 2017; Keith et al., 2019; Kinnealey et al., 2012).

Noise and Performance

This shift from passive, lecture-based instruction to an active learning environment naturally produces more noise. Passive learning environments have limited auditory distractors and only one important source of auditory information—the instructor. However, in active learning environments students are asked to collaborate and discuss content and work hands-on with materials, which results in increased noise. In these environments, students are required to ignore irrelevant sounds or distractors, including other group conversations, moving equipment/materials, and other standard classroom noises, while maintaining focus on only the relevant sounds and their sources. Therefore, as the noise levels in active learning environments increase, it is vital to evaluate the effect of noise on performance to ensure the most effective learning environment.

Different types of noise may have unique effects on performance. The present study will examine two types of auditory stimuli: social and non-social. Studies on the distractive effects of noise in typically developing (TD) individuals have shown that irrelevant social noise (i.e., speech) is more disruptive than non-speech noise on performance (Korhonen & Werner, 2017; Szalma & Hancock, 2011). In contrast, non-speech noise has been shown to have the opposite effect of improving performance for TD individuals (O'Malley & Poplawsky, 1971; Söderlund et al., 2007).

However, individuals with ASD have been shown to have an impaired ability to selectively attend to one sound source amongst several other competing sources (Teder-Sälejärvi et al., 2005), as a result of impaired filtering of irrelevant auditory information (Keith et al., 2019). In contrast to their TD peers, individuals with ASD have been shown to be less distracted by irrelevant speech stimuli than irrelevant non-social auditory stimuli—therefore demonstrating more distraction of non-social stimuli compared to social stimuli (Lepistö et al., 2005). Findings from prior studies have also shown that individuals with ASD may have a preference for non-speech sound to speech stimuli (Klin, 1991; Korhonen & Werner, 2017). Nevertheless, while non-speech noise has been shown to facilitate performance in TD individuals, potentially by increasing arousal, individuals with ASD have shown the opposite effect, especially in the context of more challenging tasks (Keith et al., 2019).

Visual Search and ASD

Paradoxically, while ASD is associated with deficits in filtering irrelevant information, results from previous studies have reported superior performance on visual search tasks in children, adolescents, and adults with ASD compared to TD peers (Kaldy et al., 2013). Selective attention is often measured using visual search paradigms in which participants are asked to locate a target hidden amongst a number of distractor items (Wolfe, 2003). The observer's goal is to determine if the target item (e.g., a "T" amongst several "Ls") is present or absent. When the features (e.g., color, shape, size) of the distractors differ greatly from the target features, search times are less affected by the number of distractors (set size). The resulting slope of the response time (RT) by set size function is relatively flat (<10 ms/item) and search is considered efficient (see Figure 1). However, in more challenging search tasks (where the target and distractors share similar features), search becomes more inefficient, resulting in steeper slopes reflecting the cost of additional distractor items. Across a number of visual search paradigms using a variety of target and distractor pairings, individuals with ASD have shown *faster* search times and *more efficient* search compared to the TD peers, especially in more difficult search conditions.

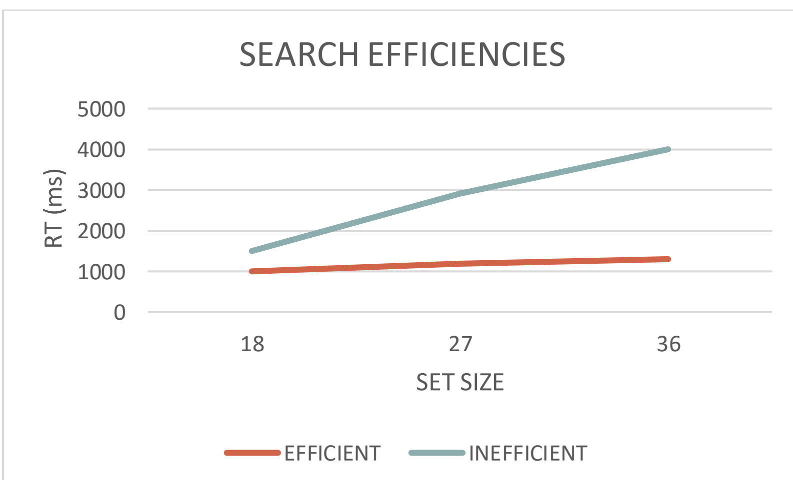

Figure 1: Examples of response time by set size slopes representing efficient (flat) and inefficient (steep) search.

Our goal in the present study was to examine the effects of auditory distractors on selective attention abilities in university students with and without ASD as measured using a visual search paradigm. We sought to answer the following questions: 1) Do auditory distractors effect students' performance on a visual search task and does the type of distractor have differing effects? 2) Does the presence of auditory distractors have a greater impact on individuals with ASD compared to their TD peers, and is this effect dependent on the nature of the distractor?

Given that individuals with ASD tend to excel at search (Kaldy et al., 2013), evidence of impaired performance in the presence of noise in this domain would be particularly compelling. We predicted that individuals with ASD would exhibit faster, more efficient search in the absence of distracting noise (i.e., quiet condition) similar to prior reports of accelerated search in ASD (Kaldy et al., 2013). For TD individuals, we hypothesized that social noise (i.e., two people talking) would result in slowed or less efficient search (Keith et al., 2019; Szalma & Hancock, 2011), whereas non-social noise may speed reaction times and increase search efficiency compared to the quiet condition (O'Malley & Poplawsky, 1971; Söderlund et al., 2007). For individuals with ASD, two potential patterns of results could emerge (see Figure 2). First, given that ASD is associated with a preference for non-social compared to social stimuli (Lepistö et al., 2005), individuals with ASD may be slower or less efficient for the non-social condition compared to the quiet condition, but show no difference in performance between social and quiet conditions (Klin, 1991; Korhonen & Werner, 2017; Kuhl et al., 2005), whereas TD individuals demonstrate preference for social stimuli (Vouloumanos et al., 2010; Vouloumanos & Werker, 2007). Alternatively, as previous studies have shown that individuals with ASD have difficulty with filtering out irrelevant information (Teder-Sälejärvi et al., 2005), the ASD group may be equally slowed and less efficient in both noise conditions. By examining the effect of noise on individuals with ASD in the context of an area of strength, we aimed to understand how filtering irrelevant auditory information affects performance so that intervention or accommodations may be developed to limit any cost of auditory distractors in the university classroom environments.

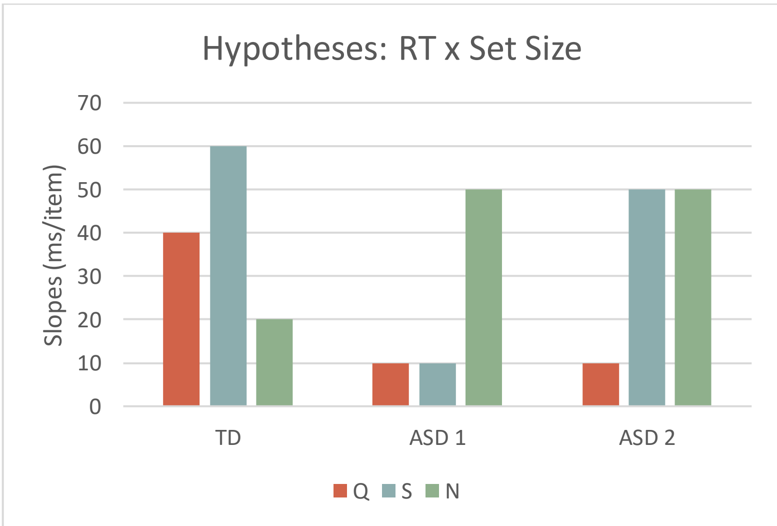

Figure 2: Hypothetical patterns of results for the search efficiency

METHODS

Participants

6 students with ASD and 25 age- and IQ-matched TD students currently enrolled at Purdue University in a STEM major participated in this study. Clinical diagnoses were confirmed using Module 4 of the Autism Diagnostic Observation Schedule, Second Edition (ADOS; Lord et al., 2000) and the Social Responsiveness Scale, Second Edition (Constantino & Gruber, 2012). Participants also completed the Wechsler Abbreviated Scale for Intelligence, Second Edition (WASI-2; Wechsler, 2011). Typically developing participants were required to have no self-reported history of ASD in their first-degree family members and to be free of clinically-significant ASD symptomatology based on the self-report. In accordance with Purdue University Institutional Review Board, informed consent was obtained from all participants prior to their involvement.

Table 1: Participant Characteristics

	ASD	TD	t-value	p-value
N (male:female)	6 (5:1)	25 (14:11)	-	-
Age (years)	19.76 (0.92); 18.99-21.41	20.79 (1.84); 18.57-26.51	-1.33	0.194
Verbal IQ	116 (25.67); 86-160	110 (11.97); 87-131	0.536	0.613
Nonverbal IQ	116 (12.5); 102-138	111 (11.3); 87-135	0.932	0.359

Apparatus

All of the experiments were presented using SR Research Experiment Builder 2.1. This was displayed on a 17-inch LCD monitor. Participants were seated approximately 60 centimeters from the display. In order to register and record manual responses, a Cedrus response pad (RB-740) was used. Auditory stimuli were presented using Sennheiser HD 280 Pro supra-aural headphones.

Stimuli

The procedure and stimuli were similar to those used by Joseph and colleagues (2009). The stimulus array consisted of 60 possible locations, arranged on 5 concentric circles (1.94°, 3.88°, 5.82°, 7.76°, and 9.70°). The target was a "T" and distractors were "Ls", which can be rotated in 1 of 4 cardinal orientations (see Figure 3). At a viewing distance of approximately 60 cm, the size of the target and distractors were 1.0 to 1.2 degrees visual angle (°). The target and distractors were drawn in black and were located on a gray background. Auditory stimuli for social and non-social conditions were played while participants completed the task. For the social condition, participants heard a combined stereo-monotract of two continuous overlapping male and female voices of different fundamental frequencies but equated amplitude, reading random stories. For the non-social condition, participants heard speech-shaped noise created by taking the amplitudes of the speech sounds from the social condition and fitting pink noise within those parameters, matching the amplitude and intensity of the overlapping speech signal. These sounds played continuously at 75 decibels (dB) throughout the social and non-social conditions. For the quiet condition, there was no auditory distractors present.

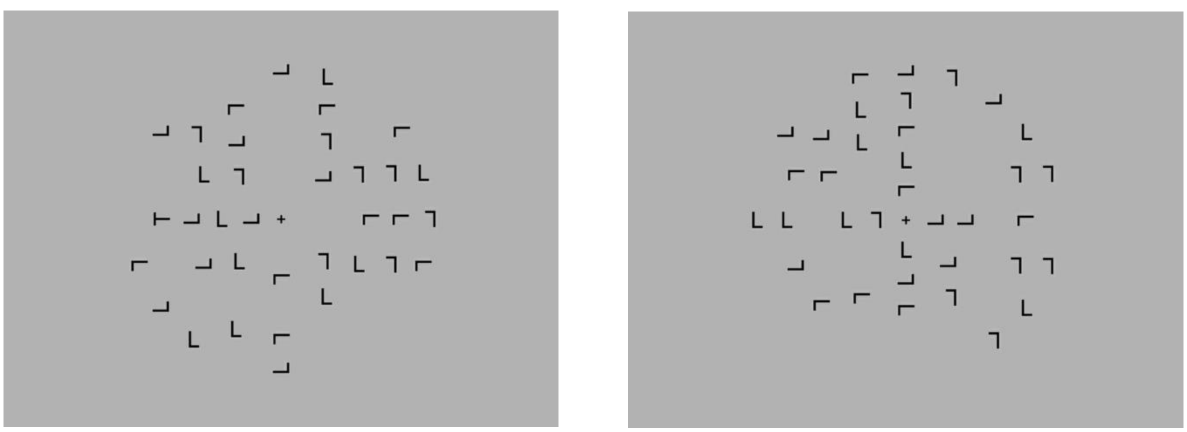

Figure 3: Example of 36-item visual search displays for target present (left) and target absent (right) conditions.

Design

The experiment was divided into three conditions: quiet (no auditory stimuli), social and non-social. The order of the conditions was counterbalanced across participants. Each condition was divided into 3 blocks, each containing 36 trials (108 trials per condition). Within each block, the target was present for 50% of the trials, and the target presence as well as the set size (18, 27, 36) were varied in a pseudorandom order. For both the social and non-social conditions, the auditory stimulus was presented for five seconds prior to the onset of each block.

Each trial began with a fixation crosshair ("+") presented alone in the center of the display for 1000 ms. Then, with the fixation cross remaining on the screen, the search array appeared until the participant responded or until 7000 ms had elapsed. Participants used their dominant hand to respond via a response box on which one button represented that the target was present and the other that the target was absent. Before beginning the task, the examiner provided instructions, including directions to ignore the sounds and to respond as quickly as possible without making errors, after which participants completed a practice block of 12 trials.

RESULTS

Median reaction times (RT; for correct trials) and the percentage of correct responses were entered into a mixed-model repeated-measures analysis of variance (ANOVA) with within-subject factors of noise (quiet, social, non-social), target presence (absent, present), and set size (18, 27, 36) and between-subject factor of group (ASD, TD). A separate repeated-measures ANOVA with within-subject factors of noise (quiet, social, non-social) and target presence (absent, present), and between-subject factor of group (ASD, TD) was used to examine RT x set size slopes. The data was analyzed using SPSS statistics 26 for Windows.

Reaction Time

Median RT was evaluated in order to reduce the impact of potential outliers. Only reaction times from correct responses were analyzed. As expected, based on prior visual search research, tests of within-subject measures on RT had a significant main effect of target presence, $F(1, 29) = 89.995$, $p < 0.001$, and set size, $F(2, 58) = 130.625$, $p < 0.001$. Participants were slower in the target absent compared to the present conditions, and were slowed in larger compared to smaller set sizes. Additionally, there was a significant interaction between target presence and set size, $F(2, 58) = 46.993$, $p < 0.001$, as increasing set size slowed RT significantly more in target absent trials. There was no significant main effect on RT for the noise conditions, $F(2, 58) = 0.216$, $p = 0.806$, nor was there a significant main effect of group on RT, $F(1, 29) = 0.208$, $p = 0.652$. However, there was marginal significant interaction between group and the noise condition, $F(2, 58) = 2.840$, $p = 0.067$**.** Group did not interact significantly with any other condition (all p-values > 0.160).

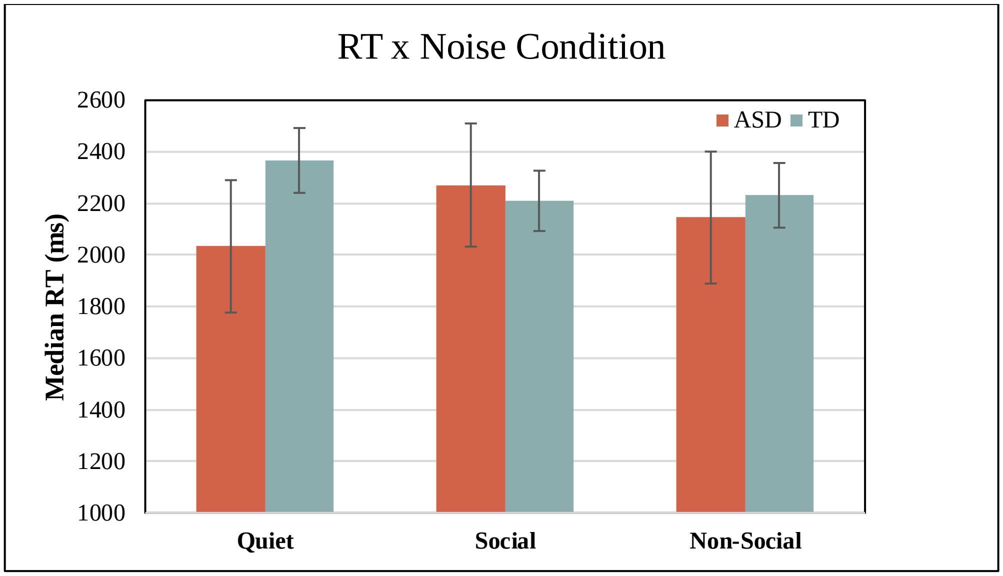

Figure 4: Median RT x noise condition

Independent-samples t-tests were used to further analyze the interaction between group and the noise condition. There were no significant group differences for quiet, t(29) = -1.257, p = 0.219, social, t(29) = -0.064, p = 0.949, or non-social sounds, t(29) = -0.112, p = 0.911. Additionally, paired-sample t-tests were conducted to compare RT from the noise conditions with the quiet condition. Although numerically the TD group demonstrated slightly faster RT in the noise conditions, there was not a significant effect of noise on reaction time for either quiet vs. social, t(24) = 1.837, p = 0.079, or quiet vs. non-social comparison, t(24) = 1.493, p = 0.148. In contrast the ASD group demonstrated slower RTs in the noise conditions; however, there was no significant effect of noise on reaction time for quiet vs. social, t(5) = -1.694, p = 0.151, or quiet vs. non-social comparisons, t(5) = -1.338, p = 0.239).

Finally, difference scores were used to examine how noise affected search performance between groups. Difference scores were calculated by subtracting median RT of each of the noise conditions from the quiet condition (quiet – social and quiet – non-social). These were then entered as within-subject factors into an ANOVA with between-subject factor group. There was not a significant main effect of noise type, $F(1, 29) = 0.172$, $p = 0.682$, and no significant interaction between group and noise type, $F(1, 29) = 0.010$, $p = 0.921$. However, there was a main effect of group, $F(1, 29) = 6.936$, $p = 0.013$, as the ASD group had significantly larger difference scores. Post-hoc independent-samples t-tests showed that there was a significant difference between group for social, t(29) = -2.051, p = 0.049, and non-social, t(29) = -2.165, p = 0.039, difference scores.

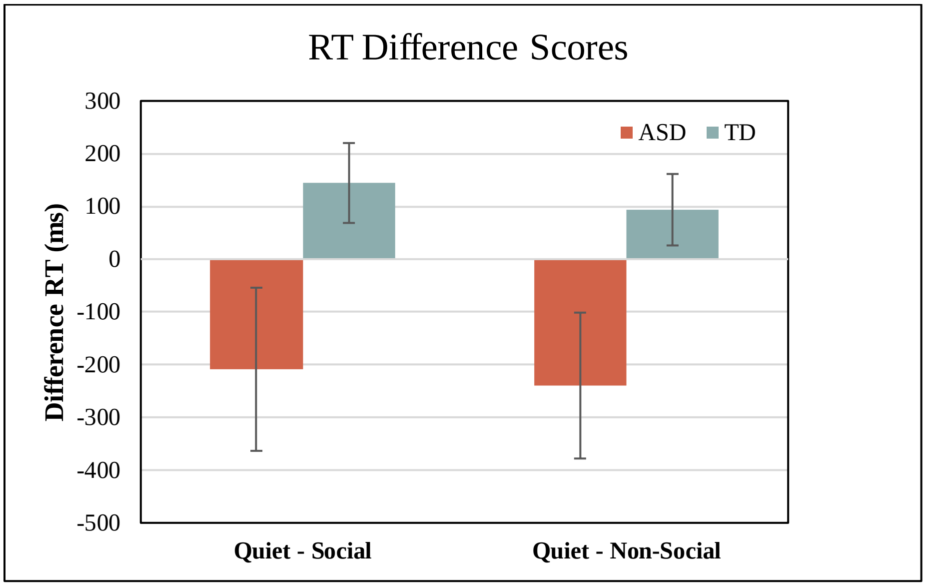

Figure 5: RT difference scores

Accuracy

The percent of correct responses was analyzed for each condition and set size. There was a significant main effect of target presence, $F(1, 29) = 8.878$, $p = 0.006$, set size, $F(2, 58) = 7.621$, $p = 0.001$, and noise condition, $F(2, 58) = 6.217$, $p = 0.004$. As expected, participants were less accurate in target present (92.2 %) compared to absent (97.7 %) trials and in increased set sizes (18 = 96.1%; 27 = 95.6%, 36 = 93.2%). The participants demonstrated less accurate performance in the non-social condition (93.2%) and compared to the social (96.0%) and quiet conditions (95.7%). There was no main effect of group on accuracy, $F(1, 29) = 0.177$, $p = 0.677$; however, there was a significant interaction between noise condition and group, $F(2, 58) = 4.479$, $p = 0.016$, as the ASD group demonstrated a non-significant increase in accuracy in the quiet condition compared to the TD group (ASD: 96.9%, TD: 94.5%; t(29) = 1.790, $p = 0.084$) and the social condition (ASD: 96.9%, TD: 95.0%; t(29) = 1.178, $p = 0.248$) compared to the TD group; however, the ASD group showed a decrease in accuracy for the non-social condition (ASD: 92.0%, TD: 94.2%; , t(29) = -1.030, $p = 0.312$). Group did not interact significantly with any other condition (all p-values > 0.214).

Table 2: Accuracy for ASD and TD groups across noise conditions

Accuracy: Group * Noise Condition

Group	Quiet	Social	Non-Social
ASD	0.969 (0.030)	0.969 (0.038)	0.920 (0.043)
TD	0.945 (0.029)	0.950 (0.034)	0.944 (0.053)

Paired-sample t-tests were also conducted to compare accuracy from the noise conditions with the quiet condition for each group. The TD group showed no difference in accuracy for either quiet vs. social, t(24) = -1.098, $p = 0.283$, or quiet vs. non-social comparison, t(24) = 0.175, $p = 0.863$. Likewise, the ASD group also showed no difference for accuracy for quiet vs. social, t(5) = 0.000, $p = 1.000$, or quiet vs. non-social comparisons, t(5) = 1.850, $p = 0.124$).

Slope

Search efficiency was evaluated through examining the slope of set size by reaction time function. There was a significant main effect of target presence, $F(1, 29) = 54.251$, $p < 0.001$, with participants demonstrating less efficient search in target absent (M = 69.0) compared to present trials (M = 24.2). There was a marginal significant main effect on slope for the noise conditions, $F(2, 58) = 2.793$, $p = 0.069$ (quiet = 45.2; social = 52.5; non-social = 42.0). Paired-sample t-tests for all participants showed no significant differences for quiet vs. social, t(30) = -0.984, $p = 0.333$, quiet vs. non-social comparison, t(30) = 0.716, $p = 0.479$, or social vs. non-social, t(30) = 1.576, $p = 0.126$. There was no significant interaction between group and the noise condition, $F(2, 58) =1.471$, $p = 0.238$, and group did not interact significantly with any other condition (all p-values > 0.158).

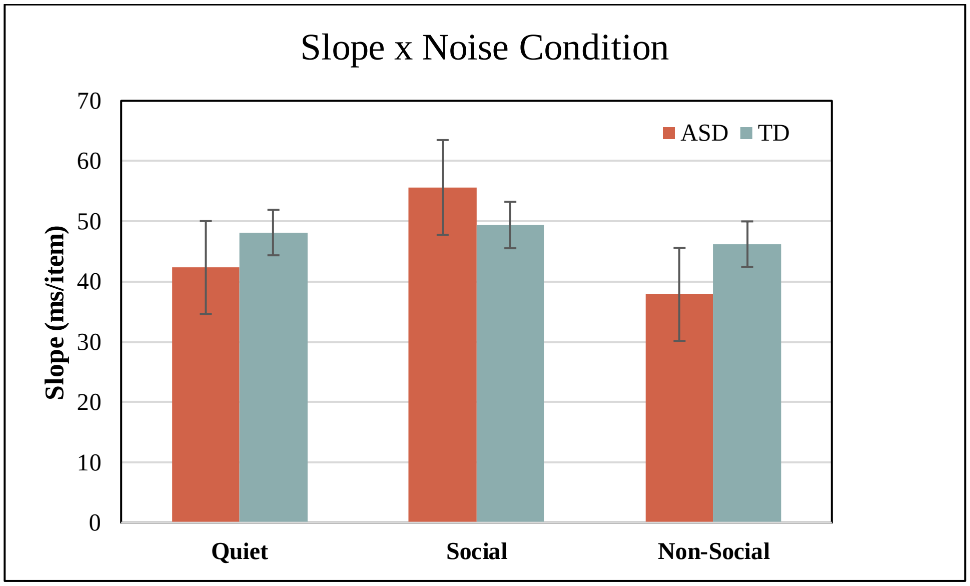

Figure 6: Slope x noise condition

DISCUSSION

The goal of the present study was to investigate the effects of irrelevant auditory distractors on search performance of individuals with and without ASD. We also aimed to evaluate if the type of distractor – social or non-social – had any differing effects on individuals with ASD compared to their TD peers. While the presence of task-irrelevant noise (both social and non-social) did not have a significant effect on RT, accuracy, or search efficiency, TD students were more likely to show faster search for noise (particularly the social condition) compared to quiet conditions. In contrast, the ASD group showed slower, less accurate search in both noise conditions compared to the quiet condition. As such, the ASD group demonstrated significantly larger difference scores compared to the TD group, which is consistent with previous research that suggests that individuals with ASD demonstrate increased difficulty with filtering irrelevant auditory distractors (Keith et al., 2019). Each of these findings will be discussed in turn.

For the TD group, we predicted that social noise would result in slower, less efficient search and that non-social noise may speed RT and increase search efficiency compared to the quiet condition. Our findings did not support these hypotheses. The TD group did not show slower, less efficient search in the social condition as we predicted. This suggests that TD participant were able to successfully filter social stimuli. Although speech has been shown to be more disruptive than non-social auditory distractors in Szalma and Hancock's meta-analysis (2011), they also found that continuous speech noise did not show as significant of a negative impact (compared to intermittent noise) due to quickly developed strategies that act to ignore the auditory distractor for both social and non-social stimuli. Due to the continuous nature of our auditory stimuli, TD participants may have been able to adjust quickly to filter social distractors. Additionally, although the TD group demonstrated slightly faster RTs in the non-social condition compared to the quiet, these did not differ significantly. Thus, while there may have been a slight benefit for non-social noise in enhancing performance as suggested in previous studies (O'Malley & Poplawsky, 1971; Söderlund et al., 2007), our findings suggest that background non-social noise is not necessarily beneficial for students to focus and may have also been filtered similar to the social condition. Together, results may suggest that continuous, task-irrelevant noise may have little effect on the TD group potentially due to effective filtering of extraneous auditory information during a visual task.

We outlined three potential hypotheses for the ASD group. First, based on prior work (Kaldy et al., 2013), we expected students with ASD to be significantly faster at search compared to their TD peers in the quiet condition. Contrary to our hypothesis, the ASD group did not significantly differ from the TD group in the quiet condition, although numerically the ASD group was faster (~300 ms) and more accurate in this condition. Second, we hypothesized that individuals with ASD may be slower or less efficient in the non-social condition compared to quiet but show no difference in the social condition. Or, alternatively, that individuals with ASD may be equally slowed and less efficient in both noise conditions. Our findings support the latter hypothesis – that there is a general deficit in filtering in ASD. Despite research that suggests individuals with ASD do not attend to or show preference for social stimuli (Klin, 1991; Korhonen & Werner, 2017; Lepistö et al., 2005), our findings suggest that participants were slowed by the irrelevant social sounds to a similar extent as the non-social stimuli. The search performance of students with ASD demonstrated a similar negative pattern in both noise conditions, suggesting that the overall presence of noise was more critical than the specific type of noise. Although speech stimuli have demonstrated a greater cost to performance for individuals with ASD some studies, non-social stimuli have also demonstrated a consistent cost in performance as well (Lepistö et al., 2005). Our findings are consistent with studies that demonstrate impaired auditory filtering of irrelevant distractors in general (Keith et al., 2019; Teder-Sälejärvi et al., 2005). The negative impact of this filtering deficit for both types of noise is particularly compelling in a task that individuals with ASD typically excel, as the presence of auditory distractors resulted in significantly greater costs to their performance compared to their TD peers.

Together, these results suggest compared to their TD peers, students with ASD have greater difficulty filtering task-irrelevant auditory information. Research has consistently demonstrated individuals with ASD show difficulty ignoring behaviorally-irrelevant distractors, including both visual and auditory information (Adams & Jarrold, 2012; Keehn, Westerfield, & Townsend, 2019; Keith, Jamieson, & Bennetto, 2019; Murphy, Foxe, Peters, & Molholm, 2014; Ohta et al., 2012). For example, Keith and colleagues (2019) found that background noise added a significant stressor for individuals with ASD. Additionally, other studies have found improvement of performance or lessening of restricted and repetitive behaviors when background noise is reduced (Kanakri, Shepley, Tassinary, et al., 2017; van der Kruk et al., 2017). This research suggests that individuals with ASD demonstrate difficulty filtering in a variety of settings and situations and that this difficulty negatively impacts their performance or completion of a task.

Another potential explanation for the negative impact of auditory distractors during search may be related to enhanced perceptual capacity in ASD (Joseph et al., 2009; Remington et al., 2009; Tillmann et al., 2015). According to the perceptual load theory (Lavie, 1995, 2005), individuals with a larger perceptual capacity will be able to process more stimuli before reaching capacity, and, therefore, will be more likely to process task-irrelevant information. Thus, for individuals with ASD – who may have larger perceptual capacity – task-irrelevant auditory information may have been more likely to be processed, including to-be-ignored input that is not relevant to the given task (Joseph et al., 2009; Remington & Fairnie, 2017; Remington et al., 2009; Tillmann et al., 2015; Tillmann & Swettenham, 2017). While this increased capacity has the potential to result in certain advantages, for example enhanced visual search abilities (Remington et al., 2009), it may also contribute to greater distraction. For the present task, while individuals with ASD were faster than their TD peers in the quiet condition, larger capacities (which could have contributed to faster search), may have also resulted in greater processing of task-irrelevant noises, and slower search in the noise conditions.

Beyond the visual search performance, a filtering deficit may have a negative impact in a number of natural environments, such as classrooms and workplaces. These settings include extraneous noise such as conversations and ambient noise. However, if an individual has a filtering impairment (or larger perceptual capacity), these individuals may be more likely to process these distractors, potentially leading to a poorer performance. For example, for a student with a filtering deficit, completing an assignment in a classroom while other students' voices and other classroom noise are in the background may be more difficult compared to their peers due to processing of the irrelevant noise (Keith et al., 2019). For students with ASD, this presents an added challenge to successful participation in these settings. This filtering deficit may help explain the significant discrepancies noted between intellectual ability and the academic performance across different subject areas for students with ASD (Jones et al., 2009; Keen, Webster, & Ridley, 2016). For example, as rated by educators, over half of children with ASD in a sample were reported as under-achieving academically and demonstrated difficulty in maintaining attention in class (Ashburner et al., 2010). Additionally, McDougal and colleagues (2020) analyzed attentional measures and classroom achievement and found a correlation between divided/distracted attention and math achievement for all students, with an increased negative impact of correlation for students with ASD as more students in this group demonstrated significantly lower scores on this measure of attention. Therefore, this suggests inhibition of auditory distractors is essential for successful educational outcomes and highlights the need to better understand the role of attentional impairments in ASD.

Clinical Implications

Impaired auditory filtering demonstrated in the present study may have important clinical implications. Accommodations could be implemented to create accessible auditory environments for individuals with ASD. Multiple studies investigating classroom environments have suggested the installation of sound absorbing walls leads to improved inhibition and auditory over-sensitivity for individuals with ASD (Kanakri, Shepley, Varni, et al., 2017; Kinnealey et al., 2012; Piller & Pfeiffer, 2016; Saggers & Ashburner, 2019). Additionally, sound-field amplification (SFA), a system that amplifies the instructor’s voice above the ambient noise in the room for all students no matter where the teacher or students are in the classroom (Rosenberg et al., 1999), has also been shown to benefit individuals with and without ASD by reducing auditory listening stress in the classroom (Rance et al., 2017; Schafer et al., 2016; van der Kruk et al., 2017). Saggers and Ashburner (2019) also suggest strategic use of the classroom space to reduce noise on communication situations. All of these modifications to the environment allow for reduced competition between irrelevant sounds and task-relevant auditory information and could be implemented in a variety of educational and occupational settings.

Limitations

Overall interpretation of our results is limited due to our small sample size of individuals with ASD. Due to the COVID-19 pandemic, participant recruitment was halted to ensure the health and safety of all involved. Additionally, the individuals with ASD who participated in our study were high-functioning individuals. Therefore, our findings may not be generalizable to all individuals on the spectrum.

CONCLUSION

Although our findings should be interpreted cautiously due to the small sample size, they are consistent with previous research suggesting a filtering deficit for individuals with ASD. Furthermore, the present study demonstrates that these filtering impairments are present for both social and non-social information. Importantly, these deficits are present on a task on which individuals with ASD excel. Our results indicate that college-aged students with high-functioning ASD demonstrate a negative impact to performance with the addition of irrelevant social and non-social auditory distractors. Due to the high prevalence of irrelevant auditory distractors in the classroom, these deficits may present additional barriers to successfully participating in the classroom. Therefore, it may be critical to evaluate the auditory environments students are working in at the post-secondary level to create a more accessible environment for students.

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