Müller-Lyer Illusion susceptibility is conditionally predicted by autistic trait expression

By

Ganesh Tailor

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Abstract

The Müller-Lyer Illusion (ML) is a visual illusion that biases size estimation. Illusory bias can be assessed using a variety of methods that may lead to different degrees of bias. There is also some evidence autistic individuals are less likely than neurotypicals to perceive illusory biases that rely on environmental experience. Varying levels of autistic trait expression have also been proposed to modulate susceptibility to illusions. The Autism Quotient (AQ) and Systemizing Quotient (SQ) are self-report measures that quantify autistic trait expression and systemizing ability in neurotypicals. The current study aimed to determine if perceptions of illusory size bias negatively correlate with autistic trait expression and the extent to which varying methods of illusion presentation change the magnitude of illusory bias. Thirty neurotypical adults completed both questionnaires as well as four size estimation tasks. Tasks 1 and 2 involved perceptual discrimination of ML figures by concurrent and successive presentation, where participants selected the longer figure by button press. In Task 3 participants adjusted the size of a non-illusory line to match its size to an illusory target ML figure. For Task 4 participants adjusted a composite ML figure to match its size to the target ML figure. Overall, task performance was not correlated with autistic trait expression. The one exception was a positive correlation with AQ when adjusting a composite illusory ML figure in Task 4. There was a stronger bias found in the concurrent figure presentation (Task 1) and composite figure adjustments (Task 4) when compared to the successive presentation used in Task 2 and the non-illusory adjustment in Task 3. Given these results, illusion susceptibility to the ML is suggested to be reduced with increases in AQ, but only when the method of illusion measurement is adjustment of concurrent illusory figures. Taken together the results provide evidence that traits associated with autism in a neurotypical population may systematically modulate perception.

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Table of Contents

List of Tables

List of Figures

Müller-Lyer Illusion susceptibility is conditionally predicted by autistic trait expression

Humans estimate the size of objects for many daily activities. Before deciding which drink cup-size to order for a fast-food combo, an estimate is made regarding how big the cup-sizes are that hang from the wall, for example. This usually straightforward process of magnitude estimation becomes challenged when perceiving visuospatial illusions. Visuospatial illusions impact our ability to discriminate between the actual size of an object compared to our perception of its size. The discrepancies experienced are suggested to be based on how visual information is received in the present context as compared to past experience with objects. The ML illusion is one such visuospatial illusion where our visual and conscious perception of the object's size contradicts its veridical size. The unique biases in perception of the ML illusion make it an appropriate experimental tool for studying interpretations of visual stimuli.

Gibson (1986) introduced the concept of object "affordances" which are the variety of actions that may be executed upon a certain object based on both its physical qualities and the ability of a specific perceiver. According to Gibson (1986), perception of an object is suggested to imply a set of affordances of that object based on the perceiver and their immediate action goals. The perceiver may then choose a behaviour that is aligned with their action goals and the perceived object's affordances. However, an object's affordances may change when visual illusions alter perception of that object with illusory affordances resulting in inappropriate actions by the perceiver as the affordances are based on biased interpretations of the stimuli (Greif, 2019).

Although our visual perception of an object's size may be inconsistent with its veridical size, evidence suggests that this inconsistency may only be partly true and not present in all contexts. The two visual-streams hypothesis (Goodale & Milner, 1992a) posits the existence of two neural pathways responsible for visual processing: vision for perception and vision for action.

The ventral, or vision-for-perception stream is responsible for object identification and identification of visual stimuli's relative spatial characteristics, as well as subsequent conscious response towards a visual illusion. Nonconscious visual processing for the control of goal-directed actions is a function of the dorsal, or vision for action stream (Milner & Goodale, 2008). These two streams cooperate to allow for accurate interpretation of the affordances available by objects (Milner & Goodale, 2008). The two visual-streams hypothesis helps explain the phenomenon where an object's size may consciously be misjudged upon perception, whereas an accurate judgement of that object's size is determined when an action towards the object is produced (Aglioti et al., 1995; Marotta et al., 1998). However, apparent immunity to illusory bias via action, as suggested by the two-visual streams hypothesis, is not without its criticisms.

The two visual-streams hypothesis has been challenged by subsequent work finding action to be susceptible to visual illusions. Franz et al. (2000) suggested methodological differences in the illusory figures' presentations explained why action had lacked a susceptibility towards visual illusions. The authors showed superior accuracy via action is diminished when the methods for comparing visual illusion effects on perception and action were controlled for. These authors report identical illusion susceptibility regardless of whether it is perceived or acted upon when the methods for perception and action experiments are kept constant. These contrary results, however, remain contested in the literature (see Milner & Goodale, 2008 for a review). Thus, understanding perception and its interaction with action requires investigation into the mechanisms underlying perception.

Conscious perception may not always be accurate when estimating the size of an object. Objects appear to reduce in size as they move farther away, for example. Visual illusions compound the issues surrounding size estimation and create larger inaccuracies in visual judgement. Determining the size of an object in space as it appears to the observer is termed magnitude estimation of size and can be used to estimate interdependence between vision and proprioception (Gilinsky, 1951). Vision and proprioception are integrated to facilitate actions involving magnitude estimation tasks (Petzschner et al., 2015), and their input is utilized to make the most accurate size estimate (Sarlegna & Sainburg, 2009). Proprioception is involved in perception and can complement vision to give a more complete sensory picture of the world around us. For example, when vision is removed during a reaching movement authors report that on-line control throughout the movement was still evident (Glover & Dixon, 2001). Glover and Dixon (2002) posit the absence of vision provides evidence for the existence of contributions from proprioception and efferent motor plans during movement execution. Thus, their planning-control model suggests a combination of vision, proprioception, and efferent motor plans allow for veridical movement to visuospatial illusions through informing on-line adjustments to the limb movement. Specifically, the planning-control model posits two stages of visuomotor control. The planning stage consists of a motor plan based on a visual representation that is context-dependent. In this stage, surrounding and background stimuli are included in the representation of this plan. Subsequent to the planning stage is the on-line control stage. The control module within this stage acquires a separate visual representation that is context-independent – the surroundings are ignored and only the spatial elements of the target stimuli are considered. Upon initial movement following perception of a stimulus, the visual representation of the planning module is gradually reduced in its relative contribution to the movement. Instead, the control module begins to take over the movement, utilizing its own visual representation, as well as an amalgamation of both proprioceptive feedback, and efferent motor plans. Together, movements can be updated based on more accurate estimations than the context-dependent planning module would have produced in isolation.

The two visual-streams model seeks to explain action's immunity to illusions as an innate feature of the dorsal stream, but this model does not explain the phenomenon of dynamic illusion effects where the illusory stimuli affect action to a greater extent during the early-stage, relative to late-stage movement (Glover & Dixon, 2002). The dynamic illusion effect can, however, be explained by the planning-control model where the planning stage incorporates context and thus falls susceptible to the illusion, but then is corrected by the on-line control module that is context-independent. Another explanation suggests a combination of the planning-control model and the two visual-streams model. The gradual trade-off between the stages of action proposed by Glover and Dixon leaves early movement to rely on a ventral stream produced visual representation used by the planning module and the late movement to rely on a dorsal stream produced on-line control module.

Accurate perception of illusions is also suggested to be modulated by autism. Researchers studying autism spectrum disorder (ASD) found evidence to suggest both those with ASD and non-clinical neurotypicals with higher autistic trait expression have a reduced ability to integrate sensory information from multiple modalities (van Laarhoven et al., 2019). Further, accuracy in estimates of visually perceived object size positively correlate with increases in the expression of autistic traits (Chouinard et al., 2013; Walter et al., 2009). Weak central coherence theory and local global processing may help explain these findings. Central coherence involves processing information for its higher-level meaning while sacrificing details. Alternatively, weak central coherence implies global processing by individuals with autism has less affinity to gestalt visual stimuli and they instead tend to perceive local elements separately – outside of their context

(Chouinard et al., 2013). Perception outside of an illusion's context would allow veridical perception of otherwise illusory stimuli. Alternatively, a Bayesian predictive coding perspective is also a consistent explanation for reduced illusion susceptibility in autistic individuals. Bayesian predictive coding (Friston et al., 2013; Pellicano & Burr, 2012) suggests when interpreting perception there is a weighting of previously acquired sensory data against presently acquired information. The weighting of the two factors results in an output of a "most likely" interpretation by the perceiver. In ASD, there is an inherently reduced weighting of the previous information factor, thus leading to an over-reliance on the present. The different weighting reduces contextual elements that may increase certain visual illusion susceptibility in typically developing populations.

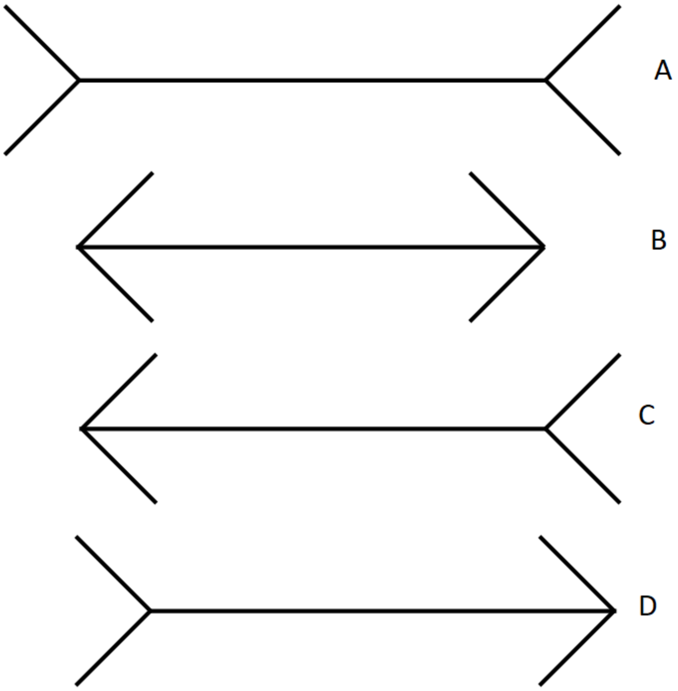


Figure 1: Four configurations of ML. (a) wings outwards; (b) wings inward; (c) wings right; (d) wings left.

The ML is one illusion where the perspectives of local element processing and weak central coherence theory have been raised as explanations for reduced susceptibility by autistic traits to visual illusions (Chouinard et al., 2013). The ML appears with a central line featuring two sets of "wings" or arrow heads on either end. The vertices of the wings heads are invariable, but the wings are either inward or outward (Pressey, 1967). Four configurations of the ML can be made (see *Figure 1*): both wings outwards (*A*), both wings inwards (*B*), both wings right (*C*), and both wings left (*D*). The illusion manipulates perception such that the central shaft of the figure to be longer when the wings are outwards, and shorter when the wings are inwards. The same direction configurations tend to induce a perception of positional shifting of the figure in the opposite direction of the wings (Glazebrook et al., 2005). Explanations for the effects of the ML are not conclusive, but the perception of a shorter or longer shaft may result from viewing the figure elements relative to the whole figure (Pressey, 1967), or interpreting the linear geometric elements of the figure as perspective-shifting depth cues (Gregory, 1963). Both the relative size explanation and the depth-perspective explanation suggest a central coherence effect that relies on global processing to cause the biased perception. Weak central coherence would thus produce a perception reliant on local processing. In the case of the ML, local element processing would separate the illusory stimuli and result in a veridical size estimation of the central shaft.

Given the suggested weak central coherence effect, the ML illusion has been used to determine correlations in autistic trait expression and perceptual magnitude estimation accuracy (Chouinard et al., 2013; Walter et al., 2009). The rubber-hand illusion uses visual and proprioceptive modality integration to associate a rubber-hand with a subject's actual hand. The literature has shown a reduced sensitivity to the rubber-hand illusion in reach-to-grasp movements for individuals displaying higher autistic traits, relative to those displaying lower traits (Palmer et al., 2015). That said, investigations into how different methods of comparison change illusion susceptibility have not yet been conducted using the ML in the context of varying autistic traits. Thus the present study used the non-diagnostic validated self-report measure of Adult-Autism Quotient (AQ) (Baron-Cohen et al., 2001; Walter et al., 2009) and the Systemizing Quotient (SQ) (Baron-Cohen et al., 2003; Groen et al., 2015) to create a spectrum of varying degrees of autistic traits expressed by typically developing adults. The research question in the present study was whether AQ and SQ (levels of autism trait expression) can predict perceptual susceptibility towards visuospatial illusions. The AQ has previously been found to negatively correlate with perceptual susceptibility to the ML (Chouinard et al., 2013). This effect, however, is contested in the literature (Chouinard et al., 2016; Walter et al., 2009) and has yet to be investigated with varying illusion measurement methods. Further, fewer similar comparisons and correlations have been studied in the context of relations to the SQ (Walter et al., 2009). An investigation of ML susceptibility and its correlation to the AQ and SQ, found with varying methods of illusion measurement will contribute to our understanding of the effect that behavioural traits have on modulating perception under varying task conditions.

The current thesis determines whether perceptual size estimation of illusions correlates with autistic trait expression as described by the AQ and SQ. Varying methods of illusion measurement were also compared with correlations across AQ and SQ in order to understand how individual and task characteristics may relate to one another. These investigations into autistic trait expression and methods of illusion measurement clarify the extent to which behavioural traits modulate perception and emphasize the conditionality of those effects as functions of how the stimuli are presented.

Review of Literature

How much uncooked spaghetti do I need to boil (in salt-seasoned water!) to make a meal for four? Before we can answer that question, we need to define magnitude estimation. Here, I will define magnitude estimation as the interpretation of some physical magnitude a stimulus possesses. An estimated magnitude can take several forms, whether those be of force, brightness, loudness, or in the present case: size (Petzschner et al., 2015). Estimating size is a quotidian task, yet, producing an accurate grip to reflect that estimation requires a plethora of processes – and those same processes become biased when presented with an illusion. Consider monocular depth cues when an image moves farther away. The image's retinal projection becomes smaller. Size constancy – understanding stimuli will maintain their veridical size regardless of changes in their retinal projection – is used to make sense of how the image appears smaller but is instead simply farther away (Leibowitz et al., 1969). So then, what happens when an illusion mimics the monocular depth cue of an object being farther away? Leibowitz et al. (1969) claim humans incorrectly interpret the image as being farther away. Thus, size constancy is not preserved and the image is interpreted as being physically smaller and having literally shrunk.

The environment plays a role in our perception. Consider someone who has never seen a rabbit. Presenting them with an image that features the embedded outline of a rabbit and asking them what they see would likely lead to any response other than "a rabbit". In a similar way, the ML in a vertical orientation mimics the appearance of the inside or outside of a cubic structure. Metropolitan and industrialized communities tend to feature many cubic structures – you are probably in one right now! However, presenting the ML to peoples who have rarely, if ever, seen a cubic structure results in immunity to the illusion (Pedersen & Wheeler, 1983). Illusion effects are contingent on experiences and individual circumstances. Though, illusory effects may not be so consistent when acting on illusions.

A variety of explanations have been offered to understand how actions are affected by illusions. Visual models such as perception-action (Goodale & Milner, 1992a), as well as planning-control model (Glover, 2002), seek to identify how visual perception and subsequent actions are executed. Relative to perception, action is sometimes purported to be immune to illusory effects (Goodale & Milner, 1992a), but other times shown not to be (Franz et al., 2000), and still other times shown to be affected only at certain points (Glover & Dixon, 2001). Further, differing methods of illusion measurement have produced varied levels of illusory bias (Coren & Girgus, 1972; Foster & Franz, 2014). A recent Bayesian predictive coding model relates the previously discussed perception and experience connection to explain movement to illusions. That is, the Bayesian predictive coding model considers past and present experience to be weighted in real-time to produce a representation of reality (Palmer et al., 2015). The relative weights of past and present experience have also been shown to be different in distinct populations. Heavier weighting of present experience is noticed in those on the autism spectrum, relative to those who are not (Palmer et al., 2013), however, higher autistic trait expression seems to have a similar relative weighting of experience as to those on the spectrum (Chouinard et al., 2013). Past experience of cubic structures may play a minor role in the perception of the ML (Segall et al., 1963) to those expressing higher levels of autistic traits, relative to those expressing lower traits.

Back to our original question: how much uncooked spaghetti do I need? The answer is of course unique from person-to-person (and how hungry they are). The raw spaghetti being held in a bunch appears much smaller than the cooked result. The basic idea of Bayesian predictive coding is to consider how big of a handful you had in the past and how much you have in your grasp now and then determining the appropriate amount of spaghetti. What follows is an in-depth investigation of the discussed topics of illusions, perception, and autistic trait expression. The literature review will feature samples of relevant experimental evidence and subsequent extrapolations that will aid in understanding perception and illusory bias modulation by autistic trait expression.

Magnitude Estimation

Interacting with the physical world requires estimated representations of size, brightness, loudness, and other phenomena to be made quickly in the cortex based on input by sensory modalities. Visual perception provides crucial information that can be used to develop estimations about magnitudes in one's surroundings but those perceptions may not always be veridical (de Wit et al., 2015; Milner & Goodale, 2008). Perceptions of length and depth become less accurate with increases in viewing distance (Norman et al., 1996). As an object moves farther away from an observer, that object reduces in perceived size, and vice versa. Further, perceivers arbitrarily select a certain distance as the distance at which the "true size" of an object exists. All other perceptual sizes of that object are then interpreted as a relative size to its true size (Gilinsky, 1951). Gilinsky (1951) presents a mathematical representation of this idea in the form of two equations. The first of the equations describes the relationship between subjective distance and objective distance:

$$\frac{d}{D} = \frac{A}{A + D}$$

Where d = the perceived or subjective distance by an observer, D = the true physical or objective distance (as could be measured), and A = the psychophysiological limit of perceived distance by an observer. Thus, a larger A approaching infinity would trend towards $d = D$, achieving perfect size constancy. Limits of observers are, however, finite and binocular depth cues relating to parallax are limited by retinal angle of the eyes. Further, the monocular depth cue of accommodation (i.e., focusing on objects at distances) cannot account for a giant *D*. Given this limitation, when *D* = infinity, *A* must be equal to *d*. The value of *d* is contingent on *A*, which modulates *d* across varying values of *D*. For example, when perceiving an object that is 100m away (*D* = 100m), though binocular parallax would be relatively intact, the perceived distance of that object (*d*) would be reduced as a function of *A*. Here, *A* would be increased or decreased depending on the availability or lack of depth cues, respectively. Assume that *A* = 100m given the attenuated availability of depth cues at *D* = 100m, then the equation would output *d* = 50m.

The second equation provided describes the relationship between subjective size and physical distance:

$$\frac{s}{S} = \frac{A + \delta}{A + D}$$

Where *s* = the perceived or subjective size by an observer, *S* = the subjective true size at a normal viewing distance for an observer, and δ = the arbitrary distance at which a specific object is normally viewed by an observer. Thus, *s* = *S* when *D* = δ. If δ is assumed to be 2m (δ = 2m), then with *A* = 100m and *D* = 10m, an object's *s* would be closer to *S* and size constancy would be more preserved (*s*/*S* = 0.9). In comparison, the same δ with *A* = 100m and a *D* = 100m would cause the perceived size to appear much smaller than its "true size" (*s*/*S* = 0.5).

Gilinsky (1951) provided experimental evidence supporting the two equations. In one experiment, a participant directed the experimenter who was holding a stick to walk away at a constant velocity and cued the experimenter to mark distance intervals that the participant perceived as equal successive increments *d* = 1m. The experiment found that the increments *d* increased at a rate that was consistent with Equation 1. The resulting perceived distance intervals

d were found to be proportional to an A = 28.5m, where each interval of d = 1m decreased at an increasing rate with linearly increasing D = 1m. This experiment showed that subjective distance becomes increasingly less accurate as objective distance increases. In a similar experiment from the same study, a disk was set 10ft away from an observer (δ = 10ft) while a comparison disk was systematically moved further at increments D = 10ft up to 120ft. With each increment, the comparison disk was increased in physical size so that its subjective size s was equal to the size of the standard disk at distance δ ($s = S$). As physical distance D increased, the slope of subjective size s decreased. Binocular and monocular vision were both employed, and it was found that (for a specific observer, with their δ = 10ft) A = 243ft with binocular vision, whereas A = 132ft with monocular vision. Thus, a decreased availability of depth cues causes a decrease in the magnitude of A. As A remains constant across all values of D, then a higher A is proportional to accurate size estimation. In other words, depth cues modulate the ability to produce accurate size estimates of objects.

Accurately estimating the size of a stimuli can be accomplished by various methods. Aglioti et al. (1995) mixed a perceptual task with an action task to investigate size discrimination in visual illusions. Magnitude estimation by action was measured with maximum grip aperture when initiating a grasp to the inside circle within an Ebbinghaus illusion (see p. 20 for an explanation of the illusion). The maximum grip aperture in a goal-directed reaching movement has been shown to occur at ~70% of movement time and is proportional to the size of the target object (Jakobson & Goodale, 1991; Jeannerod, 1984). Magnitude estimation in the study by Aglioti et al. (1995) was also required to discriminate the two figures as being equally or unequally sized. Participants were instructed to grasp the left figure if they believed the inner circles were the same size, and the right figure if they believed them different (instructions were reversed halfway through). The method of adjustment has been used to measure size estimation in animals (Tudusciuc & Nieder, 2010) and humans (Franz et al., 2000; Pressey, 1977).

Comparator stimuli can be adjusted by the participant with the goal of making the comparator stimuli match in a specified parameter (i.e., size) to the target stimuli (Coren & Girgus, 1972). Rating scale methods allow participants to indicate, verbally or otherwise, a label that describes the figures characteristics. A rating scale method can be used in conjunction with a comparator stimulus that is non-adjustable. That is, the participant is given an array of ratings from which they may choose one to apply to the comparison stimulus, relative to the target stimulus. For example, a ML figure may be presented initially and be followed by a comparison line of similar size. The participant's task in Glazebrook et al. (2005) was to rate the comparison line as being shorter, longer, or the same size as the previously displayed target ML figure. The rating scale method allows a participant to offer quick and discrete responses.

Estimating size can also be accomplished with manual estimation. Manual estimation involves producing grip apertures with the index finger and thumb. The participant represents their perceived estimated size of a presented stimulus by indicating a distance between their index finger and thumb (Haffenden & Goodale, 1998; Heath et al., 2011). Manual estimations of size were found to be nearly identical to actual widths at multiple sizes when produced to indicate the size of a three dimensional (3D) cube (Bruno & Franz, 2009b). Importantly, although manual estimations of grip aperture involve movement, these pantomimed actions have been shown to use perceptual information in their production (Goodale et al., 1994) and have been used as a measure of graspable perceived object length (Franz et al., 2001; Heath & Manzone, 2017; Holmes & Heath, 2013). Additionally, as maximum grip aperture is only proportional and not equal to object sizes, differences between maximum grip aperture and manual estimation cannot immediately be directly compared. M. T. Dewar and Carey (2006) developed an equation to correct for both methods of magnitude estimation and allow for comparisons to be made. Comparing magnitudes between maximum grip aperture and manual estimation can provide insight into how the different mechanisms of illusory size estimation between action and perception operate.

Grasping an object allows for an interpretation of that object's size relative to the grasping hand. Gilinsky (1951) claims that humans can never realize the true size of an object. Humans can, however, use strategies to produce a relative understanding of object size (Wagner, 1985). Magnitude estimation requires that an observer perceives physical parameters of an object as it is projected onto their retina and subsequently transforms that projection using visual or proprioceptive cues to compensate for a distance where the object is some other size than their subjective true size (Norman et al., 1996). Strategies that transform objects and account for variables such as distance are useful in normal, non-illusory objects. Visual illusions interfere with the usual strategy's efficacy and can lead to mistakes in magnitude estimation.

Visuospatial illusions are suggested to directly affect the ventral stream and not the dorsal stream. In the affected case, the ventral stream provides an inaccurate interpretation of a perceived stimulus upon which a visuospatial illusion is present. In contrast, the dorsal stream is considered to not be (or be less) susceptible to the perceptual discrepancies that visuospatial illusions create (Westwood & Goodale, 2011). Discrepancies in visual information from illusory objects create errors in judgements of magnitude estimation which may result in misperceptions of size or distance. One approach to understanding how veridical magnitude estimation is achieved is to study flawed magnitude estimation in response to visual illusions. Systematic manipulations in perceptual experiments of visual illusions provide insight into the role of the manipulated mechanisms that produce magnitude estimation. For example, an illusion magnitude estimation task clarifies the role of vision in the task by comparing the results of a restricted vision condition to that of a condition where vision is afforded. It may then be reasonable to assume that stimuli, such as objects and signs, designed to deliver information can instead convey alternate affordances when perceived by populations varying in certain trait expressions. Their specific affordances may lead to misinterpretations of judgements when navigating the world.

Visuospatial Illusions

Experience modulates perception of the physical world. Veridical perception of the physical world is not always possible and visual perception is no exception. There are many visuospatial illusions that give the viewer a false impression of a stimulus' characteristics. Visuospatial illusions are those that produce discrepancies in the spatial elements of a visually perceived stimulus. Although an illusion may result in spatial misjudgements via conscious report, the magnitude of that illusory bias is modulated by the utilized measurement method (Coren & Girgus, 1972). It is thus appropriate for multiple methods of measurement to be used and contrasted when determining biases in illusory size estimation.

Vision is produced by projections of light onto the retina. Humans use binocular vision which allows for depth perception by various binocular cues. Stereopsis through exploitation of parallax using binocular disparity (where elements of an image projected to one eye are slightly different from those onto the other) and eye convergence (where convergence increases as images near) are two binocular methods used to determine depth and distance of stimuli (Gonzalez & Perez, 1998; Qian, 1997). Monocular vision shows reduced accuracy in perception of depth as it lacks conventional binocular cues, however, monocular depth cues exist and are commonly used in two dimensional (2D) drawings to add depth characteristics. These pictorial cues exploit interposition (the perception of a partially covered object as being more distant than the covering object), perspective, and experience with 3D stimuli (Marotta et al., 1998) to give the illusion of depth in 2D stimuli. Gregory (1963) describes the ML as having experience-related and perspective cues when discussing the illusion’s resemblance to the interior and exterior walls of cubic structures. Pictorial cues are not the only way to produce size-constancy visuospatial illusions, but perception relies on those cues when viewing some 2D objects, and so pictorial cue use should be implicated in investigations of perception of visuospatial illusions.

Müller-Lyer Illusion

Explanations of the ML provide insight into the possible mechanisms leading to their perception. Pressey (1967) suggested a central tendency effect wherein repeated size estimations of small magnitudes are overestimated, and large magnitudes are underestimated. The central tendency effect relates to the ML by the assumption that successive presentations are not necessarily required for the effect to occur, but rather that a simultaneous composite presentation of figures (i.e., wings in and wings out) would induce the effect as well. Additionally, it needs to be assumed that estimations are made on the context of the spread produced by the wings, where outward wings lengthen the figure and inward wings shorten it. With these assumptions held, the shaft within an outward wings ML would be the shortest element (when comparing the shaft to the entire figure) and thus the central tendency effect predicts an overestimation of magnitude. Similarly, the wings in ML shaft would be the relatively longest element in the figure and thus would provide an underestimated prediction. Contending this explanation, experiments have found susceptibility to the ML when presented without a complementing figure (Binsted & Elliott, 1999a, 1999b; Elliott & Lee, 1995) and sometimes with a comparison line (Gillam & Chambers, 1985; Glazebrook et al., 2005), thus suggesting an explanation to ML susceptibility need not require an assumption of simultaneous composite figure presentation.

Over- and underestimations of two-dimensional figure elements can also be reasoned in terms of a three-dimensional interpretation of the figure. The perceived size of physical elements when viewed at different distances is maintained even though retinal projections display those elements as being smaller when distal and larger when proximal. The size-constancy explanation (Gregory, 1963) creates a sense of depth by perspective to induce distortions in visual space. Constancy scaling will change perception of a retinal image so that a three-dimensional visual element's size will hold, regardless of changes to its proximity (e.g., A car driving away from an observer will project a progressively smaller retinal image, but interpreted perception of the car's veridical size will not change). Additionally, when monocular depth cues are illustrated in a two-dimensional figure, the perception of that figure is interpreted with three-dimensional parameters. In the same way, inappropriate constancy scaling can be found in the ML where the image is falsely perceived to have depth. That is, a vertically oriented, wings out ML can be perceived as the interior corner of a structure (i.e., a home or other cubic shelter): the vertical shaft being the intersection of two adjacent walls perpendicular to the floor and ceiling, the top wing as the ceiling corner, and the bottom wing as the floor corner – with both wings implied to continue projecting proximally towards the observer. The proximal projection of the wings (analogously, the floor and ceiling if considered in a 3D context) would imply that the central shaft would be further away when considering the entire contextual image. Inappropriate constancy scaling via monocular depth cues would then suggest to the perceiver that the shaft is in fact larger, but it is just further away. Similarly, the wings in ML figure could be perceived as the outside corner of a structure with the wings now projecting distally from the observer (Gregory, 1963). The wings out figure would so imply the shaft to be longer than it appears. Extensive exposure to a society wherein linear relations of structures are the norm appears to increase susceptibility towards to the ML.

Cultures featuring and exposing individuals to predominantly curvilinear structures reduces susceptibility to the ML (Pedersen & Wheeler, 1983; Segall et al., 1963). The linear relations producing depth via the ML within societies featuring linear structures would complement well with the loss of ML susceptibility in societies of predominantly curvilinear structures (Pedersen & Wheeler, 1983). ML-induced depth cues causing inappropriate size constancy in an observer would depend on that observer being familiar with a linear structure so that the specific depth cue would be perceived as either a receding or proceeding corner. Not being familiar or having had limited experience with linear structures, and not being susceptible to the ML, may then be because a corner of a cubic structure is not a likely interpretation when viewing the ML in this population.

Vertical-Horizontal Illusion

The vertical-horizontal illusion consists of a horizontal line and a vertical line of equal length. The vertical line is positioned at either the midpoint of the horizontal line (forming an upside down ‘T’ shape) or at the end of the horizontal line (forming an ‘L’ shape) (Künnapas, 1955). Whether or not the vertical line bisects the horizontal modulates the perceived length of the vertical line to the observer (Finger & Spelt, 1947). Bisection causes a perceived 10% length increase in the vertical line relative to the horizontal line. However, the illusory effect is reduced by approximately half (3-5%) when the vertical line is affixed at either end of the horizontal (Avery & Day, 1969). The weak central coherence account (Happé, 1996) may be used to partially explain the vertical-horizontal illusion phenomena – at least for the upside down ‘T’ version. Happé (1996) describes weak central coherence as a tendency to process local information as opposed to global information causing a reduced ability to capture a concept of the whole. Rather, the tendency in weak central coherence is to focus on and to process the separate features of the whole. Central coherence, however, could influence a perceiver not to view two lines in the illusion, but one line with two short offshoots. There exists the long vertical line, but its bisection of the horizontal line produces a perception of two individual and smaller lines. A perceiver would thus assert, when tasked with determining which line is longest, the vertical line to be so. Local element processing, however, as is the case in those with weak central coherence, would instead influence a perceiver to view the two lines as discrete elements in the image, where the bisection of the vertical against the horizontal line would not "split" the horizontal. It then follows that with weak central coherence, the perceiver would accurately assess the two lines as being of equal length.

The weak central coherence account and its role in the vertical-horizontal illusion may also explain susceptibility to the ML. The weak central coherence account considers the vertical-horizontal illusion to involve a perceiver bias where a gestalt of the image does not occur, and the image's local elements are perceived discretely. Central coherence and global element processing occur in typical populations. The entire ML figure is viewed as a gestalt and global processing causes difficulty in binding the shaft as a local element. In wings out ML figures, the entire image is longer, and the shaft makes up most of the image. Compared to the wings in ML, where the entire image is shorter and the shaft makes up most of that image, the wings out ML becomes perceived as having the longer shaft as it is from the longer image.

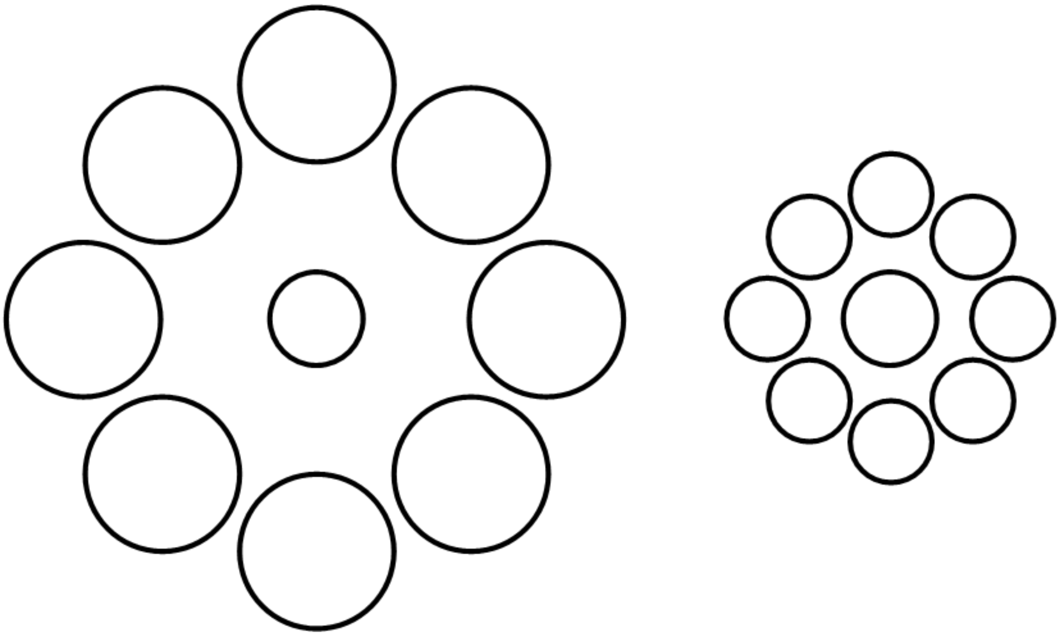


Figure 2: Ebbinghaus Illusion. The central disc in both figures is the same size. The illusion biases perception into interpreting the left figure as having a smaller central circle.

Ebbinghaus and Ponzo Illusions

Reaching towards illusions exemplifies the two visual streams by illustrating a disconnect between what humans consciously perceive and how they subconsciously act. Aglioti et al. (1995) conducted a study where right-handed participants would reach for a central disc within an Ebbinghaus illusion (see *Figure 2*). The illusion features two figures where the first has a central circle surrounded by smaller circles, and the second has a central circle – of equal size to the first figure's – surrounded by larger circles. The illusion tends to skew perception towards believing that the figure featuring larger surrounding circles has a smaller central circle relative to the other figure's central circle. The purpose of the study by Aglioti et al. (1995) was to investigate grip aperture during reaching towards an illusory object. They found that participants perceived equivalently sized central circles to be differently sized, and vice versa. To contrast, they found that grip aperture when grasping the central circles was not affected by the illusion (Aglioti et al., 1995). These results are in line with what would be expected based on the two visual-streams hypothesis where what is perceived does not affect how it is acted upon (Goodale & Milner, 1992b), however, contention does exist concerning illusory effects, or lack thereof, on action. Franz et al. (2000) claim that the results of Aglioti et al. (1995) can be explained by improper matching of perceptual and grasping tasks. In the study by Franz et al. (2000), a replication of the Ebbinghaus illusion study (Aglioti et al., 1995) was performed with an increased sample size, increased trial count, and a wider range between disc sizes. Franz et al. (2000) also employed and compared three types of perceptual measures of illusion magnitude, one of which were used in Aglioti et al. (1995). Their results demonstrated both a lack of difference in, and equal susceptibility to the Ebbinghaus illusion whether by perception or grip aperture. Similar results were produced in a different study using a comparable design (Pavani et al., 1999). In that study, only one figure was displayed during both the perception and grasping trials. The presence of two comparable figures was then suggested as the influencing factor which led Aglioti et al. (1995) to conclude a lack of susceptibility towards illusory objects by grip aperture. Pavani et al. (1999) argued that simultaneous illusory figure presentation changed how individuals responded to them. Participants were more likely to be susceptible to the illusion effects when given complementing figures than when they were offered or operated only on a single presentation. A possible explanation for the appearance of this effect by Pressey (1967) is elaborated on earlier in this section. Pressey (1967) posits a central tendency effect creating an under- or over-estimation of the length of the central shaft in ML figures caused by the smaller spread of the wings in figure compared to the wings out figure, respectively. The longer overall size of the wings out figure is compared to its relatively short central shaft, and vice versa. The central tendency effect causes an overestimation of smaller objects and an underestimation of longer objects.

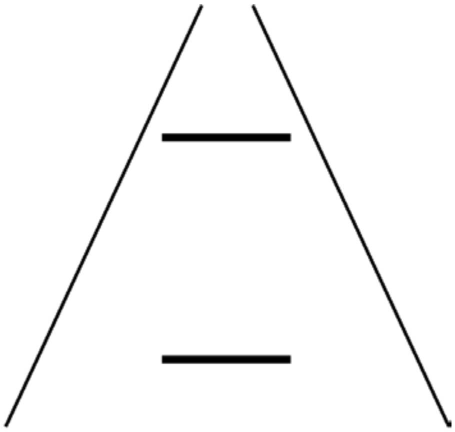


Figure 3: Ponzo illusion. The two horizontal lines are the same length, but the converging diagonal lines bias perception to interpret the top line as longer.

The Ponzo illusion (see *Figure 3*) has been used in various prehension studies (e.g., see Jackson & Shaw, 2000; Brenner & Smeets, 1996). The illusion features a set of superiorly converging lines that mimic the perspective of increasing depth as two parallel lines in the real world would produce a retinal image of convergence (Leibowitz et al., 1969). The perspective of convergence in parallel lines exploits normal size-constancy effects and causes an interpretation of increasing distance. Objects in the real world found further along the parallel lines would be interpreted as being farther away. The Ponzo illusion features two horizontal lines of equal length at two spaced points along the converging lines, where one is nearer to the bottom of the image and one nearer to the top. The image produces equal horizontal line lengths as a retinal projection, but the size-constancy effect causes the observer to inappropriately interpret the top line object as being longer than the bottom object due to the implied perspective by the converging lines. True size constancy would produce the interpretation that the top line is exactly as large as if it were farther away in a three dimensional plane (Leibowitz et al., 1969). The effect of the illusion is moderated by contextual cues and experience. When contextual cues such as the environmental features of a railroad track are included in the picture of the illusion, inappropriate size constancy and the illusion's magnitude is increased. When the illusion is shown to populations who do not have experience with flat land and where the instances of long parallel line structures are not common, there is reduced size constancy effects (Leibowitz et al., 1969). Using environmental cues depend on both prior experience and a sufficient weighting of that prior in a present context (van de Cruys et al., 2014). Thus, a reduced weighting of prior contexts may attenuate the magnitude of illusion susceptibility and size constancy changes in illusions that rely on environmental perspective cues. This weighting of prior and present contexts is elaborated on later in this literature review as the concept of Bayesian predictive coding.

Models of Visuomotor Control

The physical world can be both perceived and acted upon. Action unto an object is contingent on the perception of that object. The theory of perception-action was first suggested by Gibson (1979) where he proposed that perceptions are made with the bias of that perceiver's ability to act upon the perceived, which he termed *affordances*. That is, objects are perceived to allow a set of actions (i.e., affordances) that vary based on a specific perceiver's unique abilities and intent to act on objects at specific times (Gibson, 1986). For example, an object may be both flat and a suitable height to take a seat on as a taller adult, but it may not afford the same opportunity to a shorter child. Affordances are thus specific to the perceiver. In a similar way, objects that are meant to be grasped have affordances that dictate how a perceiver acts upon them. A cup on a table gives visual information to a perceiver that an array of actions are afforded. More specifically, a cup with a handle gives affordance to the perceiver to grasp the handle; the handle affords a specific type of grasping that a handle-less cup does not. However, the affordance offered by the handle is contingent on the ability of the perceiver to produce a specific grasping action with their hand. Additionally, the handle's affordance may also be contingent on the perceiver's veridical perception of the handle. The action-centered representation model offers further insight into how object affordances affect action. Action towards objects that provide a specific affordance to an effector (e.g., the hand) experience movement interruptions when attention is given to non-target distractor objects that are between the effector and the object (Tipper et al., 1992). In a series of experiments by Tipper et al. (1992), participants were to reach as quickly as possible to a target illuminated button while avoiding a distractor illumination that simultaneously occurred on a different button. Tipper et al. (1992) found response times to be most significantly increased when distractor buttons illuminated between the hand and the target button. Additionally, distractors appearing ipsilateral to the reaching hand more heavily increased response times compared to contralateral distractors. Response times were less reduced when the distractor appeared beside the target button, relative to distractors between the target and hand. Finally, response times were not significantly different when the distractor was located beyond the target button, relative to control trials where no distractor button appeared. The work of Tipper et al. (1992) can be extrapolated to imply actions as being susceptible to interruptions when non-target objects are located near, but not beyond, target objects. Goodale et al. (1991) split vision into vision-for-action and vision-for-perception, with the former seeming to operate on the utilization of object affordances and an action-centered framework. Their two visual-streams hypothesis asserts the dorsal stream controls action in real-time whereas the ventral stream allows perception to identify the object and make offline plans for future action (Goodale, 2008). Their hypothesis is explicit in stating the two streams are distinct in their accessibility to consciousness with vision-for-perception being a highly conscious process and vision-for-action being non-conscious. Object affordances are utilized by the dorsal stream which allows actions to be performed without extraneous influence from details that would otherwise induce a bias. Namely, illusory objects are interpreted consciously with biased spatial parameters; however, utilizing the dorsal stream gives a nonconscious but accurate view of the same spatial parameters (Bruno & Franz, 2009b). Similarly, acting on a target object produces selective attention that is action-centered (Tipper et al., 1992). That is, through the dorsal stream, the effector organ has the goal to reach the target object and the perceiver's attention is centered primarily on reaching that target, not on the distractor's spatial parameters. Actions would then only be susceptible to interruptions when non-target objects (distractors) are located between the effector and target, and less so or not affected when they are close to or beyond the target, respectively (Tipper et al., 1992). In other words, contextual illusory effects of a target stimuli that are not presented between the effector, may result in a lack of interruption to goal-directed action responses. Thus, illusory objects can be acted on without interference from their contextually illusory effects.

Glover and Dixon (2001) suggested a different model they called planning-control model which built on ideas proposed in Woodworth's 1899 paper. In 1899 Woodworth claimed goal-directed movements were divided into an initial impulse and a later adjustment. The initial impulse portion produces the bulk of the movement magnitude and draws the limb to be in proximity with the target. The later adjustments are more weighted in accurate direction towards the target than with movement magnitude. Woodworth further asserted rapid movements to result in decreased accuracy. The later adjustments are compared to reactions to the initial impulse, which – if rapid enough – cannot unfold due to a lack of time available for the later adjustments to occur. Glover and Dixon (2001) stated the division in movements was of an initial planning phase which forms the movement plan, and an on-line control phase that corrects the errors of the initial plan as the movement unfolds. The planning-control model claims on-line control utilizes a visual representation of the target that is specific to the spatial characteristics of the target (Glover & Dixon, 2001). In a similar way then to the two visual-streams hypothesis the planning-control model purports the on-line module corrects for bias induced by illusory objects. Importantly, the planning-control model is specific in that it states that illusion-induced biases are corrected for as a movement unfolds (Glover & Dixon, 2002).

Two Visual-Streams Hypothesis

Briefly, the two visual-streams hypothesis considers movements to rely on computations insensitive to the illusion's pictorial cues. That is, vision-for-action and movement should not be susceptible to the same illusion-induced biases as those found for vision-for-perception (Goodale, 2008). Originally, Mishkin et al. (1983) proposed a theory of two cortical pathways, ventrally and dorsally running, that were responsible for object vision and spatial vision, respectively. They proposed visual streams were termed as *what* and *where*. The *what* object vision stream uses the ventral neural projections which are occipitotemporal projections originating at the primary visual cortex to interconnect the striate, pre-striate, and inferior temporal areas of the brain. Object vision was considered responsible for determining physical features like size, colour, and shape, as well as applying subjective meaning to those objects. In turn, this ventral pathway also had greater retention of object qualities compared to its dorsal counterpart. Conversely, the *where* spatial vision stream uses dorsal neural projections which are occipitoparietal projections also originating at the primary visual cortex, but instead interconnecting the striate, pre-striate, and inferior parietal areas of the brain (Mishkin et al., 1983). Spatial vision was responsible for interpreting spatial relations of the objects. That is, spatial vision was primarily concerned with the location of the object in space (Mishkin et al., 1983). Interaction between both pathways would provide a complete understanding of object properties.

Goodale et al. (1991) report on a case of a patient, D.F. who was diagnosed with visual form agnosia following damage to her brain from carbon monoxide poisoning. Visual form agnosia, as defined by Tranel and Damasio (2001), is a disorder where a patient may have normal vision, but cannot recognize visually perceived nonverbal stimuli. Particular interest was placed on D.F.'s ability to recognize orientation and size. A study was conducted where the patient performed a variety of actions meant to examine her ability to recognize objects (Goodale et al., 1991). One of the tasks was to choose the correct line orientation on a card that could fit through a specific orientation of a slot; another task was to turn a card until its orientation matched that of the slot. D.F. executed both tasks poorly with evident gross impairment of responses. However, when D.F. was to put the card through the slot, regardless of orientation, the task was performed accurately. A separate set of 3 tasks were then undertaken to explore whether D.F. was impaired in her recognition of size as well. The study involved the presentation of variously sized rectangles that were meant to be discriminated verbally. The study also asked the patient to expand their grip aperture to appropriately estimate the size of a presented rectangle – without reaching for it. In both of these tasks, D.F. was unable to accurately discern the shapes. The final experiment in the set required the patient to reach and grasp the shapes. Here, D.F. was able to produce accurate grip aperture and prehension movements indistinguishable from controls. The findings here led to further investigations into the possibility of separate visual streams.

Goodale (2008) claims the ventral *what* stream not only remembers visual information with attached meaning and significance, but also acts as a foundation for future action planning and decision making. Goodale's (1992) new interpretation challenges the dorsal *where* stream previously proposed by Mishkin et al. (1983), claiming it would better be considered as a *how* stream. Goodale (2008) expands the dorsal stream's role to be more than simply determining spatial relations contending the dorsal stream further has a critical role in the control of skilled actions and in the planning of constituent movements that occur during an action. They further suggest the dorsal stream's activity as being elusive to consciousness. Should this hold true, it would indicate some level of a lack of awareness towards action. The output or function of vision was proposed to determine which stream would be primarily used in a task (Milner & Goodale, 2008). The function of the behaviour determining which stream was used was argued from an evolutionary standpoint. The authors offered the explanation that the development of actionable experience – such as locomotion – precedes perceptual experience like sight (Goodale & Milner, 1992b). Goodale and Milner (1992) clarify that the streams do not seem to function independently, but rather that they integrate to optimize behaviour. Nonetheless, numerous investigations propose nonconscious dorsal stream activity leads to accurate motor action to illusory figures (Aglioti et al., 1995; Amazeen & Dasilva, 2005; M. T. Dewar & Carey, 2006; Glazebrook et al., 2005; Haffenden & Goodale, 1998; Jackson & Shaw, 2000; Kwok & Braddick, 2003). The two streams would likely be integrated in such a way that their contribution is weighted more heavily towards the dorsal stream in the absence of adequate activity from the ventral stream.

Some contrasting evidence suggests the explanation by the two visual-streams hypothesis for various examples can rather be explained in terms of methodological differences or oversights in experiments (Franz et al., 2001; Franz et al., 2000; Schenk et al., 2011; but see M. T. Dewar & Carey, 2006). Namely, and as discussed previously, Franz et al. (2000) pointed out a previous study by Aglioti et al. (1995) had failed to utilize a consistent perceptual and motor task. Aglioti et al. (1995) required participants to view two Ebbinghaus figures and to grasp the central circle of the figure on a predetermined side if the participant believed both discs to be the same size, and the other side if they believed the figures to be different sizes. For example, the researcher may have instructed that if the participant believed that both discs were the same size, then to pick up the disc on the left side; however, if participants believed they were different sizes, then to pick up the disc on the right side. The perceptual task here was the initial determination of disc size and the grasping task was the physical grasp. Franz et al. (2000) explains how in the perceptual portion of the task there is a direct comparison between both illusory figures, whereas in the grasping portion only one figure is acted on. They reconcile these perceived errors by constructing an experiment where only one figure is displayed and compared to an isolated disc. The perceptual task required participants to adjust the size of the comparison disc until they believed it to match the Ebbinghaus figure-embedded disc. The grasping task involved grasping the disc with occluded vision upon movement. These methodological changes resulted in a disappearance of any immunity of grasping towards the Ebbinghaus illusion. A review of the conflicting research (Bruno & Franz, 2009b) proposes an alternate explanation of the reported effects. Their review was explicit in its consideration that action and perception were not equally susceptible to illusions. Rather, they maintain action is indeed less susceptible, but that this effect is controlled primarily by sensory feedback. Their review of the ML's effect on grasping compared to perception show that although the illusion's effect is significantly different, grasping is still susceptible (Bruno & Franz, 2009b). They also show that grasping is affected in multiple conditions where vision is available to varying degrees. An illusion's effect on grasping is least (though still apparent) when vision is available throughout the movement. The effect increases as vision is reduced to being occluded following movement onset, and further still as vision is occluded following an external prompt (Bruno & Franz, 2009b). Additionally, the effect on grasping seemed to be modulated by the amount of time participants were given with vision of the target. That is, the illusion's effect on grasping increased as participants received shorter durations of visual feedback (Gentilucci et al., 1996). They further claim that participants may adapt to the illusion as trials progress. With increasing trials, the illusion has a decreasing magnitude of effect on their responses (Bruno et al., 2008). In order to counter the above issues that modulate the effect requires one to determine an optimal visual feedback time and the number of trials that can be completed before significant adaptation occurs.

Concerns from studies that conflict with the two visual-streams hypothesis are acknowledged and addressed by Milner and Goodale in their 2008 paper. Primarily, it is readily stated that the two visual-streams hypothesis accepts that the ventral stream's vision-for-perception contribution can influence action by the dorsal stream. Consistently, the ventral stream identifies goal objects and utilizes other cognitive planning processes for the selection of an appropriate action class (e.g., gripping, tapping, punching, etc.). The dorsal stream then uses real-time visual information to determine movement parameters based on the selected action class (Milner & Goodale, 2008). Selection of the stimuli and the action class influence how and which movement parameters are selected and with what magnitude. They also clarify that although humans may be consciously aware of our actions, the programming of those actions by the dorsal stream and vision-for-action are withheld from consciousness. The critiques that Gentilucci et al. (1996) offers highlight that the two visual-streams hypothesis is misunderstood. Gentilucci et al. (1996) claims the two visual-streams hypothesis does not suggest a completely separate ventral and dorsal stream in typically developing persons. Rather, the two streams have compensatory roles in action for typically developing persons. In patients like D.F., vision-for-action undoubtedly acts without aide from their impaired ventral stream, though it may act with aide from other sensory modalities such as proprioception.

Concerns about comparisons of perception to action tasks were raised by Franz et al. (2000). They state that the perception task used to relate perceived size to physical size and the action task used to relate Maximum Preshape Aperture (MPA) to physical size could not be directly compared. The MPA refers to the maximum aperture increase between the thumb and index finger created while making a reach-to-grasp movement. In their critique of the dissociation of vision for perception and vision for action, they suggested that illusory influence in grasping would only be valid if the slope function of perceived size and physical size – determined by maximum preshape aperture – were equal. Although techniques for normalizing the two task types have since been suggested (Bruno & Franz, 2009b; M. T. Dewar & Carey, 2006), considerations of asymmetrical changes in perceived and physical size also lend themselves to a discussion of Weber's law. Dissociations of vision for perception and vision for action can be explained as a lack of adherence to Weber's law. Weber's law, as it relates to size, states that as a stimulus size decreases, there is a proportional linear decrease in the perceived change in size (Ganel et al., 2014). In other words, sensitivity to changes in stimuli is relative as opposed to absolute. Studies investigating visually guided reaching have found that vision for perception and vision for action do not comply equally with Weber's law (Ganel et al., 2008; Hadad et al., 2012). The Just Noticeable Difference (JND), defined as standard deviations from a response variable (via a perceptual estimate or MPA), was applied in visually guided grasping tasks towards non-illusory stimuli. The JND across stimulus sizes was interpreted as uncertainties in participants' responses to potential changes in stimulus size (Ganel et al., 2008). Vision for perception produces proportional linear decreases in participants' JND as stimulus size changes, as would be predicted by Weber’s law. Vision for action towards circular discs instead produced a constant JND as shown by nonsignificant variance changes in MPA as stimulus size was increased (Ganel et al., 2014). The results of the aforementioned studies suggest there may be a confound in visually guided grasping studies investigating the effects of visuospatial illusions. Reduced susceptibility of action, relative to perception, towards visuospatial illusions may either be compounded or explained by violations to Weber’s law. That is, when comparing JNDs to visuospatial illusions, perceptual estimates of size would produce relatively large errors in accuracy, much the same as they would in non-illusory objects. However, grasping of physical visuospatial illusory objects would be relatively as accurate as grasping towards non-illusory objects. Thus, conclusions for illusory effects as being responsible for differences in both perceived size estimation and manual grip estimation compared to grasping begin to appear questionable when violations of Weber’s law are considered. Control trials may be necessary to determine how much of the MPA biases are a result not of the illusory contexts but are instead inherent and caused by violations to Weber’s law.

Ganel et al. (2014) found a speed-accuracy trade-off occurred in grip aperture during grasping. Their study compared grasping accuracies from both open and closed initial grip apertures and noted a relative increase in aperture velocity when the target object was larger than the starting grip aperture, and a relative decrease in aperture velocity when the target object was smaller than the starting grip aperture. The authors also found that the accuracy with which participants grasped the target object was negatively correlated to the velocity with which their grasp was executed. The speed-accuracy trade-off presented in their study follow Fitts’ law (Fitts, 1954). If the fingers creating the aperture must travel a greater distance, that will increase their movement velocity and thus decrease their end-point accuracy. Illusions’ effects on action could then be the result of the consequences of adherence to Fitts' law in MPA during size estimation as detriments to end-point accuracy of apertures' increases as target objects become larger.

Planning-Control Model

An explanation for illusory effects on action can be found by dichotomizing the "planning" from the "on-line control" stages of a movement. Glover & Dixon (2001) propose the planning-control model can better explain how illusions affect action differently, compared to how illusions affect perception. Further, dynamic illusion effects – the phenomenon whereby actions are relatively more affected by illusions earlier in a movement compared to later (Glover, 2002) – are better explained by the planning-control model than by the competing two visual-streams hypothesis. The planning stage of movement recognizes kinematics and movement trajectories prior to movement initiation and involves a context-dependent representation of the visual information of a stimuli, whereas the on-line control stage is context-independent and is only concerned with the spatial characteristics of the stimuli (Glover & Dixon, 2001). The planning stage is thus affected by the surrounding context that is responsible for producing the visual illusions that cause errors in perceptual judgement. However, the control stage circumvents surrounding properties of a visual stimuli, only finding relevant its spatial characteristics. As such, susceptibility towards the illusion is mitigated in the control stage. With these two stages in mind, the occurrence of dynamic illusion effects throughout the span of a movement (Glover & Dixon, 2002) can be considered as the gradual attenuation of the planning stage's visual representation, and the simultaneous enhancement of the control stage's representation.

Glover and Dixon (2001) proposed that on-line control corrects the errors of the planning stage's visual representation through an amalgamation of various sensory inputs. In addition to the previously considered separate visual representation produced by the control module, efferent copies of the movement plan and proprioceptive feedback are together used to make inflight movement corrections. When a movement plan is executed and sent to the effector organ via an afferent signal, a copy of that plan is sent back to the brain (Scott, 2004; Wolpert et al., 1995). The control module can then estimate the state of the effector organ by comparing the proprioceptive feedback to the efferent movement plan (Wolpert et al., 1995) and its quickly decaying visual representation (Glover & Dixon, 2001). An accurate estimation of the effector organ's state influences corrections to the movement that had otherwise been dictated by the planning module's context-dependent visual representation. Dynamic illusion effects resulting in more accurate late-stage movement compared to early-stage are explained as the control module's continuously updated state estimation of the effector organ. In terms of reaching, as the movement towards an illusory stimulus progresses, the position of the arm and hand become more accurately estimated and their subsequent control is a function of that accuracy.

Glover and Dixon (2001) found evidence for their planning-control model by using an orientation illusion. The illusion appears to turn a physical bar that is placed over a grating image in the opposite orientation of the grating, relative to a participant's sagittal plane. The experiment required participants to grasp the bar with either an abducted hand grip or an adducted hand grip. An abducted grip was considered the more comfortable and likely choice in cases where the bar would be oriented 35° clockwise from sagittal, and an adducted grip when the bar would be oriented 5° clockwise from sagittal. The background grating was oriented 10° or -10° to the sagittal plane of the participant. At the start of each trial, the bar was placed at one of seven orientations at 5° steps ranging from 5° to 35°. Vision of their hand and the target stimulus was blocked after the hand moved two-thirds of the distance to the target. They found that participants were more likely to use an abducted posture in trials where the grating was oriented at -10° (i.e., when the illusion imposed a clockwise shift on the bar). Therefore, the chosen posture was that which was selected by the planning stage given the perceived orientation of the bar. The selected abducted wrist posture tended to be that which would have been most appropriate for a greater clockwise shift – one which was perceived as a result of the -10° shift. The task imposes an obstacle in posture selection in that changing posture inflight would require an excessive amount of energy. Thus, the selection of posture occurs at the planning stage of movement and is so based on previous experience of postures selected for the perceived bar orientation. In other words, the control module could not execute its control appropriately as the cost of the veridical posture selection would have been too high. A second experiment was conducted where changes in hand orientation throughout the reach were recorded. As predicted by the planning-control model, illusion effects of hand orientation were greater in the early-stage of movement, relative to the late-stage.

The two visual-streams hypothesis has been updated to include an integrative element of the two streams where actions are somewhat affected (Milner & Goodale, 2008). However, unlike the two visual-streams hypothesis, the planning-control model has always been explicit in its stance that action is in fact consistently susceptible to illusion (Glover & Dixon, 2001). The planning-control model posits a gradual shift from action based on the visual representation of planning a movement, towards action that is corrected based on the visual representation utilized by the control module. The model explains the increased susceptibility of action towards illusory stimuli when vision has been occluded for more than 2 seconds by suggesting that the control module's representation is more readily sensitive to decay, relative to the planning module (Glover & Dixon, 2001). In movements that occur within 2 seconds of visual occlusion, however, the control module has sufficient time and resources (integrated modalities) to correct movement following the early-stage of movement.

The planning-control model is, however, not without its criticisms. The on-line control module is purported to correct for the context-dependent planning module's errors as the movement unfolds (Glover, 2002). This claim has been contested and experiments have instead found that goal-directed movements towards illusions fail to show any reduction in illusion-induced bias as the movements progress, even into the late-stage (Meegan et al., 2004; Mendoza et al., 2004, 2005). In a set of experiments, Meegan et al. (2004) investigated the effect of the ML on kinematic markers of peak velocity, peak deceleration, and end-movement. The kinematic markers were observed during a stylus movement from one vertex of the ML to the other. A wings out, wings in, and wingless ML set were used in the experiments. The experiment presented the ML stimulus for either 10ms or 3000ms and subjected the participants to either a 10ms or 3000ms delay following presentation prior to movement start. Upon moving the stylus from the left vertex, vision was occluded. The illusion-induced bias remained across all figures as evidenced by a lack of correction in the movement at the end-movement kinematic marker. Another experiment was then employed to put to rest arguments that may surface stating on-line corrections were not possible due to the lack of vision and delays. Vision was thus afforded throughout the movement in the second experiment. Here, as well, all kinematic markers analyzed were found to be susceptible to the illusion-induced bias. The planning-control model is thrown into the hot seat by evidence countering its claim that illusion-induced movement bias should be reduced or eliminated as a movement unfolds, given sufficient time (Glover & Dixon, 2001). Still, as both models have been shown to have their benefits, there is reason for a consideration of both in subsequent actions towards illusion research.

Illusions and Autism Spectrum Disorder

Happé (1996) found that children with autism outperformed neurotypical control subjects who were matched for verbal mental age in accurate judgments of the illusory figures in the study. Mitchell et al. (2010) similarly found adults with autism outperformed neurotypical control subjects in their illusory task. In contrast to Happé (1996), Hoy et al. (2004) found no difference between children with autism and neurotypical children for performance on an illusion task. Although the control group can be matched in either mental or chronological age, confounds nonetheless arise. Matching for mental age would require differences in chronological age: a variable which has been shown to modulate susceptibility to visual illusions (Coren & Porac, 1978). On the other hand, with the exception of people with high functioning autism, matching for chronological age produces the opposite problem of mental age differences that also modulate susceptibility to illusions (Burack et al., 2004; Walter et al., 2009). In addition, typically developing adults also tend to vary along the AQ and thus express autistic traits. It so would be inherently confounding to compare autistic individuals against neurotypical adults as there would be a range of autistic trait expressions within neurotypicals acting as extraneous variables (Baron-Cohen et al., 2001). Instead, comparing and correlating illusion susceptibility in typically developing adults who vary in autistic trait expression, as determined by the AQ and SQ, can illustrate with more control the differences in perception- and action-related processes.

Bayesian Predictive Coding, Autism, and Illusions

Motor control and perception differences characteristic of autism as defined in ASD populations – and similar perceptual differences found in neurotypical populations displaying relatively higher levels of autistic traits – may change the affordances provided by objects compared to the general population. The theory of indirect perception suggests that the visual system produces a view of the environment by combining incoming visual stimulus information with previously acquired information (de Wit et al., 2015). Taking this theory a step further, visual perception and visuomotor control has recently been explained using Bayesian decision theory. That is, Bayesian decision theory uses the predictive coding perspective where cortical top-down prior conceptions about the world are iteratively updated by bottom-up sensory information that is weighted as a function of predetermined knowledge (Clark, 2013; Lawson et al., 2014). Sensory information (i.e., likelihood probabilities) that contradict the cortical model (i.e., prior probabilities) create prediction errors that adjust the new prediction (i.e., posterior probability) to fit with the new sensory information. An example of Bayesian predictive coding can be given by relating the concept to relative sizes of observed objects. First, imagine seeing a smaller-than-usual car directly in front of you. As discussed at the beginning of this review, a car has an arbitrarily assumed "true size" determined by an individual observer, but it also has a relative size in the current environment. When viewing that car specifically, its currently observed size is compared against the prior top-down information that argues its true size. The Bayesian predictive coding model of a car is updated by bottom-up sensory information that dictates the car's smaller size compared to the stored model of a general car. The posterior likelihood is then created to state the new known size of the car. The posterior likelihood allows for an accurate identification of the car. Let us then suppose that the car begins to drive away from the observer. The car's relative size dynamically changes, but its true size will remain. If asked to estimate the size of that car after it has driven 100m away from the observer, the top-down model's argument would be more highly weighted than the new bottom-up sensory information from the car's retinal projection that claims the car has reduced in size. Appropriate weighting of the top-down model over the new sensory information and ergo prediction error would be born as a function of understanding size constancy.

Thus, the observer would be able to give an accurate estimation of the size of the smaller-than-usual car even though the car's projected image size upon the retina decreased as it drove away.

The adjustments made by the Bayesian predictive coding model in the previous example of a car are somewhat in line with the role of the control module in the planning-control model. Both models use a means for error correction. The planning-control model uses the context-independent control module's visual representation during reaching to circumvent illusory elements of a target stimuli. Bayesian predictive coding influences reach to a target stimulus by iterative updating of likelihood probabilities from bottom-up sensory information. Bayesian predictive coding can also be used to explain how the ML affects perception. In accordance with size constancy, nearer objects are supposed to be interpreted as larger than the perceived projected retinal image would produce (relative to farther objects), and vice versa for farther objects. Depth cues retrieve cortically stored models of prior probabilities to a similar 3-dimensional figure with shared presented features as in the ML. The brain would so consider the prior model with the newly received sensory information and apply a relative weight to each in the posterior probability output. The weight, in the case of the ML, would be determined by the knowledge of size constancy. Size constancy and monocular depth cues give a false impression to the observer that the central shaft of the ML in the wings out orientation is nearer, whereas the central shaft is farther in the wings in orientation. Thus, the wings in ML would be interpreted as having a shorter shaft and the wings out as having a longer shaft. The planning-control model again shares a likeness in that experience with similar stimuli is considered when interpreting the shaft sizes. Experience, as it is in the planning-control model, could be extended to apply to knowledge of size constancy (and other phenomena), instead of simply experience with similar stimuli. Supplementing concepts of Bayesian predictive coding, such as experience with psychophysical phenomena (e.g., size constancy), with the planning-control model may produce a more complete model of visuomotor control. That is, inferences from previously experienced phenomena – rather than events or stimuli – could be made to explain the control module's function.

Perception by individuals displaying autistic traits may show an attenuation of the weight placed on prior and contextual information such that presently incoming perceptual information is weighted more heavily and therefore relied upon more by the individual (Palmer et al., 2017). The change in reliance on prior information implicates a change in perceptual interpretation of an object. Thus, there occurs a change in what actions the object affords and how those affordances alter the characteristics of that action. An illusory object, like the ML, would therefore be interpreted differently by individuals displaying autistic traits. That is, the central shaft of the ML would be perceived and interpreted with the same top-down cortical model and the same bottom-up sensory information, but the weight placed on the prior would be less, relative to neurotypicals. The interpretation would then be one that is veridical of the length of the central shaft. Considering the theory of Bayesian predictive coding, the same image projection, the same model and the same physical world knowledge (i.e., size constancy) would produce different size estimation depending on the magnitude of autistic trait expression present in the observer. That is, interpretations of size would be increasingly reliant on present information, relative to prior information, with increasing autistic trait expression. Furthermore, reduced ML susceptibility – as found in societies where cubic structures are uncommon (Pedersen & Wheeler, 1983; Segall et al., 1963) – could help add weight to the Bayesian predictive coding perspective. Weak central coherence theory cannot explain why a lack of environmental exposure to cubic structures increases participant bias to local element processing. On the other hand, the Bayesian predictive coding perspective could potentially suggest that a lack of exposure to cubic structures strongly reduces prior, regardless of autistic trait expression, facilitating the present sensory cue to form their perceptual belief or posterior probability (i.e., the behavioural response to the ML after relatively weighting prior experience less than present sensory cues – reducing susceptibility to the illusion). In this way, participants who have not been exposed to environmental instances of cubic structures would not be susceptible to the monocular depth cues employed by the ML.

In line with the weight attenuations placed on prior models in autistic individuals, sensitivity to the rubber-hand illusion was found to be decreased in clinical autism and high AQ individuals, but not low AQ individuals (Palmer et al., 2015). This finding by Palmer et al., (2015) further supports the hypothesis of sensory upweighting relative to prior information in higher AQ individuals. The prior information for the rubber hand illusion involved an idea of a new proprioceptive location of the participant’s hand as having drifted towards the rubber hand. Upon movement onset in their study, the low AQ individuals were required to reconcile their prior and likelihood probabilities while proprioceptive feedback of the moving limb iteratively upweighted the likelihood probability of the true position of their hand. On the other hand, clinical autism and high AQ individuals had inherently more weight placed on the likelihood probability and so their movement was less influenced by the prior probability set by the rubber-hand illusion. In a separate study, clinical autism participants produced further results that would support the Bayesian predictive coding hypothesis. In that study by Paton et al. (2012), they found their clinical autism group experienced reduced proprioceptive drift and performed higher hand movement accelerations when the rubber-hand illusion was induced, relative to neurotypicals. Confidence in bottom-up sensory information would encourage a decreased illusion-induced movement of their hand as proprioceptive sensory information of their hand would be weighted higher than the illusion induced prior to testing.

The Bayesian predictive coding perspective can also be used to explain – or supplement the explanations for the lack of illusion susceptibility by individuals with autism. For example, Carther-Krone et al. (2016) demonstrate difficulties in grouping stimuli pre-attentively could explain reduced illusion susceptibility to the Ponzo illusion in individuals with autism, relative to neurotypicals. The experiment used a dot pattern background that produced the Ponzo illusion where two horizontal lines were of equal length. Importantly, the dot pattern induced the illusion pre-attentively to make it so participants would be unaware of the illusion's presence. The authors found when individuals were shown the stimuli, neurotypicals selected the line which would have been consistent with the percept of the illusion (i.e., they were susceptible to the illusion). Conversely, the authors found individuals with autism performed no better than chance at the same task. That is, individuals with autism were not susceptible to the illusion. Carther-Krone et al. (2016) argue that the lack of susceptibility in individuals with autism was a result of their inability to pre-attentively group the background dot pattern into the Ponzo illusion, and thus the illusion was not induced. They additionally showed that when participants' attention towards the background was increased, the individuals with autism were less able than neurotypical participants to identify the structure of the Ponzo illusion stimuli. A Bayesian predictive coding perspective can be offered to explain the lack of illusion susceptibility by individuals with autism. Specifically, reliance on size constancy by neurotypicals induces the Ponzo illusion and biases their judgment of the relative lengths of the two horizontal lines (Leibowitz et al., 1969). However, for individuals with autism, prior experience and knowledge of size constancy is weighted relatively less than the present sensory information produced by the two embedded lines. Thus, individuals with autism are unbiased by the illusory background because the mechanisms that produce the illusion are not relied upon as heavily, relative to neurotypicals.

Autism-Spectrum Quotient (AQ)

Assessing the degree of autistic trait expression in adults with a self-report measure is useful both as a potential screening opportunity and for research purposes. The Autism Spectrum Quotient (AQ) is a validated self-report measure for non-clinical diagnosis of autistic trait expression (Baron-Cohen et al., 2001). Those scoring along the scale can be considered to fall into either a "high", "average", or "low" autistic trait-expression group (Lundqvist & Lindner, 2017) with a systematic review finding the mean neurotypical score to be 16.94, and the mean score for a clinical autistic population to be 35.19 (Ruzich et al., 2015). The original five-factor and 50-item AQ (Baron-Cohen et al., 2001) has been criticized for a lack of internal consistency (Hurst et al., 2007; Ingersoll et al., 2011). Amendments to the AQ include a three-factor 26-item AQ (Austin, 2005) that has been shown to have greater internal consistency (Hurst et al., 2007), and a three-factor 12-item AQ that has been shown to maintain explanatory power (Lundqvist & Lindner, 2017). Attained scores on the AQ are placed on a unidimensional scale assessing neurotypical expression of autistic trait magnitude.

Both academic field and sex are significantly correlated with AQ in neurotypicals (Baron-Cohen et al., 2001; Wheelwright et al., 2006). Cis males tend to score significantly higher than cis females. Additionally, a comparison of students within the physical sciences, biological sciences, social sciences, and the humanities was found to show a significant main effect with further analysis revealing a significantly higher score achieved by physical sciences students than all other student groups. Additionally, biological science students were found to score significantly higher than humanities students. Academic field and sex can thus be used to predict AQ in neurotypicals. Additionally, neurotypicals score lower on average than those with autism regardless of sex differences (Wheelwright et al., 2006). Those diagnosed with autism, however, do not show significant differences in score between sex.

The Broad Autism Phenotype Questionnaire (BAPQ) (Hurley et al., 2007) is an alternative to the AQ that was developed to measure subclinical autistic trait expression in neurotypicals but more specifically the parents of individuals with autism. The BAPQ is not meant to measure autistic trait expression in diagnosed autistic populations (Hurley et al., 2007; Nishiyama & Kanne, 2014). However, the BAPQ was found to show greater internal consistency than the AQ in measuring subclinical autistic trait expression in a general population of university students (Ingersoll et al., 2011). To contrast, the AQ was developed to measure autistic trait expression in both autistic and neurotypicals. The five-factor AQ has however been validated as a reliable instrument to assess autistic trait expression in clinical and non-clinical populations by a large sample Dutch study that compared AQ scores from those diagnosed with autism against typically developing university students and the general population, groups of adult twins and their families, and three subgroups of psychiatric outpatients (Hoekstra et al., 2008). Additionally, the AQ was originally validated by its author at its inception (Baron-Cohen et al., 2001). Most importantly for the context of this study, the original 50-item AQ has been utilized to measure autistic trait expression in studies investigating the effects of these traits on illusion susceptibility (Chouinard et al., 2013, 2016). Thus, the original AQ is the most sufficiently validated measure of autistic trait expression in neurotypical populations in the context of experiments involving illusion susceptibility.

Systemizing Quotient (SQ)

The SQ produces a score that indicates an ability to analyze complex systems and a tendency to make accurate predictions about their behaviour (Baron-Cohen et al., 2003). Males tend to score higher on average on the SQ than females (Walter et al., 2009) and those with autism score much higher than neurotypicals (Baron-Cohen et al., 2003). The SQ contains 60 questions, of which there are 40 that focus on systemizing. The 20 remaining questions are randomly dispersed throughout the questionnaire and act solely as distractors that are not scored. Further, responses to the 20 distractor questions were found to not significantly differ across participants who scored significantly differently on the 40 systemizing questions (Baron-Cohen et al., 2003). It can thus be concluded that the distractor questions do not hold explanatory relevance in the SQ and can remain in their role as distractors.

Systems that involve inputs, operations, and outputs are divided into six categories: Technical, Natural, Abstract, Social, Organizable, and Motoric (Baron-Cohen et al., 2003). Although these types exist, their discrete inclusion in the SQ would produce confounds. Those with autism can sometimes have a strong affinity towards only one type of systemizing. The SQ was developed to interpret a range of systems – with many systems being assessed in single questions (Wheelwright et al., 2006). "Well-rounded" neurotypicals would potentially score high on many questions involving all types of systems and so those neurotypicals could score higher than individuals diagnosed with autism (Baron-Cohen et al., 2003). To avoid inflated scores for neurotypicals, the SQ was developed to feature questions stemming from quotidian contexts to generally assess systemizing.

Walter et al. (2009) described systemizing as a tendency towards an analysis of variables in a system. They suggest a greater analysis of variables would draw focus towards relevant details of an illusory stimuli and decrease processing of illusion-inducing contextual information. Walter et al. (2009) found SQ, but not AQ, to negatively correlate with illusion susceptibility with multiple visuospatial illusions including the Ponzo illusion. Given the variable or element analysis found in high systemizing individuals, it is surprising to note a lack of any correlation between SQ and susceptibility towards the ML (Walter et al., 2009). Similarly, a study by Happé (1996) also found participants with and without autism to be susceptible to the ML. They suggested this lack of illusion-immunity may have been a result of the physical connectedness of figure elements forming a whole object. Comparatively, the elements of the Ebbinghaus figure are physically separated, potentially facilitating an analysis excluding contextual illusion-inducing information. The study by Walter et al. (2009) utilized an adjustable comparator line method for determining the lengths of ML figures. As the absence of a composite figure reduces illusion magnitude, addressing this issue may alter results. Given SQ's correlation with susceptibility to other illusions, alternative protocols for determining perceptual and action susceptibility to the ML may reveal a similar connection.

Potential flaws of the SQ were addressed by Wheelwright et al. (2006) where they suggest the questions in the SQ were drawn from traditionally male domains. Specific issues with questions in the SQ relating to sex-based biases are not mentioned; however, Wheelwright et al. (2006) argue that the measure would inherently have a bias in scores based on participants' sex. Questions from the SQ were therefore modified for the SQ-revised (SQ-R) to feature items from both traditionally female and male domains. Subsequently the SQ-R was found to positively correlate with the AQ (Wheelwright et al., 2006). A within-subjects analysis comparing scores on the SQ and the SQ-R revealing differences between sexes on either measure could not be found. A contemporary comparison of the SQ and the SQ-R may be necessary to investigate whether questions claiming to be of traditional sex-based domains were selected because of outdated ideas of gender. Justification for the production and use of the SQ-R is thus lacking. Until provided and validated, I suggest the original (Baron-Cohen et al., 2003) and validated SQ (Groen et al., 2015) should be utilized in determinations of autistic trait expression as they relate to systemizing in neurotypical and autistic populations.

Susceptibility to Müller-Lyer Illusion Along Varying Levels of Autistic Traits

As noted above, findings of susceptibility differences to visuospatial illusions between autistic and neurotypical populations have been mixed. Where certain studies have found a decreased illusion susceptibility by autistic groups relative to typically developing (Bölte et al., 2007; Happé, 1996; Mitchell et al., 2010), others found identical susceptibility for both groups (Hoy et al., 2004; Ishida et al., 2009). Further, susceptibility discrepancies exist across studies that compare low- and high-functioning autistic groups to populations with learning disabilities. Where some evidence points towards equal susceptibility in the autistic groups (Ropar & Mitchell, 1999, 2001), other evidence indicates their reduced susceptibility (Happé, 1996). Finally, mixed results have also been found when correlating susceptibilities to visual illusions to varying levels of autistic traits expressed in neurotypicals. Both weak-moderate correlations have been discovered (Chouinard et al., 2013, 2016) along with a lack of any correlation (Walter et al., 2009). A meta-analysis by Hallen et al. (2015) found that, overall, there was no difference in visual illusion susceptibility in autistic groups compared to typically developing. The meta-analysis however grouped visual illusions together. Different visual illusions employ illusion-specific mechanisms (Chouinard et al., 2013, 2016; Walter et al., 2009) that may, when analyzed together, aggregate to show a null net difference. It is thus appropriate to study the susceptibilities for individual illusions, rather than as an average of many.

Investigations correlating autistic traits to illusion susceptibility should also have reasonably similar groups in individual factors such as mental and chronological age. Matching for both mental and chronological age is difficult when comparing autistic and typically developing populations. As discussed earlier in this review, controlling for mental age in autistic populations lends itself to discrepancies in chronological age, and vice versa (Burack et al., 2004; Chouinard et al., 2016). A plausible and used solution for the factor discrepancy is a questionnaire-based score on the AQ and SQ.

Perceptual susceptibility to the ML has been correlated against the AQ and the SQ in previous studies. Mixed reports have shown the AQ to moderately correlate with susceptibility to the ML in some cases (Chouinard et al., 2013), and not in others (Walter et al., 2009). Alternatively, the SQ has not been shown to correlate with susceptibility to the ML (Chouinard et al., 2016; Walter et al., 2009). I suggest investigations of correlations between illusion susceptibility and autistic trait expression by either (or both) AQ and SQ are needed to fill this gap in the literature. Additionally, I see a general lack of studies investigating whether visual illusions, and specifically the ML, affect action (i.e., goal-directed reaching or grasping) differently in autistic populations, relative to neurotypicals across their spectrum of AQ and SQ scores. Studies that investigate kinematics of goal-directed action show motor impairments in those with autism, relative to neurotypicals. Children with autism appear to be slower in movement planning and execution, with increased spatial variability reported to occur throughout a goal-directed movement (Glazebrook et al., 2006, 2009). Additionally, children with autism were reported to also show larger maximum grip apertures when afforded visual feedback (Yang et al., 2014). Although, mitigations to motor impairment have been reported in high functioning autism (Mari et al., 2003; Rinehart et al., 2006). Investigating movement kinematic impairments in neurotypicals displaying varying levels of autistic trait expression can refine potential causes of movement impairments in people with autism by exercising a systematic control of specific traits. Greater control of traits that lead to kinematic impairments aid in identification of traits causing those impairments.

Studies investigating illusions and autistic trait expression are crucial for our understanding of the variations in visuomotor control across populations. Illusions offer us an avenue to scrutinize visuomotor control models. Autistic trait expression variances are relevant factors that modify perception and aid in the filtering and validation of models. Investigations of illusions and autistic trait expression in neurotypical populations can pave the way for allowing advancements in our understanding of human perception and movement.

Summary

Understanding illusions and their differing effects on autistic populations compared to neurotypical populations is necessary for a fuller understanding of perceptual processing. Using questionnaires to measure autistic trait expression in neurotypical populations can help separate findings that are specific to autism itself from those that may be a function of a range of autistic trait expression and/or differences in chronological or intellectual age. That is, determining differences in typically developing populations as a function of autistic trait expression will help advance our understanding of autism and autistic traits by assessing the proposed continuum of perceptual processing differences as a function of task. To date, the ML has been utilized in perceptual experiments where autistic traits were measured using the AQ and SQ. Overall the results are mixed, but there is some evidence to imply that a negative correlation might exist for autistic trait expression and ML susceptibility. Perspectives differ on how reduced susceptibility towards illusions in autism can be explained. The weak central coherence account claims a bias in local processing over global, where autistic traits reduce the ability to gestalt images (i.e., see the "bigger picture"). Conversely, the Bayesian predictive coding perspective explains a heavier weighting of sensory information, where presently received sensory cues are weighted more highly than previously acquired cues. Both explanations offer insight into the mechanisms by which ML susceptibility may be decreased in autism. Studies have found correlations between SQ to ML susceptibility during perceptual tasks. Additionally, AQ and a version of SQ (i.e., SQ-R) have been shown to be positively correlated. Justification thus exists for the use of SQ as a potential correlating factor to ML susceptibility. In summary, the literature is mixed as to whether AQ negatively correlates with perceptual susceptibility to the ML (Chouinard et al., 2013, 2016; Walter et al., 2009). In addition, there is a lack of studies comparing different perceptual illusory tasks directly and considering how autistic traits expression may interact with different task requirements.

Finally, there exists contention as to whether action is entirely immune to illusions (Aglioti et al., 1995; Franz et al., 2000, 2001; Haffenden & Goodale, 1998; Marotta et al., 1998). In acknowledgment of this contention, the present study's review of literature states procedural differences in illusion and action research which may have resulted in contradictory findings that imply action's immunity to illusions (Ganel et al., 2008; Hadad et al., 2012). The present study however did not investigate action tasks. Instead, the study systematically examined perceptual decision illusion tasks. Determining the effect of different perceptual illusion tasks allows future research to select appropriate perceptual tasks to compare against action tasks. Thus, the study aimed to determine how autistic traits, measured by AQ and SQ scores, differently correlate with ML susceptibility in a series of perceptual illusion decision tasks.

Objective

The primary objective of this thesis was to examine the relationship between autistic trait expression in neurotypical adults and their perception of a visuospatial illusion – specifically the ML. The first task was a forced choice discrimination task with concurrently displayed illusory ML figures. The second perceptual discrimination task was also a forced discrimination task, but with successively displayed stimuli. Two subsequent tasks used perceptual adjustment to estimate the magnitude of the illusory bias. The first perceptual adjustment task involved adjustment of a non-illusory line with the goal that it matches the length of the central shaft of a concurrently displayed ML figure. The second adjustment task used an adjustment of a ML figure to match a complementary and composite ML figure. In addition to the experimental trials, all tasks included randomly dispersed control trials within the experimental block. Control trials were the same task, except with non-illusory vertical lines. As described in M. T. Dewar and Carey (2006), having both illusory and non-illusory trials in the same task allows for corrections to any inherent size estimation biases present in individual participants. A summary table of all dependent variables for tasks 1 and 2 are provided in *Table 4*. A summary table of all dependent variables for tasks 3 and 4 are provided in *Table 5*. Explanations of dependent variable acquisition and analysis are provided in *Data Analysis*.

Hypotheses

Task 1 – Forced Choice Concurrent; and Task 2 – Forced Choice Successive

I hypothesize forced choice selection of the longer composite figure will bias selection towards the wings-out figure and produce a larger illusory bias when figures are concurrently presented (Task 1) compared to when they are successively presented (Task 2). The correct figure selection in both tasks was expected to correlate positively with participants' AQ and SQ scores. I also predicted reaction time (RT) and its standard deviation (RT SD) would correlate with AQ and SQ where increased susceptibility to the expected illusory bias was predicted to result in greater RT and RT SD for Tasks 1 and 2. I also predicted the concurrent figure presentation task would result in stronger correlations with the AQ and SQ compared to successive figure presentation for performance measures.

Task 3 – Adjustment of Non-Illusion; and Task 4 – Adjustment of Illusion

I predicted improved task accuracy in Task 3 where the adjustment figure was a non-illusory line and the target was a ML figure, relative to Task 4 where the adjustment figure was a composite ML figure. I also hypothesize participants' AQ and SQ scores will negatively correlate with the difference in length between their adjusted figures and the target stimuli in both tasks.

Illusory bias was suggested to increase when there was concurrent presentation of complementing illusory figures (Pavani et al., 1999). AQ and SQ scores will be more strongly correlated with performance in the concurrent ML figure presentation task (i.e., Task 4) than in comparator line to illusory figure presentation task (i.e., Task 3).

Method

Overview of Tasks

Participants performed all tasks using their own computer or a borrowed data collection computer. Tasks were created using E-Prime (version 3.0, Psychology Software Tools Inc.) and sent to participants via email (see Appendix E for an overview of adaptations made in response to restrictions related to in-person data collection). Task order was counterbalanced whereas trial order was pseudorandomized such that an equal amount of all possible conditions within a task occurred for all participants.

Tasks 1 and 2 – Perceptual Forced-Choice Discrimination

Perceptual task accuracy, represented by the accuracy of the forced choice selection of the longer figure, was investigated as the primary dependent variable. Measures of mean RT and RT SD were also obtained to determine mean decision time and variability, respectively.

Task 3 and 4 – Comparison Adjustment

Accuracy in length adjustments of a comparison line in Task 3, or a comparison complementary ML figure in Task 4, were determined by the primary dependent variable of constant error (CE). Variable error (VE) was investigated as a secondary dependent variable.

Dependent Variable	**Interpretation**
Forced-choice response accuracy	Response accuracy.
Response time (RT)	Time for stimuli perception, decision making and response preparation.
Response time standard deviation (RT SD)	Variability in decision/movement planning.
Constant error (CE)	Magnitude and direction of response bias.
Variable error (VE)	Variability in response about their mean.

Table 1. Dependent variables to be measured in the experimental tasks and their implications.

Participants

I recruited (n=30) right-handed typically developing adults (age=18-35; 15 cis females and 15 cis males) who expressed a range of sub-clinical levels of autistic traits to participate in tasks 1, 2, 3, and 4. Participants were recruited from the University of Manitoba and surrounding community. Criteria for inclusion were that participants were either cis-female or cis-male, were right-hand dominant, and had normal or corrected-to-normal vision. Participants additionally needed to be between the ages of 18 and 35 inclusive. Criteria for exclusion were that participants had not received a diagnosis of an autism spectrum disorder.

Autistic traits were measured by administration of the AQ and SQ self-report measures (Baron-Cohen et al., 2001, 2003). Balanced sex recruitment was controlled for in consideration of the discrepancy in sex-related autistic trait expression in both AQ and SQ (Wheelwright et al., 2006), where cis females are more likely to score lower than cis males on both measures. A balanced sample for sex allowed for an assessment of sex differences apparent in visual illusion grasping along varying levels of autistic trait expression.

Instruments

The AQ consists of 50 questions. Each question is either worth 1 or 0 points depending on the response given by the participant. A point is given for every response of either “definitely agree” or “slightly agree” in half of the questions. These questions are designed to indicate autistic-like behaviour when participants respond agreeably. In the other half, those same agreeable responses would receive no points as this other half indicates autistic-like behaviour when participants respond disagreeably. So, the other half of the questions can receive a single point if the participant responds with either “definitely disagree” or “slightly disagree”. Thus, a maximum score of 50 is attainable by participants (Baron-Cohen et al., 2001).

The SQ contains 60 questions with 20 of those questions acting solely as distractors that are not scored resulting in a total of 40 systemizing questions. Possible responses to all questions in the SQ include: Strongly agree, slightly agree, slightly disagree, and strongly disagree. A selection of “strongly agree” and “strongly disagree” are assigned scores of 2-points on specified questions (see Baron-Cohen et al., 2003), whereas “slightly agree” and “slightly disagree” are assigned 1-point on specified questions. Thus, a maximum score of 80 may be achieved in the SQ.

The questionnaires were completed with an interactive form together with the participant and the researcher prior to beginning the tasks. The answers were then coded to determine scores.

Apparatus

All four tasks were built using E-Prime (version 3.0, Psychology Software Tools Inc.) and sent to participants as executable tasks via the internet using E-Prime Go (version 1.0, Psychology Tools Inc.). Figures were built using Office Publisher (version 2106, Microsoft, Redmond, USA) with a 1920x1080px screen resolution. Participants with computers operating Windows 7 or higher used their personal computer monitors and keyboards to perform each task. Participants without access to a computer operating Microsoft Windows 7 or higher were lent a data collection laptop for the purpose of testing.

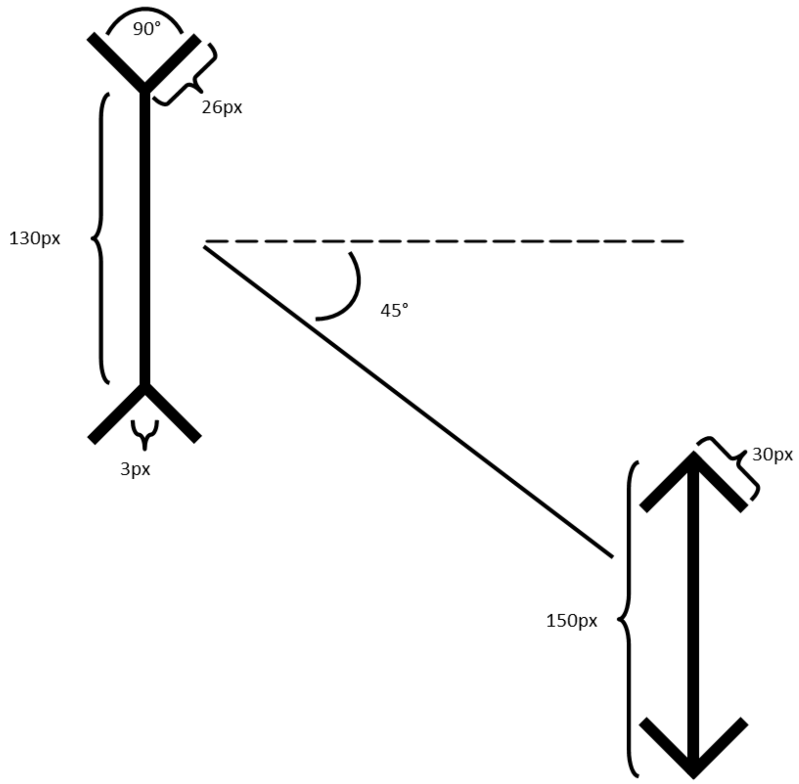


Figure 4. ML presented figure scaling (example)

On screen, participants performed four tasks in a pseudorandom order. In Task 1, participants initially saw an instruction screen. Following the instructions, a black fixation cross against a white background was displayed. Finally, participants were presented with two, vertically oriented, composite ML figures displayed concurrently on the screen. The ML figures' central shafts randomly ranged in 10px steps from 154px-184px in length to achieve a length difference between figures ranging from 10px to 30px. The individual wing-components were 20% of their respective central shaft lengths (see *Figure 4*). There were 12 figure combinations. The two composite figures were randomly staggered at a 45deg angle from their center point. Participants used their keyboard to press either the "A" key to indicate that they perceive the left-most figure to feature the longer central shaft, or the "L" key to indicate the right-most figure as having the longer central shaft. There were also 12 trials randomly interspersed where both figures were non-illusory vertical lines. The vertical lines were presented in the same way as the figures with the same length range.

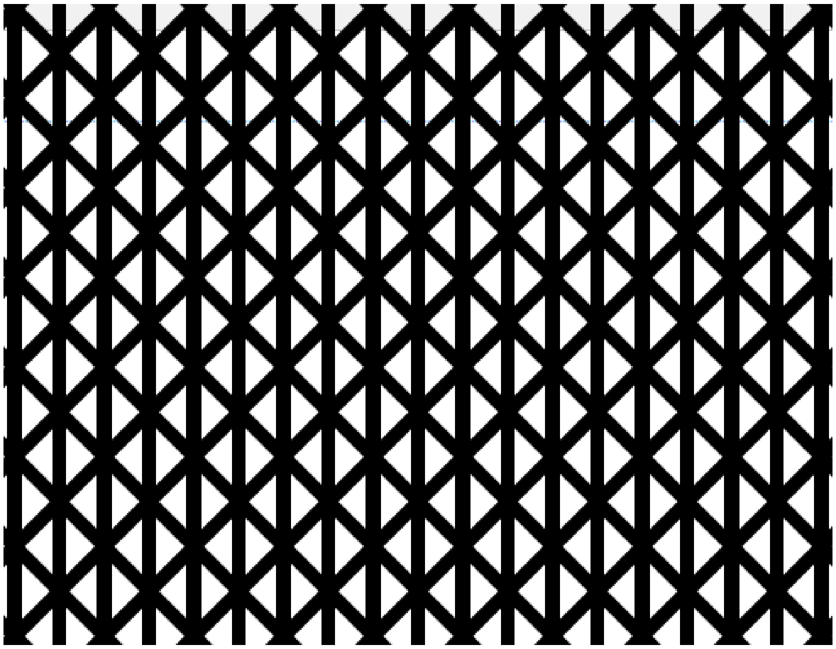


Figure 5. Visual structural pattern mask

Task 2 was similar to Task 1 except that the figures were presented successively and with a random structural pattern mask (see *Figure 5*) between presentations of the same trial (see p. 61-62 for Task 2 procedure). The range of figure sizes were from 154px-184px in length of the central shaft, with 10px step increases to achieve the same 10px-30px range, and with wings-components sized as 20% of central shaft length. The second presentation was followed by a response screen asking whether the figure that was displayed first or second was relatively longer. The "A" key indicated the first figure's presentation, whereas the "L" key indicated the second figure's presentation. As with Task 1, Task 2 also contained 12 trials randomly interspersed where both successive figures were non-illusory vertical lines. In no trials were the figure’s central shaft or the vertical line the same length as its paired figure.

Task 3 had two concurrently presented figures on the screen. One of the figures was a vertically oriented ML figure and the other was a vertical line. The vertical line length was randomly selected and ranged between 154-184px in 2px steps, whereas the ML figure was either wings-in or wings-out and ranged in 2px steps from 150px-180px for their central shaft length. Participants used the up and down arrows on their keyboards to increase or decrease the size of the comparison stimulus in 2px steps from 124px-220px.

Task 4 was identical to Task 3 except that both figures were composite ML figures. Also, adjustments to the comparison stimulus changed the size of both the central shaft, and the wing components such that each step increased or decreased the length of the central shaft by 2px while simultaneously adjusting the wing size to maintain their length as 20% of their respective central shaft’s length.

Procedure

The four tasks and both questionnaires of the present study were completed on participants’ personal computers or the loaned data collection laptop, and in both cases with concurrent video conferencing with the researcher. Instructions by the researcher were given to participants both in writing and through video conferencing. Consent to participate in the experiment was electronically obtained upon start of the videoconference call.

Task 1 – Forced Choice Concurrent

Task 1 began with an instruction slide on the computer monitor. The instructions explained to the participant which key to press on their keyboard once they had been presented with the two figures. The instructions also explained the necessity on the part of the participant to respond as quickly and accurately as possible. Advancing past the instructions required pressing the space bar. Participants began with 4 practice trials meant to acclimate the participant to the task. Upon pressing the space bar, practice trial 1 began. There were also 36 control trials randomly interspersed throughout the task. The control trials were presented with a pair of non-illusory vertical lines having identical lengths to the range of ML figures. Trial 1 began after a second welcome screen appeared once all 4 practice trials had been completed. There were a total of 184 trials – including the 4 practice trials and 36 control trials. Thus, each combination of figures was presented a total of 6 times for each participant.

For Task 1 (see *Figure 6*) the participant was presented with a centralized, black fixation cross against a white background to cue the participant to prepare themselves to respond. Following a variable foreperiod (800-1800ms) duration, the two composite figures were concurrently presented for 1000ms. This binomial forced choice discrimination task required that the participant decide which of the two figures' central shafts was relatively longer – the left, or the right. Once the participant had judged one of the central shafts to be relatively longer, they pressed one of two keys. The "A" key was to be pressed to indicate that they believed the left figure was relatively longer and the "L" key was pressed to indicate that they believed the right figure was relatively longer. There were no trials where the two figures were of the identical size. All responses were made while participants were on the figure presentation screen. The participant advanced to the feedback slide once they had responded or failed to respond within the 1000ms time limit during which the figures were presented. The feedback slide only informed the participant of their success or failure in responding without any indication of accuracy. To advance through trials, participants pressed the space bar on the feedback slide. Thus, participants had autonomy in choosing their own breaks by not pressing the spacebar upon receiving the feedback slide which indicated whether the participant responded.

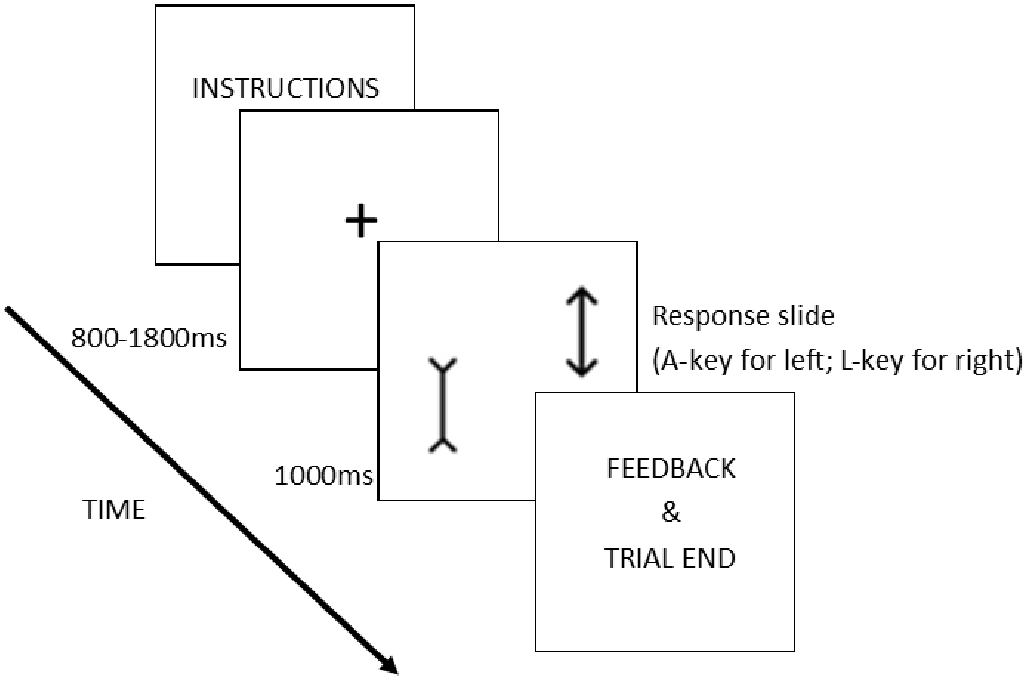


Figure 6. Task 1 trial sequence

Task 2 – Forced Choice Successive

Task 2 (see *Figure 7*) began with an instruction slide explaining the task presentations and response options. The instructions informed the participant that they would be presented with four successive slides before viewing a response slide, per trial. The first slide presented a centered, black fixation cross on a white background. Following a variable foreperiod (800-1800ms), the slide advanced to display a ML figure for 1000ms before switching to a structural ML mask. The mask persisted for 20ms and then switched out to display the composite pair of the first ML figure orientation (i.e., if the first figure was wings-out then the second figure would be wings-in, and vice-versa). Once 1000ms of presentation had elapsed for the second figure, the response slide was displayed for 1000ms. The response slide asked the participant to respond as quickly and as accurately as possible as to whether the first or second figure had a relatively longer central shaft. The participant then pressed either the "A" or the "L" key on their keyboard to indicate that they believed the first or second presentation was correct, respectively. As in Task 1, the participant started the task with 4 practice trials. Similarly, there were 36 control trials randomly interspersed throughout the task. The control trials presented a non-illusory vertical line having identical length to one of the range of ML figures' central shafts. The control trials followed the same procedure as the experimental trials. Trial 1 began once practice trials had been completed. There were a total of 184 trials – including the 4 practice trials and 36 control trials. To advance through trials, participants pressed the space bar on the feedback slide. Again, participants had autonomy over their breaks that were afforded by withholding their space bar press upon receiving the feedback slide.

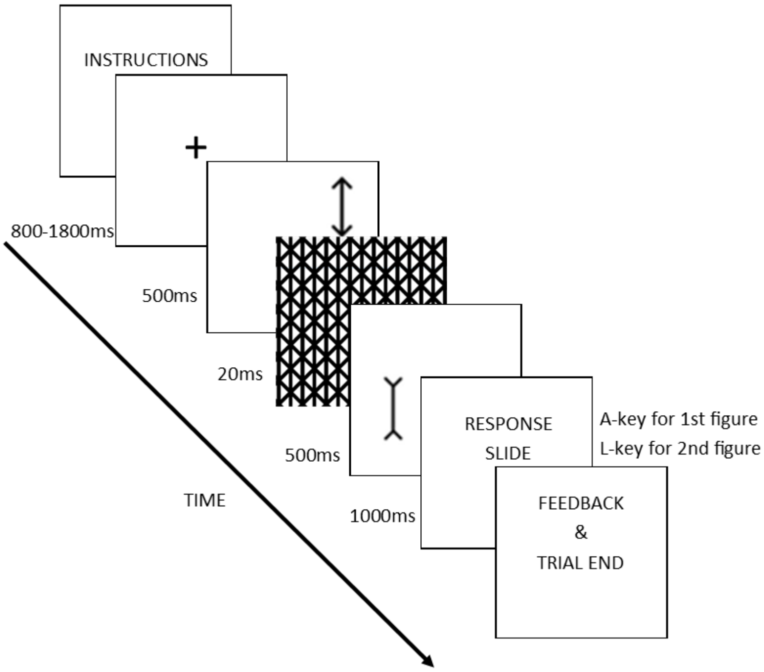


Figure 7. Task 2 trial sequence

Task 3 – Adjustment of Non-Illusion

The third task began with an instruction slide. On the slide were directions on how to adjust the comparison stimuli during trials. Pressing on the UP or DOWN arrow keys on the participants' keyboards increased or decreased the size of the comparison stimulus, respectively, by 1mm. Following the instruction slide, participants were presented with a black fixation cross against a white background. Following a variable foreperiod (800-1800ms), two figures appeared on the screen. One figure was a ML figure and the other a non-illusory vertical line comparison target figure. Target figures' central shafts ranged in size from 154px to 184px in 2px steps. Wings on ML figures varied in size to remain 20% the length of the central shaft. Participants pressed the UP or DOWN keyboard arrow keys to adjust the non-illusory line to be the same length as the ML figure's central shaft. Adjustable figure limits ranged from 124-220px Pressing the space bar indicated that the participant was satisfied with their adjustment and the trial ended. There was no maximum time, but participants were asked to respond as quickly and as accurately as possible. There were 4 practice trials preceding experimental trials. Twelve control trials were also randomly dispersed throughout the task. Control trials presented two non-illusory vertical lines – one of which was adjustable. The control trials required the participant to adjust a line to be the same length as the complementary target line. There were a total of 144 trials consisting of 4 practice trials, 12 control trials, and 128 experimental trials. Participants were free to choose their own break schedules throughout the procedure.

Task 4 – Adjustment of Illusion

The fourth task followed an identical protocol as Task 3, except that the adjustable comparison stimulus was the composite ML figure to the target ML figure. Target ML figures ranged in size from 154-184px, and adjustable ML figures ranged in size from 124px to 220px in

2px steps. Both figures' wings were automatically maintained at 20% of the length of their respective figures' central shafts. As in Task 3, there were 144 trials of which 4 were practice trials, 12 control trials, and 128 experimental trials.

Data Acquisition and Analysis

Questionnaire data from both AQ and SQ were scored individually to obtain total scores for each participant. The scoring protocol for both measures has been outlined above (see p. 55-56). The SQ has been found to have a moderate positive correlation with AQ (Wheelwright et al., 2006). However, both scores were individually investigated for correlations with dependent variables as they represent different metrics. The AQ measures autistic trait expression generally, whereas the SQ measures systemizing ability. The primary dependent variable for Tasks 1 and 2 was a forced-choice response for discriminating the longer figure. Responses were either correct or incorrect. The primary dependent variable for Task 3 and 4 was constant error with respect to the length difference between the target and adjusted figure.

Discrimination of the longer figure for Tasks 1 and 2 (perceptual estimation tasks) was acquired by key press on participants' personal keyboards. Scores were determined by number of correct responses in each pair of figure length combinations and total correct responses throughout the tasks. Task 1 RT and RT SD were determined by the elapsed time between onset of figure presentation and forced-choice key press. Therefore, this task's response time may be considered a concurrent choice response time. Task 2 RT and RT SD were determined by the elapsed time between onset of the response slide and forced-choice key press. Given that this task requires the participant to store the figure size in memory and then compare its size to the subsequently presented figure, this task's response time may be considered a memory-based choice response time. Dependent variables of Task 3 were calculated by the difference in length between the target figure and the adjusted figure. The CE and VE for Task 3 responses represented the illusory bias experienced by participants. Dependent variables of Task 4 were calculated in identical fashion to those of Task 3. Dependent variable correlations to AQ and SQ scores were individually analyzed using a Pearson's correlation coefficient with a 95% confidence interval (or Spearman's ranked correlation coefficient in the case of non-parametric data). All correlations were two-tailed unless otherwise specified. Analyses of variance (ANOVAs) were conducted to determine differences between dependent variables across conditions.

AQ/SQ scores were correlated with biased figure selection, RT, RT SD, and differences in target and adjusted figure lengths. A 2-way mixed repeated measures Task (concurrent, successive) by 2 between measures Sex (cis female, cis male) was conducted for biased figure selection. Separate 3-way mixed 2 repeated-measures Task (concurrent, successive) by 2 repeated measures Orientation of longer (wings-out, wings-in) by 2 between-subjects Sex (cis female, cis male) were conducted for RT and RT SD. A t-test was used to compare selections of wings-out and wings-in figures in Task 1 and Task 2. A mixed model repeated-measures 2 Task (non-illusion, illusion) by 2 Target (wings-in, wings-out) by between-subjects 2 Sex (cis female, cis male) was conducted on constant error of figure adjustment scores. Although magnitude of adjustment bias based on target figure orientation (wings-in, wings-out) is not explicitly involved in the hypotheses of the current study, the directional biases imposed by ML wing orientation must be factored into analyses when the direction-affected measure of constant error is investigated. A mixed model repeated measures 2 Task (non-illusion, illusion) by between-subjects 2 Sex (cis female, cis male) was conducted on variable error of figure adjustment scores from Task 3 and Task 4.

Office Excel (version 2106, Microsoft, Redmond, USA) was used to reduce data outputs from E-Prime (version 3.0) and E-Prime Go (version 1.0, Psychology Software Tools Inc.). The dependent variable of biased figure selection in tasks 1 and 2 were determined by the number of incorrect responses where the wings-in figure was in fact the longer pair. Response time was determined by the time elapsed between stimulus onset to key press response for Task 1. For Task 2, response time was determined by key press response slide onset to response. Trials were excluded when there was an absence of response and when response time was <100ms. Constant error was calculated by subtracting the participant’s adjusted figure response size from the target size. Variable error was calculated by subtracting the participant’s adjusted figure response size from their average response size and squaring this difference.

Statistical outcomes were calculated using jamovi v1.6 (The jamovi project, 2021). Significance (alpha) is set at $p<0.05$. Tukey’s Honestly Significant Difference (HSD) with significance set at $p<0.05$ was used to determine significant differences between means when main or interaction effects were found. Comparison violations to sphericity (Mauchly’s W Test of Sphericity, $p<0.05$) were corrected using the Greenhouse-Geisser procedure.

Results

Thirty participants were included for results analysis (cis female n=15; cis male n=15) with an average age of 26.2yrs (*SD* = 2.69). A total of 2.6% trials from Task 1 (*M* = 3.8 trials/participant; median = 3.5 trials/participant) and 6.48% trials from Task 2 (*M* = 9.3 trials/participant; median = 5.5 trials/participant) were rejected for absence of response or response time <100ms.

Questionnaires

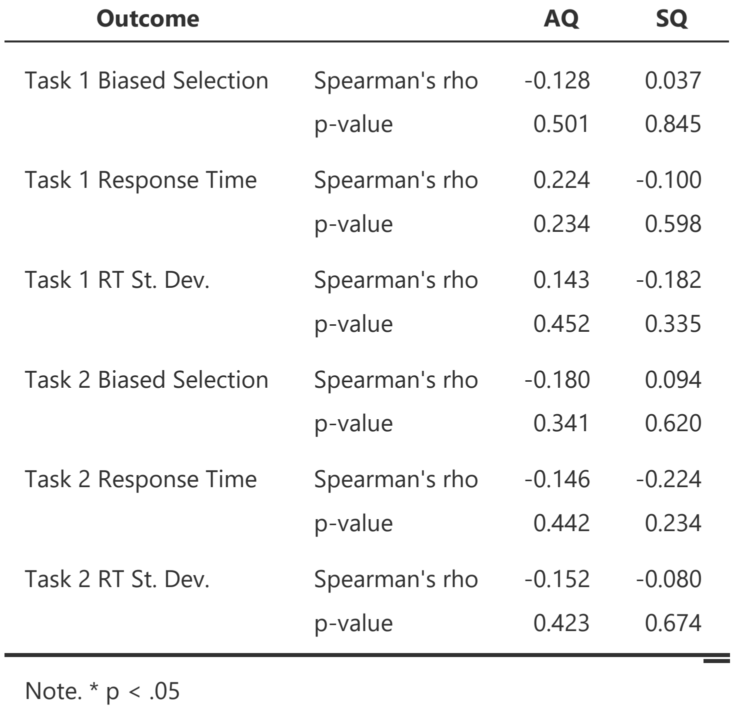
The AQ score for all participants ranged from 7 to 37 with a mean of 17.1 (SD = 6.29). The SQ score for all participants ranged from 8 to 45 with a mean of 27.6 (SD = 8.77) (see Appendix C for individual participant AQ and SQ scores). An independent samples t-test revealed cis-males (*M* = 18.3) did not score significantly higher than cis-females (*M* = 15.8) in mean AQ scores (p = 0.277). However, mean SQ score for cis-males (30.9) was significantly higher than for cis-females (24.4; p = 0.041). As predicted, participants' AQ and SQ scores were also found to be significantly positively correlated (r = 0.370; p = 0.044).

Forced-Choice Tasks

Biased figure selections in Task 1 and Task 2 were not normally distributed (Shapiro-Wilk p = 0.013 and 0.006, respectively). Spearman's rho was used to assess AQ and SQ correlations to the three dependent variables (i.e., biased figure selections, RT, and RT SD).

Scores for AQ were not found to significantly correlate with Task 1 dependent measures of RT (rho = 0.224, p = 0.234) and RT standard deviation (rho = 0.143, p = 0.452), or with biased figure selection (rho = -0.128, p = 0.501). Additionally, AQ was not found to significantly correlate with Task 2 dependent measures of RT (rho = -0.146, p = 0.442) and RT standard deviation (rho = -0.152, p = 0.423), or with biased figure selection (rho = -0.180, p = 0.341) (see *Table 2*).

Participants’ SQ scores similarly did not significantly correlate with Task 1 dependent measures of RT (r = -0.119, p = 0.533) and RT standard deviation (r = 0.037, p = 0.846), or with biased figure selection (rho = -0.037, p = 0.845). Similarly, SQ did not significantly correlate with Task 2 dependent measures of RT (r = -0.175, p = 0.355) and RT standard deviation (r = -0.088, p = 0.645), or with biased figure selection (rho = 0.095, p = 0.619) (see *Table 2*). No significant correlation was found in Task 1 (rho = -0.003, p = 0.985) or Task 2 (rho = 0.092, p = 0.628) between SQ and correct figure selection when the wings-in figure was longer.



Outcome		**AQ**	**SQ**
Task 1 Biased Selection	Spearman's rho	-0.128	0.037
	p-value	0.501	0.845
Task 1 Response Time	Spearman's rho	0.224	-0.100
	p-value	0.234	0.598
Task 1 RT St. Dev.	Spearman's rho	0.143	-0.182
	p-value	0.452	0.335
Task 2 Biased Selection	Spearman's rho	-0.180	0.094
	p-value	0.341	0.620
Task 2 Response Time	Spearman's rho	-0.146	-0.224
	p-value	0.442	0.234
Task 2 RT St. Dev.	Spearman's rho	-0.152	-0.080
	p-value	0.423	0.674

Note. * p < .05

Table 2. Spearman's rho correlation matrix between AQ and SQ to Task 1 and 2 outcome variable means.

Biased Figure Selection

For biased figure selection a Mann-Whitney U t-test found a significant difference in Task 1 ($p < 0.001$) between the number of selections of wings-out figures (median = 71.0) and wings-in figures (median = 3.97), and in Task 2 ($p < 0.001$) between the number of selections of wings-out figures (median = 70.0) and wings-in figures (median = 18.70). There was a significant main effect found for Task ($F(1, 28) = 10.0987$, $\eta^2_p = 0.265$, $p = 0.004$). Concurrent figure presentation resulted in greater biased figure selection of 55.8 (SE = 2.29) compared to successive figure selection of 47.2 (SE = 3.48) (see *Figure 8*). No significant main effect was found for Sex ($F(1, 28) = 0.358$, $\eta^2_p = 0.013$, $p = 0.555$) nor interaction effect between Task and Sex ($F(1, 28) = 0.0394$, $\eta^2_p = 0.001$, $p = 0.844$).

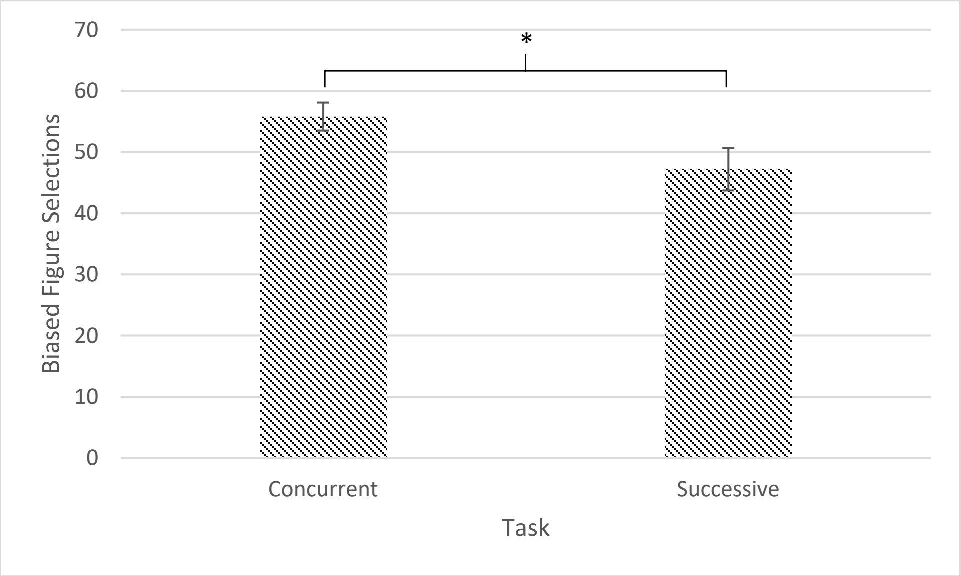
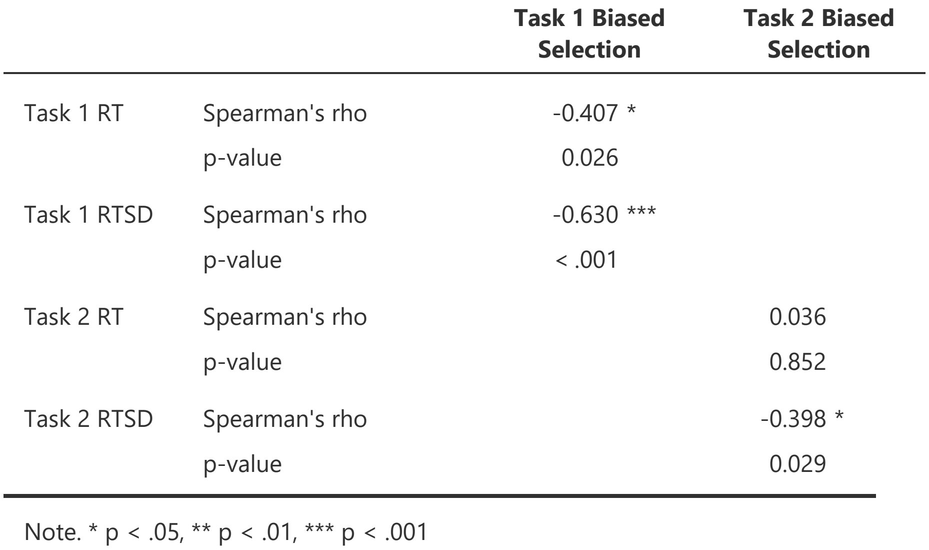


*Figure 8. Mean response frequency between concurrent and successive figure presentation where the longer (correct) wings-in figure was not selected. Error bars represent standard error. * $p < 0.05$.*

Contrary to my hypothesis, Task 1 biased figure selection was not found to positively correlate, but instead negatively correlate with RT (rho = -0.407, $p = 0.026$) and RTSD (rho = -

0.613, $p < 0.001$). Task 2 biased figure selection was not found to correlate with RT (rho = -0.036, p = 0.852) but was negatively correlated with RTSD (rho = -0.398, p = 0.029).



		Task 1 Biased Selection	Task 2 Biased Selection
Task 1 RT	Spearman's rho	-0.407 *	
	p-value	0.026	
Task 1 RTSD	Spearman's rho	-0.630 ***	
	p-value	< .001	
Task 2 RT	Spearman's rho		0.036
	p-value		0.852
Task 2 RTSD	Spearman's rho		-0.398 *
	p-value		0.029

Note. * p < .05, ** p < .01, *** p < .001

Table 3. Spearman's rho correlation matrix between Task 1 and Task 2 biased figure selections to task-respective outcome variables of response time and its standard deviation.

Response Time

Significant main effects of RT were found for Task (F(1, 28) = 187.83305, $\eta^2_p = 0.870$, $p < 0.001$) and Orientation of longer figure (F(1, 28) = 93.45189, $\eta^2_p = 0.769$, $p < 0.001$). Concurrent presentation resulted in a longer mean RT of 587ms (SE = 13.5), whereas successive presentation resulted in a relatively shorter mean RT of 357ms (SE = 14.4) (*see Figure 9*). Trials where the wings-out figure was longer (*M* = 444ms, SE = 11.1) had shorter RTs than trials where the wings-in figure was longer (*M* = 500ms, SE = 12.0) (see *Figure 10*).

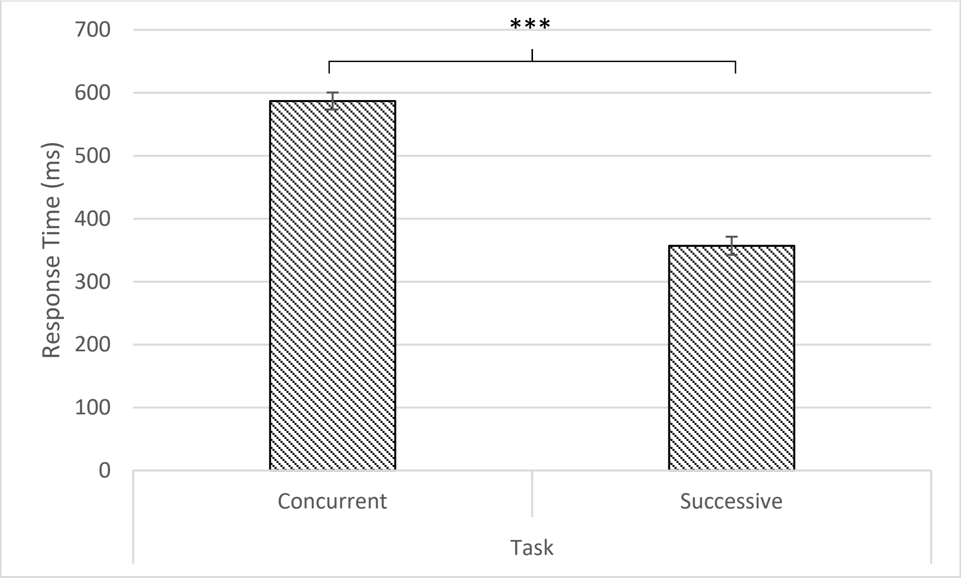


*Figure 9. Mean response time comparison between concurrent or successive presentation. *** p < 0.001.*

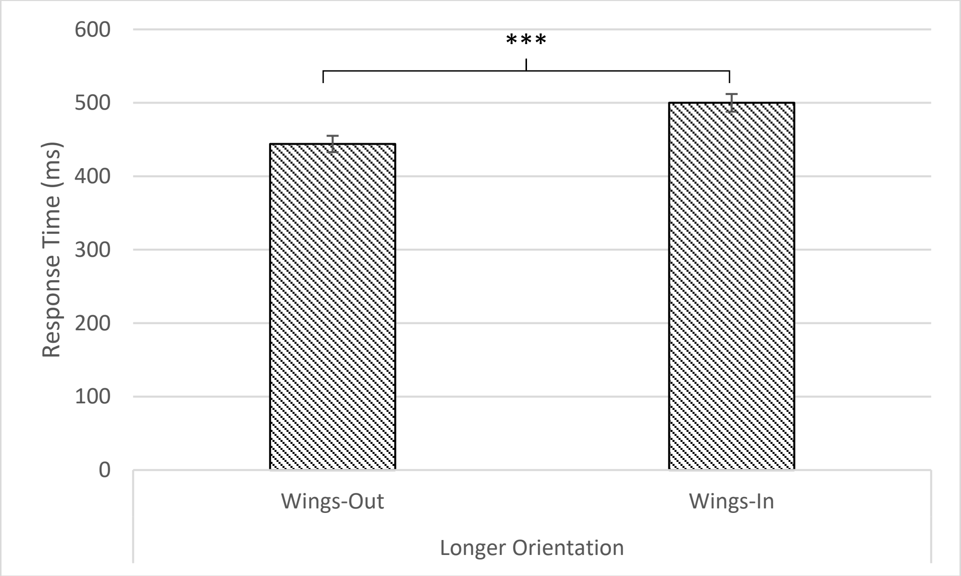


*Figure 10. Mean response time comparison between wings-out or wings-in figure orientation presentation. *** p < 0.001.*

A significant interaction effect was found between Task and Orientation of the longer figure ($F(1, 28) = 79.02779$, $\eta^2_p = 0.738$, $p < 0.001$). Tukey's HSD showed significance in all comparisons. The post hoc test found concurrent presentation resulted in a similar finding as the main effect for Orientation of the longer figure, with wings-out (*M* = 542ms, SE = 13.3) having a shorter RT than wings-in (*M* = 631ms, SE = 14.5) figures. Similarly, successive presentation of wings-out (*M* = 345ms, SE = 14.6) had shorter RTs than wings-in (*M* = 369ms, SE = 15.1) figures. Importantly, both concurrent presentation RTs were longer than those of both successive presentation RTs regardless of wing orientation.

Significant main effects of RTSD were found for Task (F(1, 28) = 289.7036, $\eta^2_p = 0.912$, $p < 0.001$) and Orientation of longer figure (F(1, 28) = 57.9871, $\eta^2_p = 0.674$, $p < 0.001$). Concurrent presentation resulted in a less variable RT with a mean RTSD of 116ms (SE = 4.05) whereas successive presentation had relatively more variability with a mean RTSD of 357ms (SE = 14.44). Trials where the wings-out figure was longer (*M* = 223ms, SE = 8.32) had less variable RT than trials where the wings-in figure was longer (*M* = 251ms, SE = 7.91). A significant interaction effect was not found between Task and Orientation of the longer figure (F(1, 28) = 1.1925, $\eta^2_p =$ 0.0.041, $p = 0.284$).

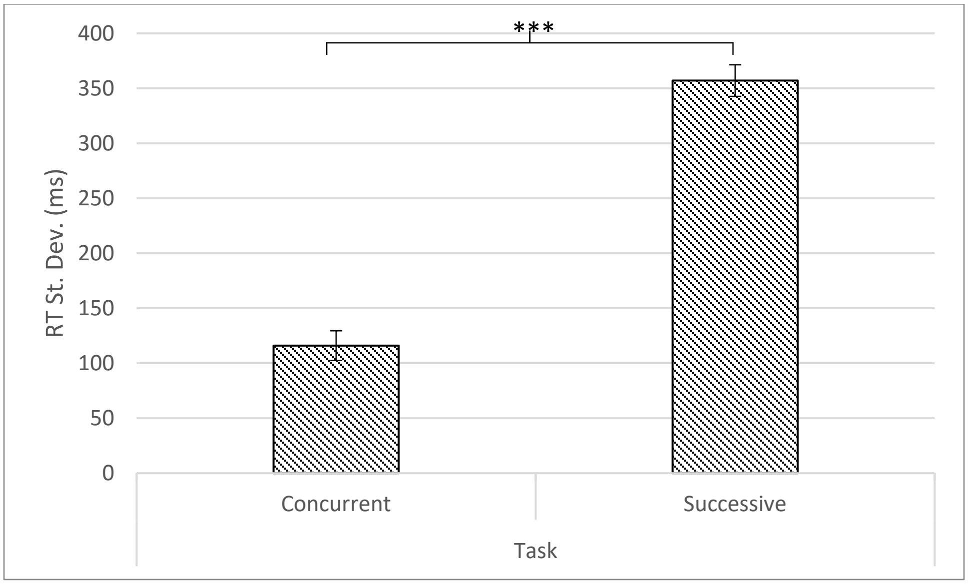


*Figure 11. Comparison of standard deviation of response time between concurrent and successive presentation. *** $p < 0.001$.*

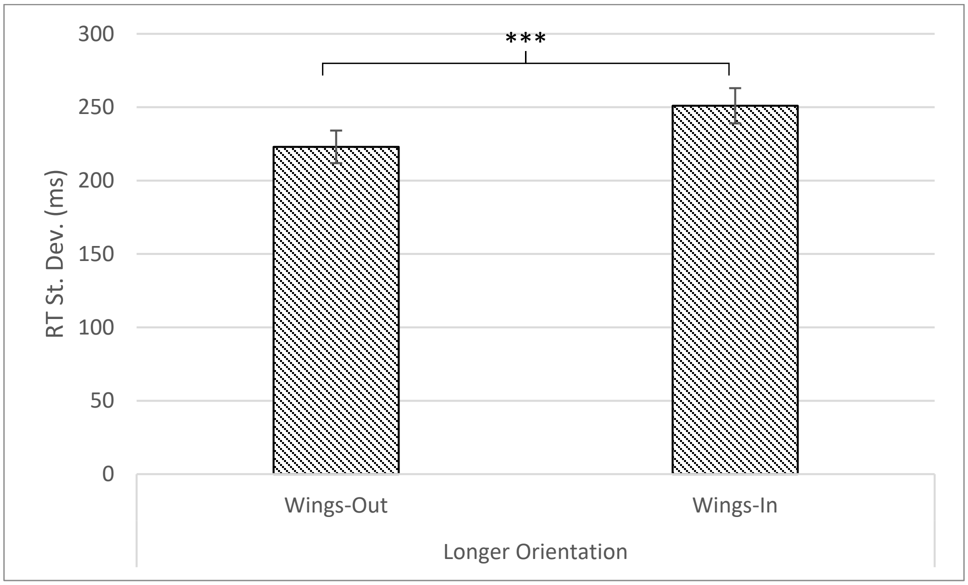
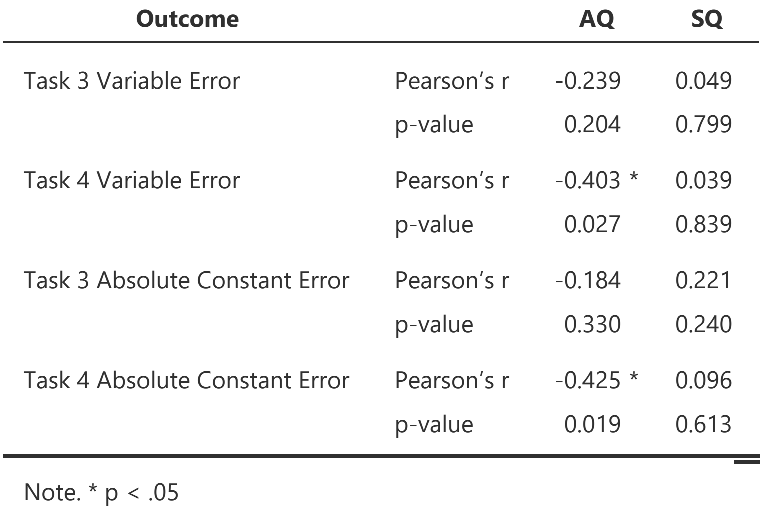


*Figure 12. Comparison of standard deviation of response time between wings-out and wings-in orientation figure presentations. *** $p < 0.001$.*

Adjustment Tasks

Statistical significance was not reached for the correlation between AQ in Task 3 to mean VE ($r = -0.239$, $p = 0.204$). However, a significant negative correlation was found between AQ in Task 4 and the mean variable error of adjustment differences ($r = -0.403$, $p = 0.027$). SQ did not significantly correlate with VE means for Task 3 ($r = 0.155$, $p = 0.415$; $r = 0.049$, $p = 0.799$) and Task 4 ($r = 0.047$, $p = 0.806$; $r = 0.039$, $p = 0.839$). Constant error was transformed to be positive by squaring all values and then taking their square root. The absolute values of constant error in Task 3 were not correlated with AQ ($r = -0.184$, $p = 0.330$) or SQ ($r = 0.221$, $p = 0.240$). Task 4 values were significantly negatively correlated with AQ ($r = -0.425$, $p = 0.019$) but not SQ ($r = 0.096$, $p = 0.613$). (see *Table 4*).



Outcome		AQ	SQ
Task 3 Variable Error	Pearson’s r	-0.239	0.049
	p-value	0.204	0.799
Task 4 Variable Error	Pearson’s r	-0.403 *	0.039
	p-value	0.027	0.839
Task 3 Absolute Constant Error	Pearson’s r	-0.184	0.221
	p-value	0.330	0.240
Task 4 Absolute Constant Error	Pearson’s r	-0.425 *	0.096
	p-value	0.019	0.613

Note. * p < .05

Table 4. Pearson’s correlation matrix between AQ and SQ to Task 3 and 4 adjustment magnitude error measures.

A linear regression was run to predict Task 4 mean VE from AQ. A significant regression equation ($F(1, 28) = 5.42$, $p = 0.027$) was found with an R^2 of 0.162. The predicted Task 4 mean VE is described by the equation: $32.309 + -0.395(AQ)$. This prediction equation states that participants' Task 4 mean VE of adjustment decreased by 0.403 with each single increase in AQ score (see *Figure 12*).

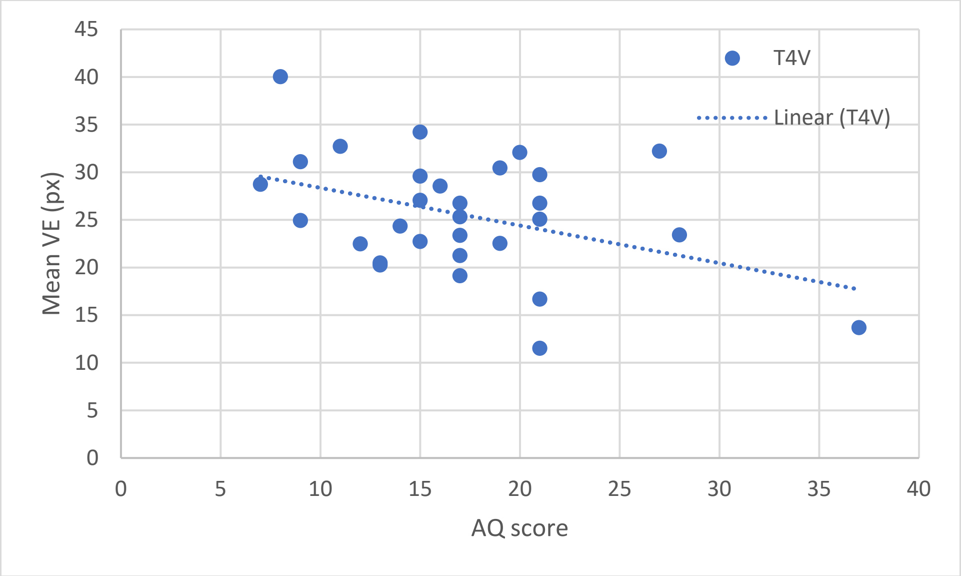


Figure 13. Relationship between AQ scores and mean variable error of adjustments in Task 4. $R^2 = 0.162$.

A linear regression was also run to predict Task 4 absolute values of mean absolute CE from AQ. A significant regression equation (F(1, 28) = 6.17, p = 0.019) was found with an R^2 of 0.181. An equation for predicting Task 4 absolute CE values by AQ was found: 23.446 + -0.304(AQ). Thus, as participant AQ increases by 1, CE absolute values of adjustment decrease by 0.304 (see *Figure 14*).

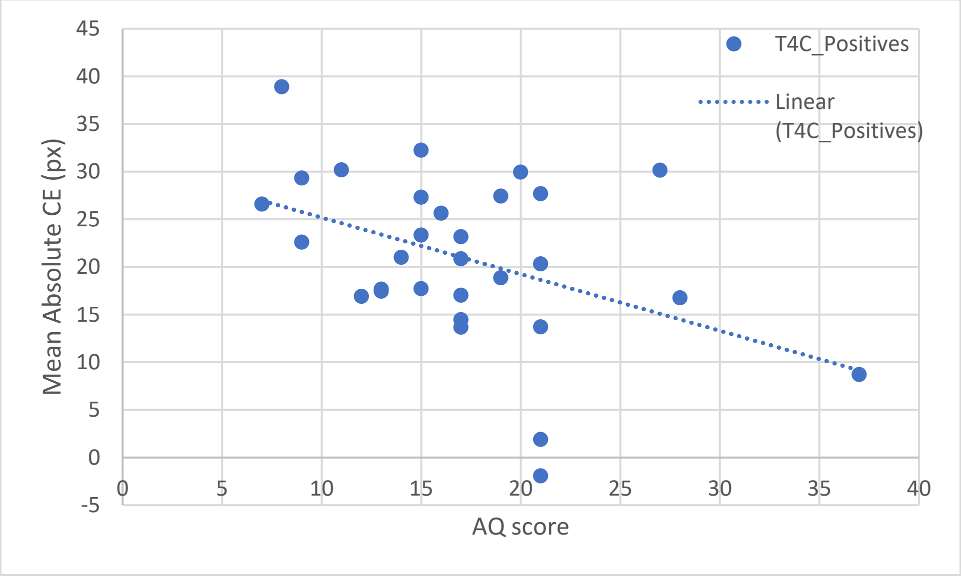


Figure 14. Relationship between AQ scores and mean absolute constant error of adjustments in Task 4. $R^2 = 0.181$.

Constant Error

Significant main effects in constant error were found for Task (F(1, 28) = 8.1786, η^2_p = 0.226, p = 0.008) and Target (F(1, 28) = 213.1905, η^2_p = 0.884, p < 0.001). Constant error for adjustment of the non-illusory figure (5.25px) was greater than adjustments of the illusory figure (2.67px). As well, trials where the target figure was oriented as wings-out were 32.4px larger than trials where the target figure was oriented as wings-in. Significant interaction effects in constant error were also found between Task and Target (F(1, 28) = 46.5349, η^2_p = 0.624, p < 0.001) with Tukey's HSD revealing mean differences between comparisons of all levels from factors were significant (ps < 0.001) (see *Figure 15)*. Interaction effects for constant error were not significant between task and sex (F(1, 28) = 0.0162, η^2_p = 0.001, p = 0.900); between target and sex (F(1, 28) = 0.6169, η^2_p = 0.022, p = 0.439); and between task, target, and sex (F(1, 28) = 0.4070, η^2_p = 0.014, p = 0.529).

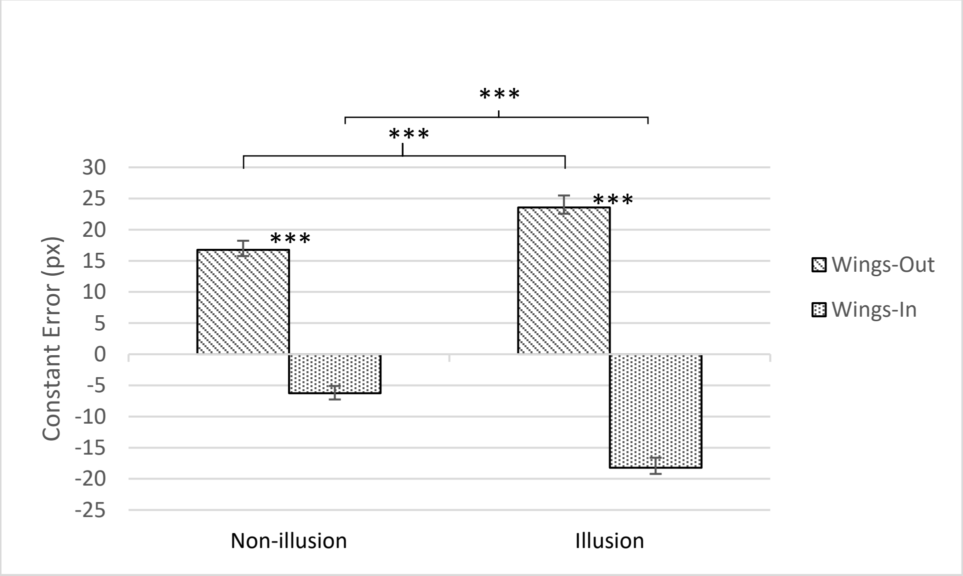


*Figure 15. Mean constant error of the interaction between task type and wing orientation. Error bars represent standard error. *** $p < 0.001$.*

Variable Error

Significant main effects in variable error were found for Task ($F(1, 28) = 72.864$, $\eta^2_p = 0.722$, $p < 0.001$). There was greater variable error in the illusory task (25.6px) relative to the non-illusory task (17.9px). There were also no interaction effects in variable error between task and sex ($F(1, 28) = 0.275$, $\eta^2_p = 0.010$, $p = 0.604$).

Discussion

The present thesis posited that perception, action, and behaviour are influenced by the relative weight put on past experience compared to current context. Collectively similar prior experiences exist in certain groups. Therefore, stimuli designed to be interacted with by a certain group sharing a common experience may not be as easily – or at least, as similarly – interacted with by those groups whose experiences are collectively different. Autistic individuals are theorized to upweight present sensory information and at the same time down-weight sensory information from past experience. In the present study, higher AQ/SQ scoring individuals were hypothesized to also weight present sensory information higher when performing different perceptual size judgement tasks. Given the current understanding of visuospatial illusions, greater weight on present sensory information should lead to decreased illusion susceptibility. Thus, the objective of the present study was to determine whether a correlation exists between autistic trait expression and ML susceptibility using two methods of perceptual measurement.

Participants in this study had AQ scores ranging from 7 to 37. Baron-Cohen et al. (2001), reported scores above 32 to be highly attributable to their participants with Asperger's Syndrome or High Functioning Autism. However, a score of 32 or higher did not lead to a diagnosis in their neurotypical participants as these participants did not express social or communication difficulties to meet the criteria for diagnosis. Participants in our study scoring higher than 32 were thus not excluded from analysis as an AQ score above 32 is not indicative of a diagnosis of ASD.

Correlation of Illusory Bias to Autistic Trait Expression

The primary hypothesis of this thesis predicted higher scoring AQ/SQ individuals would perform more accurately on the four experimental tasks compared to those with lower AQ/SQ scores. This hypothesis was tested using forced-choice selection tasks and length matching adjustment tasks. Outcomes from the forced-choice selection tasks showed differences in task performance where concurrent figure presentation resulted in greater illusion magnitude than successive presentation. A longer response time in the concurrent presentation condition is also consistent with decreased illusion susceptibility. However, contrary to the study predictions, there was a lack of any correlation between autistic trait expression and illusion susceptibility. Response time and its standard deviation in the forced-choice tasks also did not correlate with autistic trait expression.

The results from the adjustment tasks mirrored the above results when a non-illusory line was adjusted against a composite illusory target. However, when participants adjusted a paired illusion figure to a target illusory figure, performance showed a moderately positive correlation with AQ scores. Hence, in the concurrent illusion adjustment task higher AQ scores did correspond with more accurate task performance.

Task 1 – Forced Choice Concurrent; and Task 2 – Forced Choice Successive

Task 1 was a forced choice task that involved concurrent presentation of composite ML figures. When performing Task 1, participants determined the wings-out figure to be the longer of the pair more often than the wings-in figure. Participants also responded faster and more consistently when responding to trials where the wings-out figure was indeed the longer of the pair (see *Figures 10 and 11*). These results are in line with the expected illusory bias where participants perceived wings-out figures to more likely be the longer figure (even when they were not). Participants also required less time to decide on their response when selecting a wings-out figure. Combined with the decreased standard deviation in response time, it was suggested that participants’ faster and more consistent response times reflected their confidence in their decision. In contrast, participants tended not to select the longer wings-in figure, and deliberated for longer with larger response time variability, on trials where the wings-in figure was in fact longer. Successive presentation of the composite ML figures in Task 2 showed a similar bias towards selecting the wings-out figure as the longer of the pair (see *Figure 8*) with shorter response times in that selection (see *Figure 9*). The above findings are consistent with the expected illusory biases and thus indicate the tasks functioned as expected based on previous literature.

The results from the forced-choice tasks indicate that neurotypical participants' susceptibility to the ML cannot be predicted by AQ and SQ scores. Thus, the hypotheses stating reduced susceptibility to the ML with increasing AQ and/or SQ scores in neurotypical participants is rejected. To my knowledge, the present study is the first to investigate this relationship using a forced-choice task with both direct visual comparison of stimuli (Task 1), and memory-based comparison (Task 2). Specifically, Task 1 requires participants compare two externally generated figures, whereas Task 2 requires a memory representation of the first figure that is then compared to a subsequently presented figure. Together the results of these two tasks provide insight into the perceptual mechanisms governing visuospatial illusions and the relationship to autistic traits. Specifically, illusory magnitude was *not* related to autistic traits when participants made forced choice decisions in the presence, and in the absence, of direct, real-time, visual comparison.

The results from the forced-choice tasks of the present study are consistent with those of Happé (1996) and Schwarzkopf et al. (2014) in that susceptibility to the various illusions was not influenced by autistic traits, and add to the literature investigating ML susceptibility in people with higher autistic trait expression. The forced-choice method for determining illusory susceptibility used in the Tasks 1 and 2 is similar to the procedure Schwarzkopf et al. (2014) used. They studied the susceptibility of neurotypical participants and participants with Asperger's syndrome to the Ebbinghaus illusion. The authors found both groups to be equally susceptible to the illusion.

Similarly, Happé (1996) reported that children with autism were less susceptible to most of the six illusions they tested, but that all groups experienced equal susceptibility to the ML illusion. Along with the different participant demographics, their study differed from the present study in that instead of judging which ML figure was longer, experimenters used comparison cards and asked participants to judge whether the figures were of the same or different lengths. Specifically, participants were asked to determine whether there *was* a longer line (as in Happé, 1996), but not *which* line was longer. While the present study's results cannot be directly compared to the Ebbinghaus study by Schwarzkopf et al. (2014), or the results from the younger participants of Happé (1996), the similarity in methods of using a forced choice paradigm and the lack of influence of autistic traits on the perceived size difference is important to note.

While there was a lack of difference in ML susceptibility with forced-choice tasks in Happé (1996) between autism and control participants and also between the neurotypical participants and participants with Asperger's in the study by Schwarzkopf et al. (2014), others have reported a difference in illusion susceptibility in autism with adjustment-based tasks (Manning et al., 2017; Ropar & Mitchell, 1999). Likewise, the present study found a lack of difference between autistic trait expression, as measured by AQ or SQ, and susceptibility to the ML with forced-choice tasks, but greater performance by those with higher autistic trait expression in the adjustment of illusion task (Task 4).

Task 3 – Adjustment of Non-Illusion; and Task 4 – Adjustment of Illusion

The constant error of the adjustment figure compared to the target figure found illusory bias to exist in the expected directions (*see Figure 14*). That is, when wings-out or wings-in figures were presented as targets, participants overestimated or underestimated the figure sizes, respectively. These over- and underestimations were evidenced by longer or shorter adjusted figure lengths, respectively, relative to the target size. When a wings-out target figure was to be matched, participants adjusted their line (Task 3) or composite ML figure (Task 4) to be larger than the target. Conversely, when a wings-in target figure was to be matched, participants adjusted their line or composite ML figure to be shorter than the target. The direction and magnitude of these results are the expected biases of the ML illusion. Thus, the two tasks produced the typical illusory effect.

Illusion susceptibility to the ML appeared to attenuate with increasing autistic trait expression, but under limited or specific task circumstances. Confirming a hypothesis for adjustment tasks, variability in adjustment length differences and adjusted figure length differences to target figures decreased as participant AQ increased (see *Figure 13 and 14*). Notably, this relationship only existed when participants compared the composite figure pairs in Task 4 and not when adjusting a non-illusory line in Task 3. Contrary to my hypothesis no such relationships were found for participant SQ (see *Table 4*).

Adjusting a non-illusory figure to an illusory target is considered a separate comparison, whereas adjusting an illusory figure to a composite illusory target is considered direct comparison (Foster & Franz, 2014). Manning et al. (2017) used a direct comparison adjustment task for the ML with children with and without autism and found children with autism to express a slightly increased susceptibility to the ML. Importantly, in the present study, a relationship of increasing AQ and decreased illusion susceptibility was only present in direct comparison – when adjusting a ML figure to its composite pair ML figure target – but not in separate comparison. The findings from the present study are contrasted by Chouinard et al. (2013) who found susceptibility to the ML to decrease with increasing AQ using a separate comparison task. However, Walter et al. (2009) and Chouinard et al. (2016) were unable to find this same relationship with separate comparison. The results of Manning et al. (2017) run contradictory to those of the present study as they show an increased susceptibility to the ML in people with autism, but are confounded for comparison by their participants' younger age and their formal autism diagnosis. Nevertheless, the effect of attenuated illusory magnitude from the ML by increasing autistic trait expression in neurotypicals may be conditional on task details, including the method of adjustment.

Conditions to Müller-Lyer Susceptibility

The biased figure selection refers to selection of the wings-out figure as being the longer figure when it was in fact the shorter of the pair. The perceived shortening of the wings-in figure's shaft makes it appear to be shorter than its veridical size. Thus, participants incorrectly selected the shorter wings-out figure during forced-choice perceptual judgments. The amount of time participants required to select a figure was determined by response time. A longer and more variable response time implies greater cognitive resources were required to make the size discrimination. My hypotheses stated biased figure selections in Task 1 and Task 2 would positively correlate with RT and RTSD. As these hypotheses were constructed with the assumption that task performance would be better in those with greater confidence in figure selection, shorter response times with tighter variability would have been considered a function of greater confidence in selection and thus reduced susceptibility. These hypotheses were rejected as significant negative correlations were found for all relationships except between Task 2 biased figure selection and RT (see *Table 3*). Upon reflection, the hypothesis neglected other aspects of perception and cognition involved in making the selection, specifically, the effect of stimuli presentation time. A longer response time also afforded participants with longer viewing time.

A likely explanation for the response time negative correlation to biased figure selection from Task 1 is that the increased stimuli viewing time allowed for a decrease in illusion susceptibility. A study by de Brouwer et al. (2014) indicated very short presentation times resulted in increased illusory effect to the ML whereas longer presentation times attenuated the effect. The results of the present study coincide with their findings as longer response times, and thus effectively longer presentation times, saw a decreased illusory effect illustrated by fewer biased figure selections. Performance on the tasks also differed based on how the figures were presented. In line with my hypothesis, performance on the forced-choice tasks was biased further when the figures were presented concurrently, rather than successively (see *Figure 8*). That is, participants were more strongly affected by the illusion when they had to directly compare, simultaneously, a wings-out figure and a wings-in figure. As fewer biased figure selections imply a reduced illusory effect and biased figure selections negatively correlated with RT, it may be proposed that reduced illusion susceptibility to the ML results in longer RTs. However, this relationship was only apparent when figures were presented concurrently. While the successive presentation task imposed a relatively smaller illusory bias and a shorter response time, the lack of any relationship between these outcomes implies that accurate size discrimination of illusory figures in memory are not dependent on longer viewing times.

In the present study, the concurrent presentation task provided 1000ms viewing time for both composite figures. On the other hand, the successive presentation task provided 1000ms viewing time for each figure as each was presented separately. It may be argued that the successive presentation task thus afforded participants with greater viewing time than the 1000ms the concurrent task afforded. In the study by de Brouwer et al. (2014), they found longer presentation time of the ML as the primary reason for decreased illusory effect. However, in their study, presentation times of 200 and 306ms were found to be significantly different in terms of the magnitude of illusory effect from presentation times of 706 and 1000ms, but the difference between 706ms and 2000ms were not significant. Thus, although a longer presentation time may result in decreased illusory effect, the viewing durations employed in the present study should not account for the resulting decreased illusory effect. Illusory bias in de Brouwer et al. (2014), was stronger with a presentation time of 306ms than it was with a presentation time of 706ms. Treating the present study's similar mean RTs of 357ms for the successive presentation task and 587ms for the concurrent presentation task (see *Figure 9*) as effective viewing times suggests a contribution of viewing time to the differing levels of bias. The shorter viewing time in the concurrent presentation task may have increased illusory bias relative to the longer viewing time and lesser illusory bias of the successive presentation task.

Decision times were more consistent in concurrent presentation than those made after successive presentations. The relationship between illusion magnitude and consistent decision time was also stronger when figures were displayed concurrently rather than successively. Having the stimuli presented one at a time, as in the successive task, required participants to store the first presented figure's size in memory. The stored memory of the first figure needed to then be compared to the newly presented figure after a short period of time. Therefore, participants needed to make size comparisons using their memory of figure lengths in the successive task. Memory may have played an attenuating role in the consistency of participant decision times. Specifically, relying on memory could have induced a less reliable internal representation of size differences. Although biased figure selections in the successive task was less than in the concurrent, this perceived lacking reliability of stored figure size representations in memory may have made decision time less consistent. Additionally, the inconsistent decision times in successive presentation provides evidence for accurate discrimination not necessitating longer viewing times. Conversely, the consistency in decision times for concurrent presentation implies this longer viewing time is in fact necessary for accurate size judgements. This interpretation of the study’s results proposes the utilization of memory in the perceptual judgment task seemed to reduce the illusory magnitude of the ML illusion, independent of viewing time.

A reduction in ML illusory magnitude with the use of memory during a perceptual judgement task is contradictory to current understanding of how memory and illusion magnitude interact when performing goal-directed actions. When acting on illusions, the utilization of memory produces a greater illusory magnitude (Bruno & Franz, 2009a). Visually guided action is understood to be guided by dorsal stream representations. However, when action is guided by memory, in the case of action towards stimuli that are no longer visible, it is instead thought to be controlled by the ventral stream (Goodale et al., 2004). Goodale et al. (2004) suggested the dorsal stream representation perceives the environment irrespective of context and in real-time so that actions are precise towards potentially moving stimuli, whereas the ventral stream representations are made to be relative to their environment and surroundings (Goodale & Milner, 1992b). Bruno and Franz (2009) have argued that continuous visual feedback of the illusory target and the grasping hand aids in the supposed immunity of action to illusions. The absence of visual feedback, where action is controlled by a memory-based representation of the target, results in increased illusory effects. The reduced susceptibility to the ML by perceptual judgement when composite figures were compared through memory implies further differences in illusory effects between action and perception that are not explained easily by dorsal and ventral stream operations. That is, perceptual judgements and action guided by memory are both posited to utilize the ventral stream. It appears then whereas the use of memory in ventral stream guided action produces increased illusory effect, the present study found that using memory in ventral stream guided perceptual judgements produces decreased illusory effects.

Perceptual judgment results from Experiment 1 of Glazebrook et al. (2005) found participants had longer response times when figures appeared similar in size to their comparator lines, which was interpreted as a condition where greater discrimination difficulty existed. Greater size discrimination difficulty in the ML, leading to increased response times, implies increased illusory effects. Concurrent presentation of composite ML figures causes a perceived reduction in size differences between the two figures. Importantly, this reduction is relative to the larger perceived size difference when the figures are presented successively. Thus, the findings from the present study's forced-choice tasks' RT and biased figure selection results further suggests that simultaneous, composite figure presentation increases the illusory effect of the ML.

Superadditivity

A reduced illusory magnitude during a memory-based perceptual task is contested by Franz et al. (2009). Specifically, these authors found no difference in illusory magnitude when there was and was not inclusion of a 5-second delay between illusion presentation and the comparison bar presentation. The contrasting results between the study by Franz et al. (2009), which used a non-illusory comparison bar, and the present study, which used an illusory comparison figure, may be explained by superadditivity. Superadditivity in illusions is the phenomenon that occurs when directly comparing two composite versions of the same illusion. The combination of illusory figures results in a larger illusory effect than would otherwise be seen when only assessing one of the composite pair. In the case of the ML, superadditivity means a wings-out ML appears larger when presented alongside a wings-in ML than it would be when presented alone. This phenomenon has been found to occur with adjustment tasks for the Ebbinghaus illusion (Foster & Franz, 2014; Franz et al., 2000), and sometimes the ML (Foster & Franz, 2014; Gilster & Kuhtz-Buschbeck, 2010). In the present study, concurrent presentation of composite figures may have contributed to a superadditive illusory effect. That said, the superadditive effect has only been investigated using adjustment tasks and only with simultaneous adjustment (adjusting one figure adjusts the other in the opposite direction), not independent adjustment (adjusting only the size of one figure) in the ML (Foster & Franz, 2014). In the present study, superadditivity is suggested to have been present in the concurrent forced-choice task and the concurrent illusion adjustment task. The superadditive effect would have increased illusory bias magnitude in these two tasks.

Direct and separate comparison have been studied in both the ML and the Ebbinghaus illusion to determine the presence of superadditivity. Consistent with my predicitons, there was improved task accuracy in Task 3's separate comparison while a superadditive effect was found during Task 4's direct comparison. Specifically, the difference in absolute constant error was larger in direct comparison than in separate comparison when wing orientation was factored in (see *Figure 15*). Participants were also more variable in their adjustments during direct comparisons which suggests they were less confident in length determinations. Together, these findings clearly illustrate the presence of increased illusory magnitude during direct comparison – implying superadditivity.

The finding of increased illusory magnitude during direct comparison is contrary to Gilster and Kuhtz-Buschbeck (2010) who reported not finding a superadditive effect during direct comparison of the ML in their perceptual experiment. However, and notwithstanding the smaller sample size of their experiment (n=8), this contrary finding may be explained by their additional same configuration adjustment (SCA) condition wherein participants made adjustments to a figure that had the same wing orientation as the target figure. That is, participants adjusted a wings-in figure to a wings-in target figure and a wings-out figure to a target wings-out figure. They analyzed the difference in illusion magnitude between the direct comparison condition and the SCA condition results and found no increased illusory effect. The authors do note that had they not compared to the SCA condition results, and instead compared the adjustments in the direct comparison to the real lengths, their results in the direct comparison would have shown a superadditive illusory effect (Gilster & Kuhtz-Buschbeck, 2010). Thus, those results do in fact mirror the present study's. The direct comparison condition of the present study (i.e., Task 4) increases the illusory magnitude of the ML by facilitating superadditivity.

Sex Differences

The present study also found an absence of contribution from sex differences to performance on all four of the illusory tasks. That is, cis females and cis males showed equal susceptibility towards the ML. Observing a sex-based advantage was not hypothesized and the results here are in-line with those of R. E. Dewar (1967a), where the difference between sexes on ML susceptibility was also found to be negligible. Phillips et al. (2004) did, however, find a performance benefit for males during a forced-choice Ebbinghaus figure task. They interpret their data to suggest males to be less context-sensitive than females in their sample, but state their evidence is not overtly indicative of genetic contribution and suggest further investigation of the phenomenon. The claim of male's reduced reliance on context is repeated by Hansen and Elliott (2006), who found males' grip apertures to rectangular target stimuli were not be affected by the presence of smaller or larger rectangles that were meant to induce a size bias on the target. Conversely, females did show a context-induced biased grip aperture. It has also been suggested that cis males score higher on the AQ and SQ than cis females (Baron-Cohen et al., 2001), and this finding could justify hypothesizing a sex-based advantage in illusion susceptibility favouring cis males in subsequent studies. However, while cis males did score higher on the SQ than cis females in the present study, they did not differ in AQ scores and their performance on outcome measures also did not differ. Thus, while sex was indeed a significant variable determining SQ in the current sample, it was not a significant variable in determining illusion susceptibility.

Implications

The results of the present study contribute to our understanding of perceptual processing by assessing how individuals with varying autistic and systemizing traits perform different perceptual illusion discrimination tasks. With one exception, higher autistic trait expressions were not related to decreases in Müller-Lyer illusion susceptibility in every measure of the current study. The one exception occurred during direct comparison in Task 4 in which illusory magnitude was inversely related to AQ only. Chouinard et al. (2013, 2016), Manning et al. (2017), and Walter et al. (2009) also used adjustment tasks, but only Chouinard et al. (2013) found a reduced susceptibility relationship with increasing AQ. Manning et al. (2017) conversely found the opposite relationship with adolescents diagnosed with autism. Thus, the findings are mixed in the direction of the effect for a relationship between AQ score in neurotypicals and ML illusion susceptibility. When compared to findings from forced choice paradigms, any relationship appears to be specific only to adjustment tasks. I suggest further investigation into the effects of AQ on ML illusion susceptibility and other size contrast illusion susceptibility using adjustment tasks is needed in order to clarify under what task conditions a relationship is present and the direction of the relationship.

In the present study, the positive correlation between participants' autistic trait expression and their performance on the ML direct comparison perceptual adjustment task provides evidence for the Bayesian predictive coding perspective. The Bayesian predictive coding model supposes behaviour (the posterior probability) is governed by combined weighting of past experience (prior probability) and present sensory information (likelihood probability) (Lawson et al., 2014).

Bayesian predictive coding in the context of autism posits a reduced reliance on prior information, such as environmental experience, and a greater weight on present sensory information in analysis and execution of the present tasks. Reduced illusory bias in the direct comparison adjustment task by higher AQ scoring individuals can be interpreted as a down-weighting of prior information and an upweighting of present information. Decreases in illusory bias would result from the increased weighting of the present visual input – seeing two composite ML figures – as compared to how much weight or emphasis is placed on previous experiences – the effect of induced depth present in ML figures. In summary, reduced susceptibility to the direct comparison ML adjustment task with higher AQ scores is in line with, and thus supports, the Bayesian predictive coding perspective.

When considering the broader implications of the present research, I suggest perception of the world to be based on individual prior experiences unique to each person. A recent and tragic example of reliance on experience of perception and action can be found in the infamous Boeing 737 MAX crashes of October 2018 and March 2019. In March of 2019, a Boeing 737 MAX took off. In moments, the plane began to nose-dive unexpectedly. The two pilots used regular operation procedures when the plane began to nose-dive. Those procedures failed to correct the plane’s pitch. Unfortunately, a newly added software forced a nose-dive in lieu of the pilots’ efforts. When the pilots finally disabled the software, it was too late – the plane was too low to effectively control. Prior experience dictated to the pilots that they should operate as usual. The drop in pitch stimulus received by the pilots resulted in implementing the learned pitch correction procedures. The pilots had no reason to adjust their reliance to shift it to be more heavily influenced by any new information as the precision of their weighting on prior experience was produced from external assurances by a governing body. In the context of this study, higher autistic trait expression may have biased performers to more heavily weight new information over old information when directly comparing two illusory figures that induce superadditivity of the illusory bias. This is not to suggest people with autism piloting the planes would have changed the severity of the devastating crashes. The pilots were not given proper notice of the new system's characteristics, and therefore were lacking any impetus to shift to considering it as a consequential detail of operation. Instead, proper and responsible notice from Boeing to pilots would have heightened the likelihood of the pilot's disabling the software when the systems malfunctioned.

Delimitations

Although biased figure selection differences between Task 1 and Task 2 may be compared, it is possible that response time and RT standard deviation outcomes between these two tasks may not be directly compared because of task design differences which became apparent following data acquisition and analysis. In Task 1, participants needed to view the illusory figures, decide on a response, and respond on the same slide. However, in Task 2, participants could decide on their response in the second figure presentation slide and prepare to respond immediately upon presentation of the response slide. This difference may be observed by looking at the range of response times in Task 1 (417-710ms) versus those of Task 2 (184-535ms). It seems likely that participants in Task 2 could decide on their response at some point during the second figure presentation slide and would be waiting to respond immediately upon response slide presentation. Thus, a comparison of RT and RTSD between the two tasks may be akin to comparing a complex response time (Task 1) to a simple response time (Task 2).

There were limitations of the data collection method for the present study that may have caused deviations from predicted outcomes. The online and remote nature of the current experiment is different from the in-person and lab-based protocols employed in the studies with which I constructed my hypotheses. In-person lab-based experiments give the experimenter more oversight over adherence to protocol. There were likely large variances in protocol adherence between participants in my study which caused unaccounted noise in analyses. Differences would include viewing distance to the screen and the screen's refresh rates, keyboard size and thus responding finger placements, keyboard input latencies, and also environmental distractions both visual and auditory. Additionally, far less in known about perceptual differences between neurotypicals placed along the spectrum of autistic trait expression via the AQ, and even more so the SQ, than differences in perception comparing neurotypical to autistic participants.

Conclusion

The present study adds evidence to doubt the existence of straightforward immunity to ML susceptibility in people expressing higher autistic traits while, at the same time, suggesting reduced biases may exist in some special cases. Specifically, the attenuating effect of AQ on illusion susceptibility was found only in an adjustment task where superadditivity was present. That is, the relationship of reduced illusory bias with increasing AQ scores existed only when illusory pairs were presented together in an adjustment task. Thus, higher autistic trait expression without diagnosed autism may present a more muted change in how visual stimuli are perceived. The findings of the present study show the relationship between illusion susceptibility and autistic trait expression to be task dependent. Hence, changes to illusion susceptibility as a function of autistic trait expression should be further investigated using adjustment-based tasks in order to elucidate how figure adjustment modifies size perception and why this modification varies with autistic trait expression.

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Appendix A – Consent Forms

Informed Consent

Title of Study: How do individual traits influence perception of visual illusions?

PRINICIPAL INVESTIGATOR:	Dr. Cheryl Glazebrook Faculty of Kinesiology & Recreation Management University of Manitoba (204) 474-8773 cheryl.glazebrook@umanitoba.ca
OTHER INVESTIGATORS:	Ganesh Tailor Master's of Science student Faculty of Kinesiology & Recreation Management University of Manitoba [redacted] tailorg@myumanitoba.ca

SOURCE OF SUPPORT: Natural Sciences and Engineering Research Council (NSERC)

This consent form, a copy of which will be left with you for your records and reference, is only part of the process of informed consent. It should give you the basic idea of what the research is about and what your participation will involve. If you would like more detail about something mentioned here, or information not included here, you should feel free to ask. Please take the time to read this carefully and to understand any accompanying information.

PURPOSE: The purpose of this study is to examine how individual traits influence perception of visual illusions when performing size estimation tasks. Methods for measuring size estimation of visual illusions will also be investigated to determine how their inherent biases differ.

DESCRIPTION: During the study, you will participate in four tasks. In the first and second you will be asked to look at figures on your own computer screen and respond by keypress which figure you believe to be longer. In the third and fourth tasks you will be asked to adjust the figure by keypress to match its size to another figure. Prior to this task, you will be asked to fill out a brief demographics questionnaire that asks about your age, gender, handedness, whether you wear glasses, and whether you have ever been diagnosed with an Autism Spectrum Disorder. You will also work through a pair of questionnaires with the experimenter. One will quantify your individual, non-diagnostic, autistic trait expression and the other will quantify your systemizing ability. The whole procedure will take approximately 60 to 90 minutes to complete.

RISKS AND BENEFITS: There are minimal risks inherent in the tasks you will perform but some of the tests may become repetitive and you may experience boredom and/or mild muscle fatigue in your hands. You are free to take a break as needed.

Participation in this experiment will not directly lead to any health benefits. You will gain knowledge of current perceptual and behavioural research. Participation in this experiment will contribute to our understanding of how humans perceive visual illusions and how those perceptions differ as a function of behavioural traits. It will also contribute to understandings of illusory measurement techniques.

COSTS AND PAYMENTS: There are no fees or charges to participate in this study. You will receive a $15 e-mailed gift card for Amazon.ca to thank you for donating your time.

CONFIDENTIALITY: Your information will be kept confidential. Once you begin the study your name, information, and results will be referred to by a code number. All files containing identifying information will be stored on a secure, password protected, and encrypted drive with your code number. The Principal Investigator, Dr. Cheryl Glazebrook, and other investigators will have exclusive access to identifying information. Your files will only be accessible by the investigators and will be destroyed by Dr. Glazebrook seven years after the completion of the study (approximately Dec 2028). All documents containing personal information will be destroyed and all electronic files will be deleted. Only Dr. Glazebrook and the other investigators listed will have access to any lists that contain identifying information. Dr. Glazebrook will only access the consent forms if audited by ENREB or when it is time to destroy the consent forms.

Results will be presented at academic conferences, invited presentations, and peer-reviewed academic journals. No identifying information will be used in any presentations.

DEBRIEFING: Upon completion of the study, the experimenter will describe the research questions being considered.

VOLUNTARY CONSENT: Participation in this study is strictly on a voluntary basis, and you can withdraw from the study at any time during the study or by contacting the PI or student research assistants in person, by phone, or email. If you do not wish to participate in the study, you are free to withdraw from the experiment at any time without consequence and we thank you for your consideration. Upon withdrawal from the study, you will still receive an honorarium of a $15 e-mailed gift card to Amazon.ca, and your data will be destroyed. You can withdraw from the study by telling the RA in person, through e-mail or by calling the number on this form.

Your signature on this form indicates that you have understood to your satisfaction the information regarding participation in the research project and agree to participate as a subject. In no way does this waive your legal rights nor release the researchers, sponsors, or involved institutions from their legal and professional responsibilities. You are free to withdraw from the study at any time, and /or refrain from answering any questions you prefer to omit, without prejudice or consequence. Your continued participation should be as informed as your initial consent; feel free to ask for clarification or new information throughout your participation. If you choose to withdraw from the study you will still receive compensation for the time you have participated. The University of Manitoba may look at your research records to see that the research is being done in a safe and proper way.

This research has been approved by the Education/Nursing Research Ethics Board. If you have any concerns or complaints about this project you may contact any of the above-named persons or the Human Ethics Coordinator (HEC) at 474-7122 or humanethics@umanitoba.ca**.**

A copy of this consent form has been given to you to keep for your records and reference.

Participant's Name ____________________________

Participant's Signature ____ Date ____________

Researcher/ Delegate's Signature __________________________________Date ___________

FINDINGS FROM THE STUDY: I wish to have a summary of the findings of the current study sent to me upon completion of the current study.

(check one) YES NO

If "YES", this is my preferred method of contact (please fill one):

Address: ____________________________________

____

Email: ____________________________________

COVID-19 Consent

Research Project Title: How do individual traits influence perception of visual illusions?
Principal Investigator and contact information: Ganesh Tailor
Research Supervisor (if applicable) and contact information: Cheryl M. Glazebrook
Co- Investigators (if applicable) and contact information: ______________________
Sponsor (if applicable): ____

This document contains important information about in-person research during the COVID-19 public health crisis. COVID-19 (also called SARS-CoV2) is an illness caused by the coronavirus. Coronaviruses are most commonly spread from an infected person through: a) respiratory droplets when you cough or sneeze; b) close personal contact, such as touching or shaking hands; or c) touching something with the virus on it, then touching your eyes, nose or mouth before washing your hands.

The University of Manitoba is committed to taking measures to protect the health and safety of their campuses and the wider community. Your safety is important to us. The university has suspended most research that cannot be conducted remotely or virtually. This project requires in-person visits. Therefore, it is important to understand that your participation in this study may increase your exposure to COVID-19.

Our project has been approved to proceed by the Research Ethics Board, our Faculty, the COVID Recovery Response Team, the COVID Recovery Steering Committee, and the University Provost. In order to gain approval, we created policies to ensure the safety of the research team and participants. These plans were reviewed and approved by the parties above. These precautions include:

- The study will be conducted online using the participant's personal computer, unless the participant requests to use the research study's designated computer. - If the research study's computer is requested by the participant, research equipment will be delivered to the residence or preferred place of testing - Physical contact or approach within 6 ft. of any person will not occur at any time - Research staff will not enter the participant's residence or place of testing - Sanitizing fluid will be used to sanitize the research equipment before delivering it to the participant to perform the experiment - Hand sanitizer will be used by the research staff before handling the research equipment - All research staff will wear masks while handling the research equipment and we will ask all participants to wear a mask while handling the research equipment - All research staff will wear gloves while handling the research equipment - Research staff will screen themselves and each participant for symptoms the day of their equipment delivery and study participation using the Manitoba COVID-19 Shared Health Screening Tool (https://sharedhealthmb.ca/covid19/screening-tool/) - We will ask participants for their contact information so that we may inform them if there is a risk of COVID-19 exposure to them as a result of your participation. We also ask particpants to contact reserach staff if they suspect their participation may have caused the transmission of COVID-19 to research staff

COVID-19 is a serious health threat and the situation is evolving rapidly. If you feel that you are from a group that is more vulnerable to COVID-19 effects (e.g., senior (over the age of 60 years), immuno-compromised), please discuss your participation with the research team before providing your consent. You are under no obligation to participate and can change your mind about participating in the research at any time and without consequence.

The University of Manitoba is closing watching the situation in Manitoba and may restrict in-person research at any time. We will continue to keep you informed as to changes that may occur to this study.

There is a possibility that during your participation in the study you could come into contact with someone with COVID-19. We are required to collect your personal contact information that we must retain in order to follow up with you and/or conduct contact tracing if you may have been exposed to COVID-19 in coming to the research site. **We cannot guarantee anonymity as the personal contact information identifies you as a participant and we may be required to disclose this information in the event of a possible exposure.** Your contact information will be kept separately from data collected through the research study to allow for de-identification of the research data. You maintain your right to withdraw from the study at any time, including your research data. If you do withdraw from the study, we will still need to continue to maintain your contact information and will only give it to the University's Environmental Health and Safety (EHS) Office and/or Manitoba Health if required for contact tracing. Please note, Manitoba Health or the University's EHS office will not have access to your research data.

If you have questions regarding this study, measures we are taking to keep all parties safe, or have any concerns, please do not hesitate to ask. You can contact any of the above named researchers or the Human Ethics office at humanethics@umanitoba.ca.

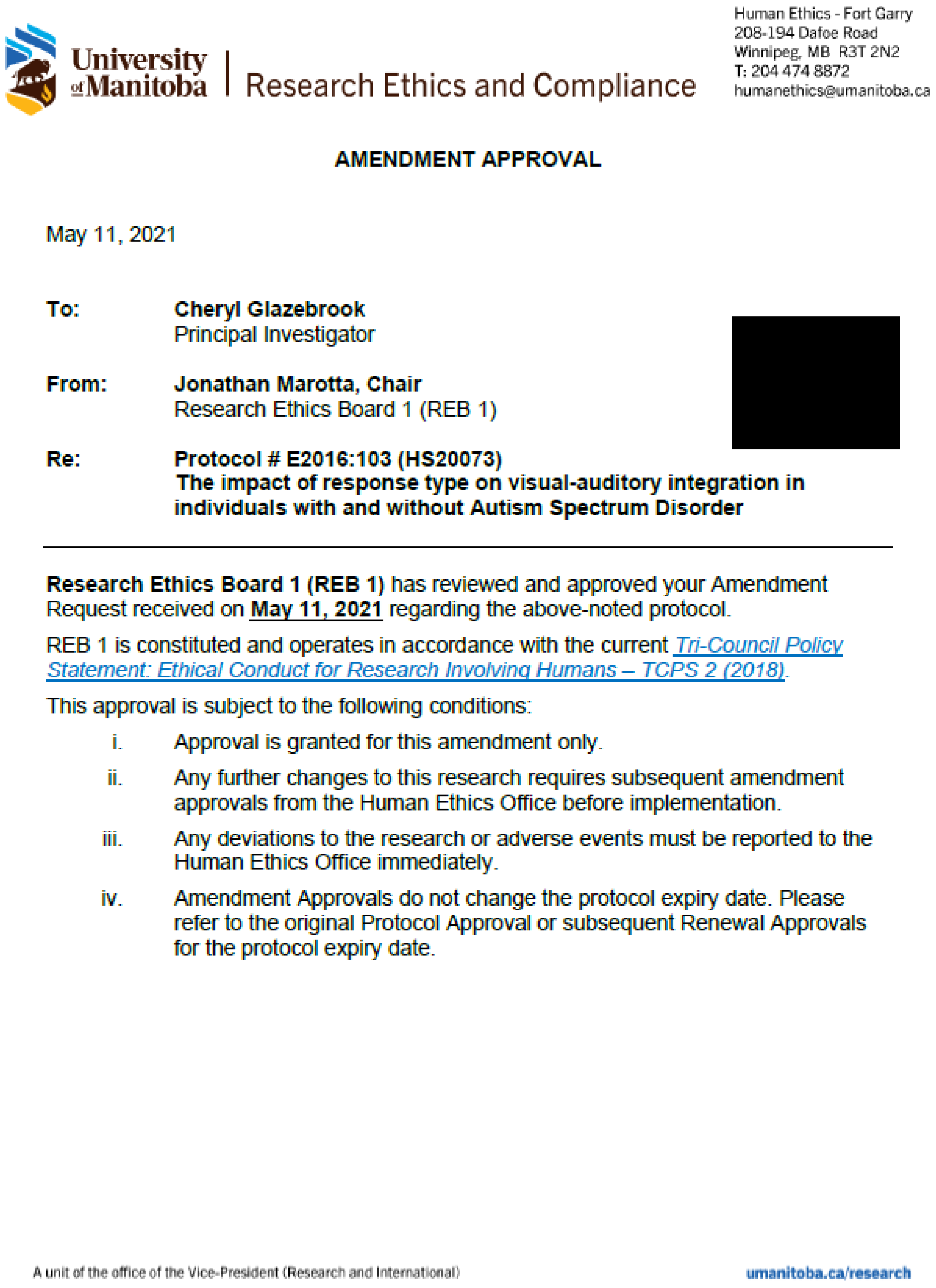
Your signature on this form indicates that you have understood to your satisfaction the information regarding participation and the COVID-19 risk and agree to participate. In no way does this waive your legal rights nor release the researchers, sponsors, or involved institutions from their legal and professional responsibilities. Your continued participation should be as informed as your initial consent, so you should feel free to ask for clarification or new information throughout your participation.

Participant Name ________________________

Contact Information (phone # or email): __________________

Participant's Signature ___________________________ Date: _________________

Appendix B – Ethics Certificate of Approval



University of Manitoba | Research Ethics and Compliance

Human Ethics - Fort Garry
208-194 Dafoe Road
Winnipeg, MB R3T 2N2
T: 204 474 8872
humanethics@umanitoba.ca

AMENDMENT APPROVAL

May 11, 2021

To: **Cheryl Glazebrook**
Principal Investigator

[redacted]

From: **Jonathan Marotta, Chair**
Research Ethics Board 1 (REB 1)

Re: **Protocol # E2016:103 (HS20073)**
The impact of response type on visual-auditory integration in individuals with and without Autism Spectrum Disorder

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Research Ethics Board 1 (REB 1) has reviewed and approved your Amendment Request received on **May 11, 2021** regarding the above-noted protocol.

REB 1 is constituted and operates in accordance with the current *Tri-Council Policy Statement: Ethical Conduct for Research Involving Humans – TCPS 2 (2018)*.

This approval is subject to the following conditions:

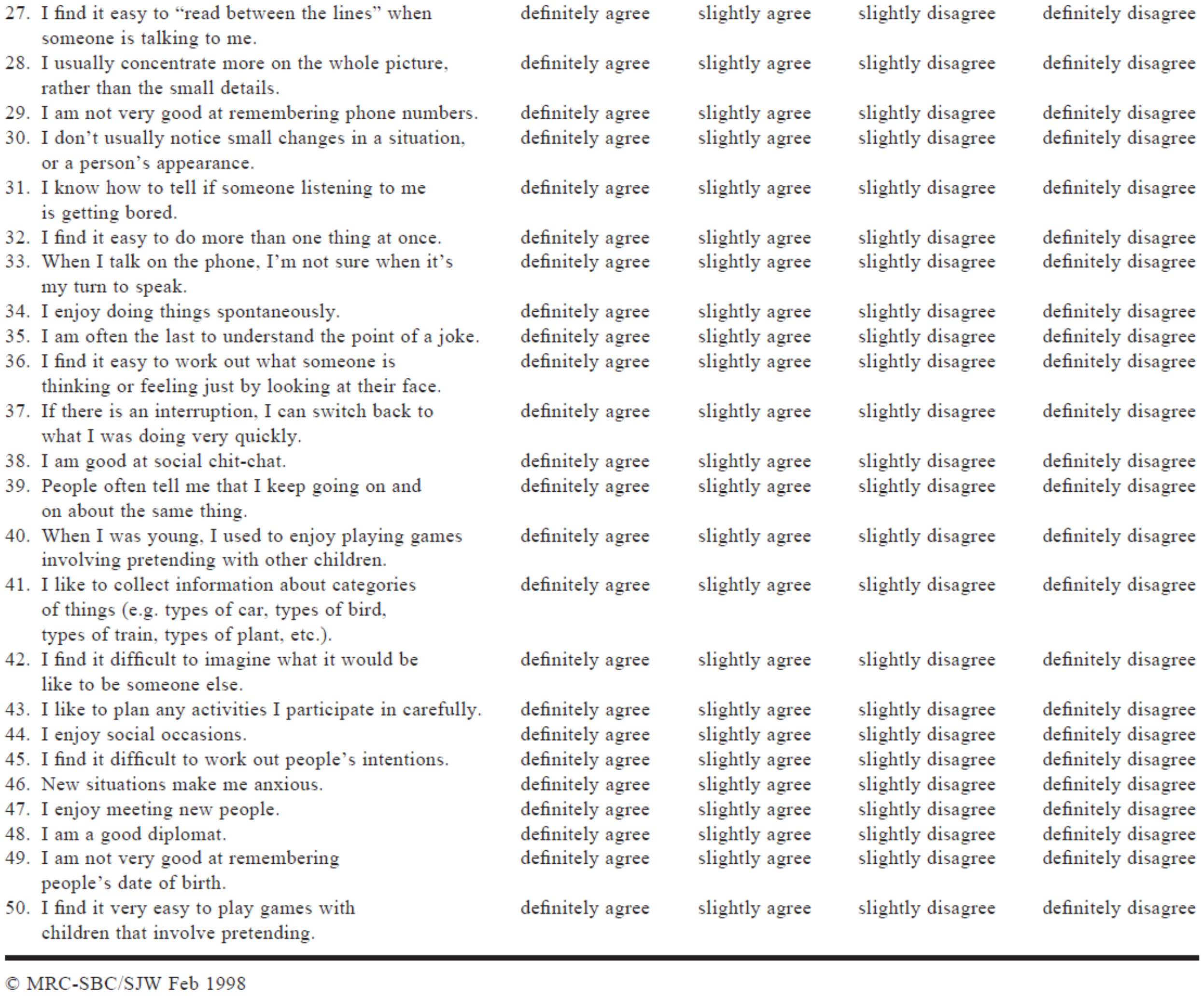
- i. Approval is granted for this amendment only.
- ii. Any further changes to this research requires subsequent amendment approvals from the Human Ethics Office before implementation.
- iii. Any deviations to the research or adverse events must be reported to the Human Ethics Office immediately.
- iv. Amendment Approvals do not change the protocol expiry date. Please refer to the original Protocol Approval or subsequent Renewal Approvals for the protocol expiry date.

A unit of the office of the Vice-President (Research and International) umanitoba.ca/research

Appendix C – Questionnaires

Adult Autism Quotient

1. I prefer to do things with others rather than on my own.	definitely agree	slightly agree	slightly disagree	definitely disagree
2. I prefer to do things the same way over and over again.	definitely agree	slightly agree	slightly disagree	definitely disagree
3. If I try to imagine something, I find it very easy to create a picture in my mind.	definitely agree	slightly agree	slightly disagree	definitely disagree
4. I frequently get so strongly absorbed in one thing that I lose sight of other things.	definitely agree	slightly agree	slightly disagree	definitely disagree
5. I often notice small sounds when others do not.	definitely agree	slightly agree	slightly disagree	definitely disagree
6. I usually notice car number plates or similar strings of information.	definitely agree	slightly agree	slightly disagree	definitely disagree
7. Other people frequently tell me that what I've said is impolite, even though I think it is polite.	definitely agree	slightly agree	slightly disagree	definitely disagree
8. When I'm reading a story, I can easily imagine what the characters might look like.	definitely agree	slightly agree	slightly disagree	definitely disagree
9. I am fascinated by dates.	definitely agree	slightly agree	slightly disagree	definitely disagree
10. In a social group, I can easily keep track of several different people's conversations.	definitely agree	slightly agree	slightly disagree	definitely disagree
11. I find social situations easy.	definitely agree	slightly agree	slightly disagree	definitely disagree
12. I tend to notice details that others do not.	definitely agree	slightly agree	slightly disagree	definitely disagree
13. I would rather go to a library than a party.	definitely agree	slightly agree	slightly disagree	definitely disagree
14. I find making up stories easy.	definitely agree	slightly agree	slightly disagree	definitely disagree
15. I find myself drawn more strongly to people than to things.	definitely agree	slightly agree	slightly disagree	definitely disagree
16. I tend to have very strong interests, which I get upset about if I can't pursue.	definitely agree	slightly agree	slightly disagree	definitely disagree
17. I enjoy social chit-chat.	definitely agree	slightly agree	slightly disagree	definitely disagree
18. When I talk, it isn't always easy for others to get a word in edgeways.	definitely agree	slightly agree	slightly disagree	definitely disagree
19. I am fascinated by numbers.	definitely agree	slightly agree	slightly disagree	definitely disagree
20. When I'm reading a story, I find it difficult to work out the characters' intentions.	definitely agree	slightly agree	slightly disagree	definitely disagree
21. I don't particularly enjoy reading fiction.	definitely agree	slightly agree	slightly disagree	definitely disagree
22. I find it hard to make new friends.	definitely agree	slightly agree	slightly disagree	definitely disagree
23. I notice patterns in things all the time.	definitely agree	slightly agree	slightly disagree	definitely disagree
24. I would rather go to the theatre than a museum.	definitely agree	slightly agree	slightly disagree	definitely disagree
25. It does not upset me if my daily routine is distubed.	definitely agree	slightly agree	slightly disagree	definitely disagree
26. I frequently find that I don't know how to keep a conversation going.	definitely agree	slightly agree	slightly disagree	definitely disagree

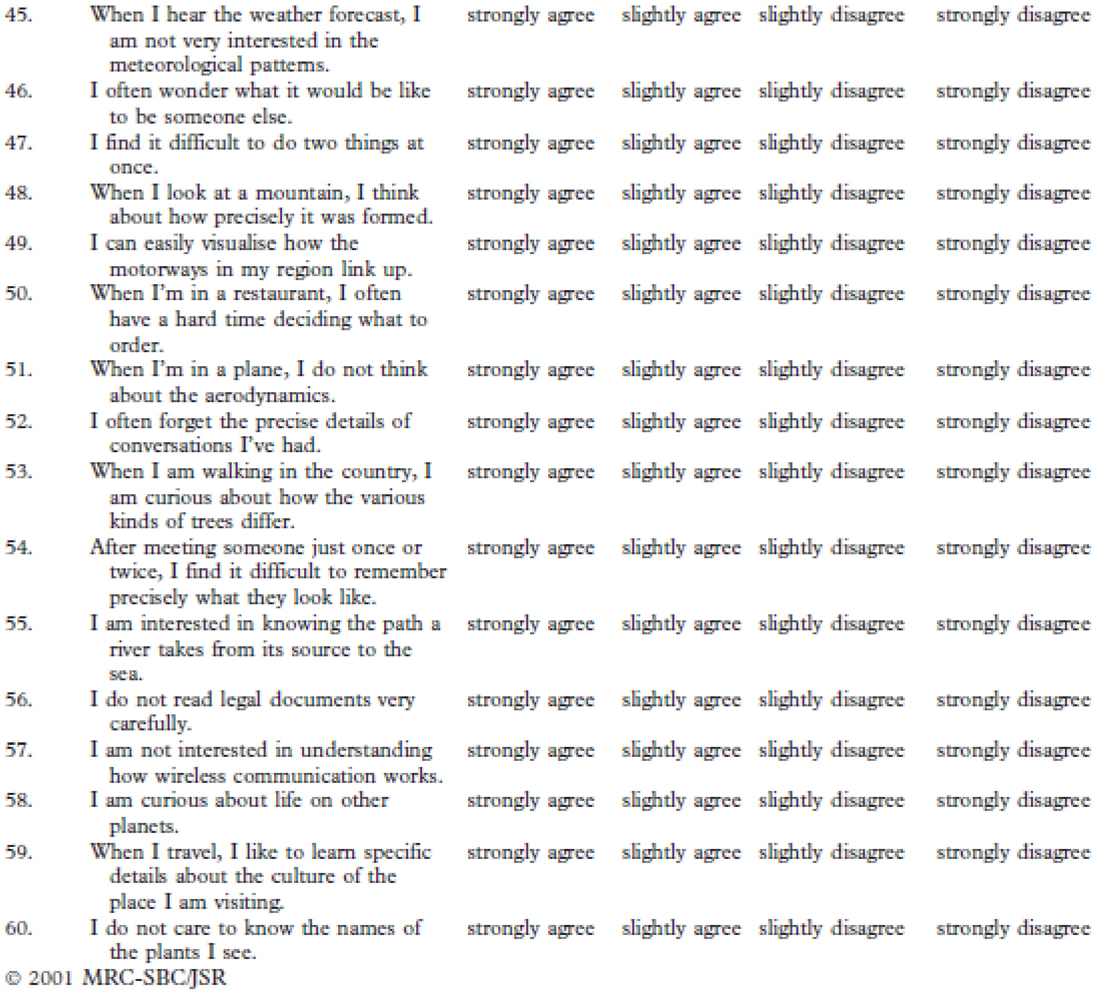


27. I find it easy to “read between the lines” when someone is talking to me.	definitely agree	slightly agree	slightly disagree	definitely disagree
28. I usually concentrate more on the whole picture, rather than the small details.	definitely agree	slightly agree	slightly disagree	definitely disagree
29. I am not very good at remembering phone numbers.	definitely agree	slightly agree	slightly disagree	definitely disagree
30. I don’t usually notice small changes in a situation, or a person’s appearance.	definitely agree	slightly agree	slightly disagree	definitely disagree
31. I know how to tell if someone listening to me is getting bored.	definitely agree	slightly agree	slightly disagree	definitely disagree
32. I find it easy to do more than one thing at once.	definitely agree	slightly agree	slightly disagree	definitely disagree
33. When I talk on the phone, I’m not sure when it’s my turn to speak.	definitely agree	slightly agree	slightly disagree	definitely disagree
34. I enjoy doing things spontaneously.	definitely agree	slightly agree	slightly disagree	definitely disagree
35. I am often the last to understand the point of a joke.	definitely agree	slightly agree	slightly disagree	definitely disagree
36. I find it easy to work out what someone is thinking or feeling just by looking at their face.	definitely agree	slightly agree	slightly disagree	definitely disagree
37. If there is an interruption, I can switch back to what I was doing very quickly.	definitely agree	slightly agree	slightly disagree	definitely disagree
38. I am good at social chit-chat.	definitely agree	slightly agree	slightly disagree	definitely disagree
39. People often tell me that I keep going on and on about the same thing.	definitely agree	slightly agree	slightly disagree	definitely disagree
40. When I was young, I used to enjoy playing games involving pretending with other children.	definitely agree	slightly agree	slightly disagree	definitely disagree
41. I like to collect information about categories of things (e.g. types of car, types of bird, types of train, types of plant, etc.).	definitely agree	slightly agree	slightly disagree	definitely disagree
42. I find it difficult to imagine what it would be like to be someone else.	definitely agree	slightly agree	slightly disagree	definitely disagree
43. I like to plan any activities I participate in carefully.	definitely agree	slightly agree	slightly disagree	definitely disagree
44. I enjoy social occasions.	definitely agree	slightly agree	slightly disagree	definitely disagree
45. I find it difficult to work out people’s intentions.	definitely agree	slightly agree	slightly disagree	definitely disagree
46. New situations make me anxious.	definitely agree	slightly agree	slightly disagree	definitely disagree
47. I enjoy meeting new people.	definitely agree	slightly agree	slightly disagree	definitely disagree
48. I am a good diplomat.	definitely agree	slightly agree	slightly disagree	definitely disagree
49. I am not very good at remembering people’s date of birth.	definitely agree	slightly agree	slightly disagree	definitely disagree
50. I find it very easy to play games with children that involve pretending.	definitely agree	slightly agree	slightly disagree	definitely disagree

Systemizing Quotient

1.	When I listen to a piece of music, I always notice the way it's structured.	strongly agree	slightly agree	slightly disagree	strongly disagree
2.	I adhere to common superstitions.	strongly agree	slightly agree	slightly disagree	strongly disagree
3.	I often make resolutions, but find it hard to stick to them.	strongly agree	slightly agree	slightly disagree	strongly disagree
4.	I prefer to read non-fiction than fiction.	strongly agree	slightly agree	slightly disagree	strongly disagree
5.	If I were buying a car, I would want to obtain specific information about its engine capacity.	strongly agree	slightly agree	slightly disagree	strongly disagree
6.	When I look at a painting, I do not usually think about the technique involved in making it.	strongly agree	slightly agree	slightly disagree	strongly disagree
7.	If there was a problem with the electrical wiring in my home, I'd be able to fix it myself.	strongly agree	slightly agree	slightly disagree	strongly disagree
8.	When I have a dream, I find it difficult to remember precise details about the dream the next day.	strongly agree	slightly agree	slightly disagree	strongly disagree
9.	When I watch a film, I prefer to be with a group of friends, rather than alone.	strongly agree	slightly agree	slightly disagree	strongly disagree
10.	I am interested in learning about different religions.	strongly agree	slightly agree	slightly disagree	strongly disagree
11.	I rarely read articles or web pages about new technology.	strongly agree	slightly agree	slightly disagree	strongly disagree
12.	I do not enjoy games that involve a high degree of strategy.	strongly agree	slightly agree	slightly disagree	strongly disagree
13.	I am fascinated by how machines work.	strongly agree	slightly agree	slightly disagree	strongly disagree
14.	I make it a point of listening to the news each morning.	strongly agree	slightly agree	slightly disagree	strongly disagree
15.	In maths, I am intrigued by the rules and patterns governing numbers.	strongly agree	slightly agree	slightly disagree	strongly disagree
16.	I am bad about keeping in touch with old friends.	strongly agree	slightly agree	slightly disagree	strongly disagree
17.	When I am relating a story, I often leave out details and just give the gist of what happened.	strongly agree	slightly agree	slightly disagree	strongly disagree
18.	I find it difficult to understand instruction manuals for putting appliances together.	strongly agree	slightly agree	slightly disagree	strongly disagree
19.	When I look at an animal, I like to know the precise species it belongs to.	strongly agree	slightly agree	slightly disagree	strongly disagree
20.	If I were buying a computer, I would want to know exact details about its hard drive capacity and processor speed.	strongly agree	slightly agree	slightly disagree	strongly disagree
21.	I enjoy participating in sport.	strongly agree	slightly agree	slightly disagree	strongly disagree
22.	I try to avoid doing household chores if I can.	strongly agree	slightly agree	slightly disagree	strongly disagree
23.	When I cook, I do not think about exactly how different methods and ingredients contribute to the final product.	strongly agree	slightly agree	slightly disagree	strongly disagree

24.	I find it difficult to read and understand maps.	strongly agree	slightly agree	slightly disagree	strongly disagree
25.	If I had a collection (e.g. CDs, coins, stamps), it would be highly organised.	strongly agree	slightly agree	slightly disagree	strongly disagree
26.	When I look at a piece of furniture, I do not notice the details of how it was constructed.	strongly agree	slightly agree	slightly disagree	strongly disagree
27.	The idea of engaging in 'risk-taking' activities appeals to me.	strongly agree	slightly agree	slightly disagree	strongly disagree
28.	When I learn about historical events, I do not focus on exact dates.	strongly agree	slightly agree	slightly disagree	strongly disagree
29.	When I read the newspaper, I am drawn to tables of information, such as football league scores or stock market indices.	strongly agree	slightly agree	slightly disagree	strongly disagree
30.	When I learn a language, I become intrigued by its grammatical rules.	strongly agree	slightly agree	slightly disagree	strongly disagree
31.	I find it difficult to learn my way around a new city.	strongly agree	slightly agree	slightly disagree	strongly disagree
32.	I do not tend to watch science documentaries on television or read articles about science and nature.	strongly agree	slightly agree	slightly disagree	strongly disagree
33.	If I were buying a stereo, I would want to know about its precise technical features.	strongly agree	slightly agree	slightly disagree	strongly disagree
34.	I find it easy to grasp exactly how odds work in betting.	strongly agree	slightly agree	slightly disagree	strongly disagree
35.	I am not very meticulous when I carry out D.I.Y.	strongly agree	slightly agree	slightly disagree	strongly disagree
36.	I find it easy to carry on a conversation with someone I've just met.	strongly agree	slightly agree	slightly disagree	strongly disagree
37.	When I look at a building, I am curious about the precise way it was constructed.	strongly agree	slightly agree	slightly disagree	strongly disagree
38.	When an election is being held, I am not interested in the results for each constituency.	strongly agree	slightly agree	slightly disagree	strongly disagree
39.	When I lend someone money, I expect them to pay me back exactly what they owe me.	strongly agree	slightly agree	slightly disagree	strongly disagree
40.	I find it difficult to understand information the bank sends me on different investment and saving systems.	strongly agree	slightly agree	slightly disagree	strongly disagree
41.	When travelling by train, I often wonder exactly how the rail networks are coordinated.	strongly agree	slightly agree	slightly disagree	strongly disagree
42.	When I buy a new appliance, I do not read the instruction manual very thoroughly.	strongly agree	slightly agree	slightly disagree	strongly disagree
43.	If I were buying a camera, I would not look carefully into the quality of the lens.	strongly agree	slightly agree	slightly disagree	strongly disagree
44.	When I read something, I always notice whether it is grammatically correct.	strongly agree	slightly agree	slightly disagree	strongly disagree



45.	When I hear the weather forecast, I am not very interested in the meteorological patterns.	strongly agree	slightly agree	slightly disagree	strongly disagree
46.	I often wonder what it would be like to be someone else.	strongly agree	slightly agree	slightly disagree	strongly disagree
47.	I find it difficult to do two things at once.	strongly agree	slightly agree	slightly disagree	strongly disagree
48.	When I look at a mountain, I think about how precisely it was formed.	strongly agree	slightly agree	slightly disagree	strongly disagree
49.	I can easily visualise how the motorways in my region link up.	strongly agree	slightly agree	slightly disagree	strongly disagree
50.	When I'm in a restaurant, I often have a hard time deciding what to order.	strongly agree	slightly agree	slightly disagree	strongly disagree
51.	When I'm in a plane, I do not think about the aerodynamics.	strongly agree	slightly agree	slightly disagree	strongly disagree
52.	I often forget the precise details of conversations I've had.	strongly agree	slightly agree	slightly disagree	strongly disagree
53.	When I am walking in the country, I am curious about how the various kinds of trees differ.	strongly agree	slightly agree	slightly disagree	strongly disagree
54.	After meeting someone just once or twice, I find it difficult to remember precisely what they look like.	strongly agree	slightly agree	slightly disagree	strongly disagree
55.	I am interested in knowing the path a river takes from its source to the sea.	strongly agree	slightly agree	slightly disagree	strongly disagree
56.	I do not read legal documents very carefully.	strongly agree	slightly agree	slightly disagree	strongly disagree
57.	I am not interested in understanding how wireless communication works.	strongly agree	slightly agree	slightly disagree	strongly disagree
58.	I am curious about life on other planets.	strongly agree	slightly agree	slightly disagree	strongly disagree
59.	When I travel, I like to learn specific details about the culture of the place I am visiting.	strongly agree	slightly agree	slightly disagree	strongly disagree
60.	I do not care to know the names of the plants I see.	strongly agree	slightly agree	slightly disagree	strongly disagree

Questionnaire Scores

Participant	**Autism-Spectrum Quotient**	**Systemizing Quotient**
1	14	26
2	19	39
3	37	45
4	9	15
6	16	21
7	13	25
8	8	30
9	13	17
10	11	33
11	15	25
12	21	28
13	15	23
14	20	34
15	15	43
16	28	23
17	17	35
18	17	34
19	19	41
20	9	8
21	17	30
22	17	23
23	7	29
24	17	27
25	21	23
26	27	26
27	15	35
28	12	15
29	21	19
30	21	36
31	21	21

* *Note*. Participant 5 data was not collected

Appendix D – Descriptive Statistics

	Task 1 Biased Selections	Task 2 Biased Selections	Task 1 RT (ms)	Task 1 RT SD (ms)	Task 2 RT (ms)	Task 2 RT SD (ms)
Mean	55.8	48.7	583	126	345	142
Median	60.5	55.5	574	126	345	135
Minimum	24	3	417	95.2	184	74.4
Maximum	71	71	710	172	535	223

Table 5. Outcome variable descriptive statistics of total participants' trials for Task 1 and 2. Note: Biased figure selections are measured as the frequency of incorrect responses for trials where the wings-in figure was the longer of the pair.

	T3V	T4V	T3C	T4C
Mean	17.9	25.6	11.9	21.0
Median	17.2	25.2	12.1	20.9
Minimum	11.3	11.5	1.33	-1.94
Maximum	30.1	40.0	24.5	38.9

Table 6. Outcome variable descriptive statistics of total participants' trials for Task 3 and 4.

Note: "T#" refers to task #. "V" refers to variable error and "C" to absolute constant error

Appendix E – Remote Learning

COVID-19

The original thesis proposal was written prior to the beginning of the COVID-19 pandemic and, as such, the experiments were meant to be conducted in-person and to include motor tasks. As the pandemic began, changes to the thesis became necessary to adapt to the changing environment. The restrictions imposed by the University and lockdown measures in the Province of Manitoba required minimal contact between the researcher and participants. For this reason, a new method of acquiring data for the thesis needed to be devised.

E-Prime

An online, remote form of data collection was built using E-Prime 3 and E-Prime Go. The E-Prime Go software was a new software that had, until now, not been used. Additionally, the University of Manitoba campus was closed and thus, learning to use the tool required an extensive period of at-home learning with minimal assistance from other lab members – and where assistance could be given, it was through phone calls and online video conferencing.

The E-Prime Go software had many limitations, the greatest of which for our purposes being that it was only compatible with Microsoft Windows computers, and only on certain computers with specific hardware specifications. These specifications meant that participants who did not own a personal computer running Microsoft Windows would not be able to participate in our study unless they were given, from the researcher, a data-collection laptop running Microsoft Windows.

Delivering and retrieving the data-collection laptop required navigating “red-tape” (although necessary for the safety of participants and researchers) imposed by both the University and the Province of Manitoba. Navigating the various newly created and necessary paperwork took additional time and resources, leading to further delays in conducting research and subsequent completion of the thesis.

When participants did own a computer running the specific requirements to run E-Prime Go, other issues such as typical technology mishaps occurred which also needed to be solved over phone calls and video conferencing with the researcher. Solving technical issues of hardware and software, while sometimes not being able to see the computer having the issues, delayed experimentation – sometimes requiring rescheduling of participants.

Lessons Learned

While the thesis would no doubt be vastly different from its current form had the pandemic not occurred, the lessons learned from the ensuing struggles have opened a new avenue for experimentation. The obstacles that needed to be overcome to conduct the current research will facilitate further online, remote experimentation that will allow much larger sample sizes of participants to be collected than would otherwise be feasible. Thus, the silver-lining of the context in which the current research was carried-out is that it opened the doors for new research protocols to be possible with greater ease.

It is currently uncertain when the international and national situation which the virus that causes COVID-19 has produced will end. It is thus crucial we learn from the experiences of research conducted during this time and use those experiences to adapt to the conditions in which we find ourselves.