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Impacts of Motor and Sensory Impairment on Language in Young Children with Autism

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Table of Contents

List of Tables

List of Figures

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Abstract

Children with autism spectrum disorder (ASD) present with varying degrees of deficit in the broader areas of social communication and stereotyped behaviors, but emerging research proposes delayed motor skill and atypical sensory processing as additional factors worth closer examination. In the current study, I sought to investigate the impacts of visual motor skills and sensory differences on language ability in young children with autism. I hypothesized that young children with autism, atypical sensory processing (Short Sensory Profile, 2nd Edition), and impaired visual motor integration (Beery VMI, 6th Edition) would have the most impacted language ability scores (Differential Ability Scales, 2nd Edition). A total of 22 children, eight with autism (25% female; *M* age = 66 months or 5.5 years) and 14 with typical development (50% female; *M* age = 73 months or 6 years) between the ages of 3:0 and 9:6 and their parents completed measures for this study. Findings were significant for the relations of status (i.e., TD vs. ASD) on language ability [$t(20) = 2.66$, $p = .015$], status on visual motor integration [$t(20) = 2.27$, $p = .035$], and for status on sensory processing [$t(20) = -5.35$, $p < .001$]. Results of the three-way interaction indicated that 72% of the variance in language ability was accounted for by the key variables in this model, but this hypothesis was not supported: $p = .09$, $B = .15$, $CI_{95} = -.031$ to .33. Related hypotheses of visual motor integration on status and language, sensory processing on status and language, and between visual motor integration and sensory were also not supported. Ancillary analyses of individual moderation indicated significant status group (TD vs. ASD) differences for children with visual motor integration full form standard scores of 119 and below ($p < .05$) and for children with total sensory scores of 25 to 36 ($p < .05$). These post

hoc findings are consistent with previous literature and demonstrate promise for replication in future research with a larger and more heterogeneous sample. Further research on these constructs is encouraged as it could inform meaningful pathways for early intervention.

CHAPTER I: Introduction and Literature Review

Autism spectrum disorder (ASD) is an early onset, pervasive neurodevelopmental disorder distinguished by core impairment in the broader domain of social communication, along with varying degrees of co-occurring restrictive and repetitive behaviors and stereotyped interests (American Psychological Association, 2013). Deficits in these areas yield highly varied, but meaningful adverse outcomes across the lifespan (Bellini, 2006; Humphrey & Symes, 2011). The latest revision of *The Diagnostic and Statistical Manual of Mental Disorders, Fifth Edition* was released in 2013 (DSM-5; American Psychological Association, 2013), with diagnostic criteria now including sensory abnormalities (Ben-Sasson et al., 2009) and disruptions in motor functioning (i.e., atypical and delayed motor skill development; Shoener et al., 2008). There is a growing body of literature which proposes that the presence of long-recognized stereotyped behaviors in ASD (i.e., the adoption of atypical sensory or motor behaviors) may in part be a product of impaired processing of sensory input. Specifically, stereotypic behaviors may ultimately be an individual’s attempt to make sense of and regulate a behavioral response elicited by sensory information (Baker et al., 2008). Moreover, retrospective studies like those performed by Heathcock and colleagues stress the importance of monitoring early motor development for individuals at increased risk for autism (Heathcock et al., 2015), as it could provide a critical pathway for intervention.

Despite the wealth of existing literature on language, motor, and sensory impairments in ASD, these constructs have been exclusively explored as separate contributing constructs and in samples of children either very young (i.e., before 36 months) or in older elementary school years (i.e., ages 7 and older). For example, the one discovered study to explore these constructs together sought to investigate the impact of vestibular sensory responsivity and motor integration on social communication challenges in children ages 7 to 16 years with autism (Hannant et al., 2016). Research of these early and later lifespan timepoints provide meaningful information—the former examines disruptions at birth through early infancy during Piaget's sensorimotor stage of cognitive development and the latter addresses outcomes on social and academic performance and beyond during the concrete and formal operations stages (Piaget, 1976). However, the time frame between ages 3 to 7, commonly referred to as the preoperational stage (Piaget, 1976), is critical to connecting these early delays with their later operational outcomes. Thus, there remains a distinct gap in the literature regarding the combined effects of these constructs and specifically as examined within this underrepresented age range, both of which the current study sought to address (see Figure 1).

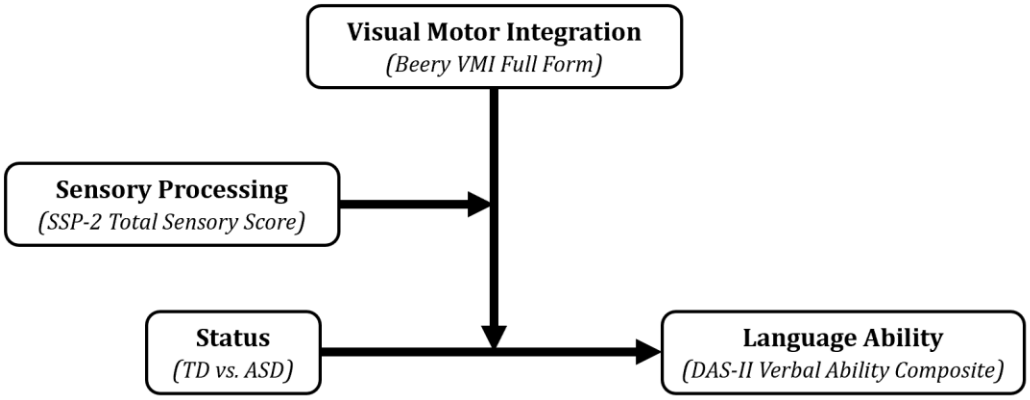

Figure 1. The proposed moderated multiple regression model of the effects of developmental status on language ability through visual motor integration and sensory processing.

Autism Spectrum Disorder

Overview

Autism is an enduring neurodevelopmental disorder characterized by deficits in three core areas of functioning—social communication, restrictive and repetitive behavior, and stereotyped interests (American Psychological Association, 2013). Most recognized features of

ASD include challenges with social functioning, such as social-emotional reciprocity (e.g., failure to initiate and/or respond appropriately in social interactions with others), nonverbal communication (e.g., lack of or limited use of functional gesturing, modulated and sustained eye contact), and with initiating and maintaining social relationships (American Psychological Association, 2013). Other common features of autism that manifest in varying degrees of severity and directly exacerbate these social domain deficits are rigidity and highly specified interests (e.g., insistence on sameness, difficulty with change and/or transitions), stereotyped or repetitive motor behaviors or speech (e.g., simple gross motor stereotypies, echolalia, use of idiosyncratic phrases), as well as unusual and fixated interest in sensory aspects of the environment (American Psychological Association, 2013). Because ASD manifests on a spectrum of severity, it is important to note that the symptom profile of autism is highly variable and the severity of symptom presentation is often described in the literature as cross-domain dependent (Bellini, 2006; Duvekot et al., 2018; Sukhodolsky et al., 2008). In other words, the amount of impact observed in one domain is often associated with delays or deficits in another. For example, in a sampling of school-aged children with ASD, increases in restricted and stereotyped interests were found to be positively correlated with social communication challenges (Duvekot et al., 2018).

Epidemiology

Recent estimates from the CDC's Morbidity and Mortality Weekly Report (MMWR) Surveillance Summary in March 2020 report that prevalence rates continue to be on the rise, with now 1 in 54 children diagnosed with an autism spectrum disorder and with males still diagnosed roughly four times more than females (an increase from 1 in 59 children reported in 2014; Baio et al., 2018; Christensen et al., 2016; Maenner, 2020). Overall, this marks a 150% increase from estimates reported in 2000, with no evidenced partiality for any one culture, ethnicity, or socioeconomic group (Baio et al., 2018; Maenner, 2020). However, socioeconomic status has been found to be linked with age of first diagnosis, in that lower SES has been associated with later diagnosis (Hill et al., 2014). Reliable age of ASD diagnosis has been determined for children as young as 24 months (Johnson, 2007; Ozonoff et al., 2010), although most diagnoses typically occur after the age of four (Johnson, 2007). Emerging research has also proposed that earlier identifiable markers for autism may even be present as early as 6 months following birth (e.g., poorly modulated eye contact and gross motor delays; Ozonoff et al., 2010).

Intervention

Early and reliable diagnosis is a critical step in allowing families to access evidence-based intervention services for autism. A better understanding of the underlying challenges experienced by young children on the spectrum as well as identifying specific areas for effective mediation has thus never been more critical, as targeted interventions with this population have been found to be most impactful when implemented earlier in life (Bhat et al., 2012). However, presentations of ASD symptomatology and their respective evaluations across systems vary greatly from one individual to the next, particularly with higher functioning autistic individuals (Mazzone et al., 2012), resulting in increasingly complex approaches to intervention and treatment. Moreover, with the latest revision of the DSM in 2013, increased attention has been placed on individual variability of sensory abnormalities and delays in motor skill development in autism populations (Ben-Sasson et al., 2009; Shoener et al., 2008). However, it remains unclear as to how these early and increasingly complex symptom profiles impact later development.

Language Development

Communication is the tool by which individuals socially connect with others and make sense of the world around them. In addition to verbal language skills, communication also includes nonverbal abilities, such as eye contact, body posturing, gestures, and facial expressions (Franchini et al., 2018); all of which are important skills throughout child development. However, for the purposes of the present project, the focus was placed on the verbal language aspects of communication. Associated with many positive outcomes—such as improved school readiness and better social adaptation (Feldman & Klein, 2003)—verbal language is critical to individuals reciprocally interacting with and learning from their external world. As such, it follows that language development and acquisition is at the forefront of recent research on early childhood development (Eigsti et al., 2011). Language development is an important developmental milestone for all children, as it plays a key role under the broader umbrella of cognitive functioning (Eigsti et al., 2011; Schmidt et al., 2017). Language often falls into two widely recognized categories: expressive language and receptive language (Eigsti et al., 2011). Expressive language describes the production and functional use of language; while receptive language is the pathway through which language is comprehended (Schmidt et al., 2017). A vast number of individual differences and environmental factors may negatively impact language development throughout early childhood. It is important to identify these factors because delays or deficits in language skills have often been recognized as early indicators of developmental impairment (Eigsti et al., 2011).

Language in ASD

The compounding effects of language delays, rigid and fixated interests, and higher rates of externalizing behaviors often found in ASD populations uniquely influence social communication development (American Psychological Association, 2013). ASD has thus become known as a social disorder in that opportunities for optimal socialization become markedly diminished as the severity of ASD symptoms increases. Language skills in ASD populations are highly variable (Pickles et al., 2004), with children presenting on a wide range of linguistic ability (Tager-Flusberg & Kasari, 2013). Research suggests that the majority of children on the autism spectrum exhibit significant challenges with language, with an estimated 25-30% remaining minimally verbal even following years of intervention (Anderson et al., 2009; Kasari et al., 2014; Tager-Flusberg & Kasari, 2013). Because research studies of children with limited verbal ability are less common, exact prevalence rates are unknown (Kasari et al., 2014). However, projective data suggest that failure to develop spoken language by the age of five is strongly linked with poorer long-term prognoses within the domains of social and adaptive functioning (Anderson et al., 2009; Wodka et al., 2013). Thus, given that language development in autism populations remains one of the best predictors of adaptive functioning and social skills later in life (Gillespie-Lynch et al., 2012), it follows that a better understanding of these early individual differences, as comprised of language and other related developmental delays, may help guide more effective targets for early intervention.

Theoretical Framework of Embodied Cognition

The theory underlying the current study was that of embodied cognition, which proposes that cognition emerges within the interaction between an individual and its environment as a product of sensorimotor activity (Smith & Gasser, 2005). In other words, because cognitive development is comprised of perception, action, and thought, advancement of higher mental functions takes place between the interactions and experiences of an individual and the physical world (Gibson, 1988). Under this premise, motor skill and environment exploration provide critical opportunities for learning and acquiring new skills, which highlights the active role children must play in their own early developmental trajectories (Smith & Gasser, 2005). An important yet nuanced process within the interactions of a child and its environment, the emergence of language is argued to be inherently tied to these sensorimotor opportunities (Iverson, 2010). Thus, emerging research has begun to explore the processes that may be disrupting optimal language development, most notably delays in fine and gross motor skills (Bhat et al., 2012).

Motor Development

Motor development is another widely recognized critical milestone of an individual's early life (Heathcock et al., 2015; Ozonoff et al., 2010) and the first of two moderators assessed in the present study. Comprised of a number of complex and interactive mechanisms, emerging research has begun to focus on the systemic impact of early motor development delays on later outcomes (Leonard et al., 2015; Thelen & Smith, 1994). This is of particular interest to autism research, as increased focus has been placed on the cascading effects of early disruptions in certain domains on other critical areas of development, such as motor and language (Bhat et al., 2012; Leonard et al., 2015). Atypical motor behaviors are common in ASD populations, persist from infancy onwards, and are currently described in the DSM-5 as stereotypical repetitive behaviors (American Psychological Association, 2013; May et al., 2016), or "motor stereotypies" (i.e., hand/arm flapping, finger mannerisms, and body rocking; McCleary et al., 2013). However, disruptions in motor development for this population are not limited to motor stereotypies, but also often include varying degrees of challenge within broader areas of motor function, such as difficulties with gross and fine motor coordination, visual motor integration, postural instability, as well as gait abnormalities (Bhat et al., 2012; Libertus et al., 2014; McCleary et al., 2013). Retrospective studies of autism populations have proposed the following as potential early indicators for risk: delays in or failure to achieve early motor milestones (i.e., rolling over, sitting up or without support, and crawling) and atypical movement behaviors (i.e., asymmetrical movement patterns, abnormal reflexes and rigidities, etc.; Bhat et al., 2012; Ozonoff, 2010). Additionally, several of these impacted motor skill areas—including gross motor (i.e., running, jumping, throwing, etc.) and fine motor (i.e., tying shoe laces, handwriting, buttoning shirts, etc.)—are associated with and may negatively impact tasks of daily living, school or work performance, and social functioning in children on the autism spectrum (MacDonald et al., 2013; May et al., 2016).

Motor skills in ASD

From the theoretical framework of embodied cognition, the central premise behind motor development is that advances in motor skills (i.e., progression from postural control in the body and neck, independent movement and crawling, object manipulation, handwriting etc.) serve as critical pathways for children to operate in and learn from the physical world around them (Iverson, 2010; Smith & Gasser, 2005). These avenues provide the foundation (or context) for skill acquisition, practice, and refinement, which all directly and indirectly inform development within other critical domains (Smith & Gasser, 2005). For example, in their study of young children on the autism spectrum, Stone and Yoder (2001) described elements of motor imitation as being comprised of a child’s ability to (a) orient to another individual, and (b) create a detailed-enough mental representation of the other individual’s behavior in order to imitate that behavior. They argue that challenges with motor imitation is inherently linked with deficits in social processing and, as such, may serve as an underlying factor in children’s ability to process linguistic input and acquire language (Stone & Yoder, 2001). Consequently, there has been growing support in the literature that motor skill and visual motor difficulties may be an essential predictor of language ability in children with autism (Bhat et al., 2012; Iverson, 2010; Leonard et al., 2015).

Research on atypical motor development in autism populations has increasingly focused on the outcomes and implications of early motor skill disruptions (Bhat et al., 2012; Iverson, 2010; Leonard et al., 2015). In their study comparing high-risk siblings (those with a diagnosed sibling on the spectrum) to those with lower risk, Bhat and colleagues (2012) found that 70% of all children who presented with early motor delays, regardless of developmental status risk, demonstrated language deficits by the age of three. Within this finding, they reported that early motor delays were more common in high risk siblings than their low risk cohort and that communication delays later emerged in 67-73% of this high-risk sample (Bhat et al., 2012). These findings support further recent research demonstrating that age of onset for walking predicted both receptive and expressive language skills (Bedford et al., 2016; Walle & Campos, 2014). Bedford and colleagues cited theorized connections to such phenomena as early exploratory behaviors, object manipulation, fine motor skills, and frequency of opportunities for social reciprocity with adults. Further, overall motor ability was found to predict rates of expressive language acquisition but not receptive language (Leonard et al., 2015). Fine motor skills have also been cited as strong predictors of later expressive language ability in ASD samples (LeBarton & Iverson, 2013). Specifically, manual-motor skill (i.e., handwriting, tracing, drawing) by the age of two was identified to be the best predictor of expressive language skills at age 4 (Stone & Yoder, 2001), a finding that was later replicated in a school-age sample, which reported significant associations between fine motor skills and speech fluency two years later (Gernsbacher et al., 2008). In sum, the relation between motor skills and cognitive functioning (i.e., specifically within the language domain) is gaining increased support in the literature because of its important implications on later prognoses. Moreover, these associations are argued to be even more impactful for those with autism above and beyond those without intellectual impairment because as the severity of autism symptoms increase so do the combined correlations between development across the domains of motor, cognitive, and language. These relations vary from .61 to .94 for children with neurological impairment to .24 to .56 for those with typical development (Houwen et al., 2016). Research therefore supports the importance of developing more targeted early intervention for motor skills in children with autism, which may consequently support their language development (Houwen et al., 2016, MacDonald et al., 2013).

Sensory Processing

The second moderational construct of interest in the present study was sensory. The human brain is involved in a number of important processes, including the processing and integration of sensory input (Ayres, 1985). Sensory data can take the form of auditory, tactile, vestibular, proprioceptive, gustatory, and olfactory (Ayres, 1985; Kientz & Dunn, 1997). Optimal integration and modulation of sensory information is a critical component of effective functioning in daily tasks across the lifespan (Ayres, 1985), from adaptive behavior and learning to coordinated movement (Ben-Sasson et al., 2009; Jasmin et al., 2009). Disruptions in effective sensory processing early in life have been correlated with impaired outcomes across several critical developmental domains, including language (Bar-Shalita et al., 2008).

Atypical sensory functioning is classified into a group of disorders known as sensory processing disorders (SPDs), which relate to varying degrees of challenge with the modulation, integration, organization, and discrimination of sensory input in response to internal or external demands (Ben-Sasson et al., 2009). Sensory processing (SP) theory posits that effective functioning in daily tasks is dependent on the optimal reception and integration of sensory input and that several important areas (e.g., adaptive behavior, learning and memory, and coordinated movement) may be impacted as a result of impaired functioning (Baker et al., 2008; Kern et al., 2006). Under the umbrella of SPDs are sensory modulation disorders (SMDs), which involve challenges in regulating and appropriately matching the type and intensity of behavioral responses from sensory input received from internal or external demands (Miller et al., 2004). Segmented further, SMDs manifest as: (a) hyper-responsiveness/over-responsiveness to sensory input through rapid onset and/or prolonged duration (e.g., overreaction to a loud noise), (b) hypo-responsiveness/under-responsiveness to sensory input as evidenced by a lack of or delayed response (e.g., not responding to one's name being called), and (c) sensation seeking as a result of an intense interest in or craving for that sensory input (Miller et al., 2004). For the present study, I gathered data on the following four sensory integration and response types: sensory seeking (i.e., the degree to which sensory input is sought or obtained), sensory avoidance (i.e., the degree to which sensory input is avoided or not tolerated; hyper-reactivity), sensory sensitivity (i.e., the degree to which sensory input is detected, such as being a picky eater), and sensory registration (i.e., the degree to which sensory input is missed or not registered; hypo-reactivity; Dunn, 1997; Woo et al., 2015), but only the total sensory symptom score (as comprised of all four subscales) was used for primary analyses given the limited scope of this study. In sum, much like the expressive and receptive systems of language, sensory processing and integration can be further understood as the nuanced and often cyclical processes of receiving and integrating of sensory input, and the behavioral reaction or response to that stimulus (Jasmin et al., 2009; Miller et al., 2004)

Sensory Processing in ASD

An estimated 90 to 95% of individuals with autism spectrum disorders (ASD) present with comorbid sensory processing challenges or sensory symptoms (Baker et al., 2008; Tomchek & Dunn, 2007). Research also highlights markedly higher sensory abnormalities exhibited by children with autism than children with other developmental disabilities (Wiggins et al., 2009) and typical development (Leekam et al., 2007). Moreover, children with ASD demonstrating a higher frequency of sensory behaviors have been shown to experience pervasive challenges across multiple domains, such as social functioning (Ben-Sasson et al., 2009), daily activities (Bar-Shalita et al., 2008), and emotion regulation (Miller et al., 2004).

Despite research documenting high rates of sensory issues for children with ASD, research remains varied on the nature of sensory subtype presentations found in ASD populations (Woo et al., 2015). For example, individuals with ASD appear to have problems integrating multisensory information into a single focus (Brandwein et al., 2015; Woo et al., 2015). More specifically, the concurrent processing of input from auditory and visual senses has been found to be compromised in individuals with ASD (Stevenson et al., 2014). Further, several atypical sensory responses (e.g., sensory avoidance/hyper-reactivity) that have long been described in ASD populations have also been found to co-occur with increased activity in neural sensory processing pathways (Brandwein et al., 2015; Woo et al., 2015) and therefore incite discussion around whether some core features of ASD may be a response to abnormal sensory input (Woo et al., 2015). In fact, it has been suggested that engagement in repetitive behaviors and/or the insistence on sameness may be a function of coping with anxiety evoked by atypical sensory responses (Wigham et al., 2015). Moreover, positive associations between severity of ASD symptoms, specifically deficits involving language and social development, and severity of sensory challenges illustrate the continued need for research in this area (Brock et al., 2012;

Watson et al., 2011). Additionally, sensory issues could be a more meaningful area for targeted early intervention in autism populations than previous research suggests.

Sensory Processing and Motor Skills

Sensory processing challenges and impaired motor skills have garnered increased attention in the research of autism populations (Baranek et al., 2013; Ben-Sasson et al., 2009; Jasmin et al., 2009), but it is unclear when and to what degree the combination of these unique challenges impact other functional domains. Thus, the timing and type of sensory issues typically experienced by children on the spectrum need to be considered in conjunction with the motor skills developing at that time. Although recent literature posits that ASD groups exhibit many combinations of sensory challenges across the lifespan, hypo-responsiveness (i.e., a lack of or under-responsiveness to sensory input) may be more specific to and prevalent in younger children with ASD (from 6 to 12 months; Baranek et al., 2013). Further, hyper-responsiveness (i.e., an over-responsiveness to sensory input) may be more prevalent in preschool and school-aged children with ASD (ages 3 to 9; Ben-Sasson et al., 2009). These age-specific presentations of sensory symptoms pose interesting questions for early motor skill development, which has not appeared to yield any age-specific patterns, but rather a pattern of motor skill type. For example, deficits in fine motor skill and motor coordination along with increases in sensory challenges (i.e., sensory avoiding and sensory sensitivity) were found to be the greatest predictors of expressive language ability in children with ASD at ages 7 to 36 months (Leonard et al., 2015), adaptive skills at ages 3 to 4 years (Jasmin et al., 2009), and receptive language at ages 7 to 16 years (Hannant, 2018). These findings highlight the important connection between various sensory processing deficits and motor coordination skills, specifically for autism populations during different periods of development. Moreover, research is lacking regarding these challenges in younger children ages 3 to 9.

Visual Motor Integration

Visual motor integration is the coordination between things we see and the appropriate motor response that follows (Green et al., 2016). In other words, it involves the perception and integration of visual input (e.g., letters and shapes) with a coordinated motor response (Tseng & Cermak, 1993). On one hand, visual motor integration requires effective processing and modulation of sensory input (Jasmin et al., 2009). On the other, the necessary motor response in these tasks involves fine motor or motor coordination skills, or rather the effective integration of visual information with coordinated motor movements (Green et al., 2016). Because visual motor integration involves the integration of multiple types of sensory information, it has been hypothesized that deficits in this area may be associated with disruptions observed with sensory processing and motor skill development in children with autism (Green et al., 2016). Children with ASD often demonstrate significant challenges with visual motor integration (Green et al., 2016; Hannant, 2018), which in turn has been associated with a number of cascading challenges in other domains. For example, in their sample of children with autism, Hannant (2018) found that children on the spectrum scored significantly lower in receptive language ability, motor coordination, and visual motor integration than their typically developing group. Moreover, they found that motor coordination uniquely predicted receptive language ability for the ASD sample, supporting the important connection between early sensorimotor experiences, visual motor integration, and language outcomes in autism populations (Hannant, 2018). Nevertheless, despite the increasing interest in visual motor integration challenges of children with autism, there remains a gap in the literature regarding these challenges of visual motor integration specifically in relation to other areas of deficit, including sensory processing and language ability.

Current Study

Overview

Autism is a pervasive developmental condition characterized by commonly recognized challenges in the domains of social communication, restrictive and repetitive behavior, and stereotyped interests (American Psychological Association, 2013). Only more recently have the effects of sensory processing challenges and motor skill deficits on cognitive functioning been featured as influential factors worth further exploration (Duvekot, et al., 2018; Hannant, 2018; Sukhodolsky et al., 2008). Of these influential cognitive domains, language development, remains one of the best predictors of both adaptive and social functioning later in life for those with ASD (Gillespie-Lynch et al., 2012). However, the impacts of sensory processing and motor skill on language development have only been assessed either as separate predictors or jointly in children either very young (i.e., before 36 months) or in older elementary school years (i.e., above the age of 7; Hannant et al., 2016). This is an area worth more attention, as the theory of embodied cognition holds that cognitive development, and arguably language development (Iverson, 2010), is contingent upon the sensorimotor interplay between an individual and its physical environment (Smith & Gasser, 2005). As such, when deficits with motor development are combined with sensory processing challenges, it is conceivable that cascading effects may be observed in an individual's language ability.

Hypotheses

In the current study, I examined visual motor integration, sensory processing, and language ability in children with autism and in children with typical development between the ages of 3:0 and 9:6 years. More specifically, visual motor integration and sensory processing were examined as moderators of the relation between the child's developmental status (TD vs. ASD) and their language ability score. Based on prior research, the following hypotheses were proposed.

Hypothesis 1A: Language ability by developmental status

Child developmental status (TD vs. ASD) would predict language ability, in that children with autism would produce lower language ability scores than TD children. Compared to those with typical development, previous research indicates that children with ASD exhibit varying degrees of impairment in the language domain (APA, 2013; LeBarton & Iverson, 2013; Tager-Flusberg & Kasari, 2013). Like the majority of prior research of children with autism (Tager-Flusberg & Kasari, 2013), it is worth noting that the current study included an ASD sample with average to above-average verbal skills.

Hypothesis 1B: Visual motor integration by developmental status

Child developmental status (TD vs. ASD) would predict visual motor integration scores. Children with ASD have been found to demonstrate significant challenges with visual motor integration (Green et al., 2016; Hannant, 2018), fine motor skill and motor coordination (LeBarton & Iverson, 2013; Libertus et al., 2014), and with visual perception (Beery et al., 2010).

Hypothesis 1C: Sensory processing by developmental status

Child developmental status (TD vs. ASD) would predict total sensory processing scores. Sensory processing challenges present comorbidly in about 90 to 95% of individuals with autism and have been well documented in previous research (Baker et al., 2008; Tomchek & Dunn, 2007; Woo et al., 2015).

Hypothesis 2: Status and language moderated by visual motor integration

Scores on the task of visual motor integration would moderate the relation between child developmental status (TD vs. ASD) and language ability score. Specifically, children with lower scores on visual motor integration were predicted to yield lower language ability scores, and this effect was expected to be even more severe for children with autism. Research suggests that targeted intervention for motor skill development may support language development and acquisition in children (MacDonald et al., 2013), and that this relation would be more impactful for children with autism than TD (Houwen et al., 2016).

Hypothesis 3: Status and language moderated by sensory processing

Sensory processing was also predicted to uniquely moderate the relation between child developmental status (TD vs. ASD) and language ability scores. Positive associations between severity of sensory challenges and language impairment have been well documented in the literature (Brock et al., 2012; Watson et al., 2011).

Hypothesis 4: Language moderated by visual motor integration and sensory processing

Given previous literature on the two moderators of interest, visual motor integration and sensory processing were predicted to moderate language outcome when controlling for developmental status (Duvekot, et al., 2018; Hannant, 2018).

Hypothesis 5: Status and language moderated by visual motor integration and sensory processing

Lastly, performance on the task of visual motor integration and sensory processing total score would moderate the relation between child developmental status (TD vs. ASD) and language ability score. Specifically, those expected to demonstrate the most impacted language ability scores were children with an autism diagnosis and both lower scores on the visual motor integration task and higher sensory processing challenges. Emerging research has highlighted the paucity of research examining the relation between the constructs of motor skills, sensory processing, and language development, specifically for young children in autism (Duvekot, et al., 2018; Hannant, 2018; Sukhodolsky et al., 2008). This project attempted to contribute to this gap in the literature (see Figure 1 presented again below).

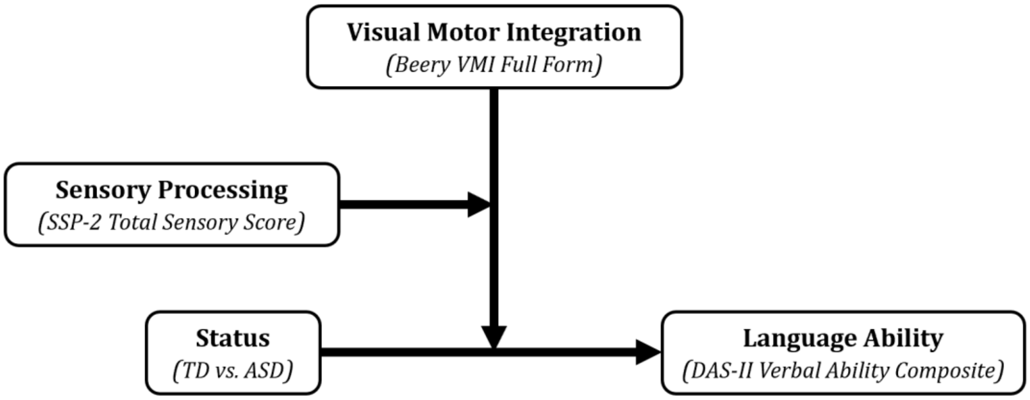

Figure 1. The proposed moderated multiple regression model of the effects of developmental status on language ability through visual motor integration and sensory processing.

CHAPTER II: Method

Participants

This project was part of a larger, on-going investigation examining self-regulation abilities in young children with autism and typically developing children. The current study was approved by the Institutional Review Board (IRB) at Seattle Pacific University. Eligibility and inclusion criteria comprised of: (a) children between the ages of 3:0 and 9:6 years, (b) children with adequate verbal abilities required to complete study tasks (Differential Abilities Scales—Second Edition, DAS-II; verbal ability standard score above 85; Elliott, 2007), (c) children eligible for the ASD sample must have had a documented diagnosis of ASD from a licensed provider, (d) children eligible for the typically developing sample may not have a sibling diagnosed with ASD, receive a parent-reported score in the “high risk” range on an autism screening questionnaire short form (Social Communication Questionnaire—Current Form, SCQ, score above 14; Rutter et al., 2003), demonstrate any other significant elevation in ASD symptoms (Autism Behavior Checklist or ABC; score above 68; Krug et al., 1980), or have a previous psychiatric or developmental diagnosis.

Demographic Information

Participants included 22 children and their parents, of which 8 were children with ASD and 14 with typical development. During their enrollment visit, parental guardians provided demographic information via a structured demographic questionnaire. Relevant data from this questionnaire are presented in Table 1, separated by developmental status group and with group differences provided. No demographic variables in the present sample were found to be significant with one another.

Table 1.
Demographic Characteristics by Status Group, N = 22

Child Variables	ASD (n = 8)	TD (n = 14)	χ^2
Average Age in Months (*SD*)	73.40 (18.74)	66.7 (18.46)	.180
Average Age in Years (*SD*)	6.01 (1.53)	5.5 (1.52)	.172
Gender (% female)	25%	50%	-.245
Child Ethnicity (%)			
White/Caucasian	50%	71.4%	.116
African American	12.5%	7.1%	
Hispanic/Latino	25%	7.1%	
Asian American/Pacific Islander	12.5%	14.3%	
Parental Questionnaire Completer Variables			
Parental Ethnicity (*same as child*)	—	—	
Parental Education Level (%)			.017
Bachelors or Some College	37.5%	50%	
Some Professional Schooling	25%	0	
Masters	37.5%	35.7%	
Professional Degree/Doctorate	0	14.3%	
Average Annual Family Income (*SD*)	$143K (81.66)	$132K (79.78)	.065
Minimum—Maximum	$38—$300K	$9—$280K	

Procedures

Subject Recruitment

Families were recruited from local autism treatment clinics, research centers, and public and private schools in the greater Seattle area. Recruitment handouts were provided to schools and clinics to allow interested families to contact graduate research coordinators for additional information about the study. Research staff also organized information tables at recruitment sites where families could learn more about the study and sign up to receive a phone call from graduate research coordinators. Additionally, pull-tab flyers were posted at schools, local libraries, community centers, and businesses that serve children and families and study announcements were placed in local ads. Announcements, handouts, and pull-tab flyers provided general information about the study and contact information for graduate research staff coordinating subject enrollment.

Study Visits

Parents and children completed two study visits, an enrollment visit (EV) and a visit at the university (UV).

Enrollment Visit. Lasting approximately 90 to 120 minutes, the enrollment visits served as introduction to the study, wherein families were consented and eligibility for study enrollment was re-confirmed (i.e., parents completed the SCQ and ABC measures to ensure that children with typical development did not demonstrate significantly high elevations of autism symptoms; children completed the DAS-II verbal subtests to ensure a verbal ability score above 85). EVs were completed in the family home or at a local library. In addition to their informed consent, parents of ASD children were also asked to sign medical release forms to obtain their child's diagnostic records. All parents completed assessment paperwork regarding family demographics as well as several screening questionnaires for their child. Children were also assented and then completed verbal assessments, attention tasks on a computer, assessments of emotion knowledge, and the visual motor integration task with a graduate student assessor.

University Visit. Within approximately 1 to 2 weeks following their EV, families were scheduled for their next visit at the university. The UV lasted between 120 to 240 minutes and consisted of several child tasks, including assessments of the child's emotion knowledge, attention, and theory of mind. Additionally, parents completed several questionnaires about their child's social and emotional behavior and an interview about their thoughts and feelings about emotion. Parents and their children also completed two video-taped tasks together, a semistructured parent-child reading task and an unstructured parent-child free play task. As compensation for their contribution to the study, parents received $50 and a $5 coffee card and children received a small gift of roughly $5 monetary value and stickers.

COVID-19 and Adapted Remote Procedures. Due to the COVID-19 pandemic and social distancing restrictions, it was not possible to gather participant data during in-person meetings and achieve the proposed sample size, which will be discussed further in the results section. Alternately, a revised procedure was developed for gathering participant information remotely. After IRB approval was obtained for these revised procedures, an additional recruitment wave was completed from March to May 2020. This adapted procedure involved re-enrolling families who had previously completed the larger, ongoing study and who were willing to complete these additional dissertation measures (e.g., re-consenting and re-assenting, updated demographics, and assessments of verbal ability, visual motor integration, and sensory processing). This single “virtual” visit took place through a researcher-home to family-home, HIPAA-compliant web platform and a same-day front porch materials drop-off/pick-up. Visits were completed by either me or one other doctoral student who both complied fully with CDC guidelines around the sanitization and handling of materials between families. Because this was part of a later enrollment wave, participant eligibility age was raised from the originally proposed age of 6:11 to include children up to age 9:6 years.

Measures

Developmental Status

Parents of children with ASD confirmed their child’s diagnosis by either providing a copy of the original diagnostic report or by providing consent for diagnosing clinics to release report. For the latter, graduate students would ensure collection of this report directly from diagnostic agencies and/or providers.

Demographic Information

Parental guardians provided child and family demographic information including child age, gender, and ethnicity as well as parent ethnicity, level of education, and annual household income. Additional information collected from this form included: whether the child was currently enrolled in school, whether concerns were ever raised by a primary physician regarding the child’s development, and whether a developmental evaluation was ever completed.

Verbal Ability

The Differential Abilities Scales, Second Edition (DAS-II; Elliott, 2007) is a performance-based intellectual assessment (IQ test) for children ages 2:6 through 17:11. Children were assessed on their verbal comprehension (receptive language, RL) and naming vocabulary (expressive language, EL) skills. *T*-scores for EL and RL were used to calculate the child’s verbal ability composite score, also referred to as their verbal IQ.

The DAS-II was normed and standardized using a sample of 3,480 individuals, yielding good internal reliability for the Verbal Cluster—with coefficients ranging from .86 to .93 for ages 3:0 to 6:11 (Elliot, 2007). The test-retest reliability coefficients of the Verbal Cluster have also been high at .90 for ages 3:6 to 4:11 and .89 for ages 5:0 to 9:11 (Elliot, 2007). Additionally, the DAS-II has been tested against other measures of intelligence and achievement and has received an average mean correlation of .80 (Elliot, 2007).

Motor Coordination and Visual Motor Integration

The Beery–Buktenica Developmental Test of Visual–Motor Integration, Sixth Edition (Beery VMI; Beery et al., 2010) is a widely used assessment of the extent to which individuals can integrate their visual and motor skills. Not only a platform through which appropriate interventions (i.e., eligibility for occupational therapy services and/or school- or employment-based accommodations) are often determined, results from the Beery VMI can also be used as an outcome measure for evaluating the effectiveness of education and intervention programs (Poole, 1991). Internationally respected and backed by decades of research and clinical use, the Beery VMI offers a convenient and economical way to screen for visual-motor deficits that can lead to impacted learning, neuropsychological, and behavior problems (Beery et al., 2010). The domains of application of the Beery VMI broadly include cognition, coordination, dexterity, infant and child development, as well as vision and perception. More specifically, the primary areas evaluated for impairment are visual perception, motor integration, and visual-motor integration (i.e., hand-eye coordination), three domains closely associated with important outcomes in behavioral, academic, and cognitive functioning (Beery et al., 2010). The Beery VMI is appropriate for use with individuals ages 2 to 99 and is comprised of a full form and two subtests: Visual Motor Integration, Visual Perception, and Motor Coordination (the last two are supplemental and used for isolating specific skill areas). A pencil-and-paper assessment, the Beery VMI is typically administered individually and usually takes 10 minutes to complete the full VMI form, with an additional five minutes each for the supplemental Visual Perception and Motor Coordination subtests. While all three tasks were completed for the present study, only the full VMI form was used for primary analyses in this study.

The Beery VMI was normed in the United States six times during a 40-year period on a total of more than 12,500 children, with VMI scores remaining remarkably stable overall. The authors of the Beery VMI report strong validity and reliability in their measure. For internal consistency, the manual reports strong correlations between halves of test items in an even-odd split using the Spearman-Brown method (.95), a strong Cronbach's alpha of .96., and validity remains relatively strong across the three subtests—from .80 to .95. Additionally, reliability reports are strong for the three subtests, for both inter-rater reliability (VMI [.93], Visual Perception [.98], and Motor Coordination [.94]) and test-retest reliability (VMI [.88], Visual Perception [.84], Motor Coordination [.84]). The authors also advertise their instrument as a virtually culture-free, non-verbal assessment that is useful with individuals of diverse environmental, educational, and linguistic backgrounds (Beery et al., 2010).

Sensory Processing

The Short Sensory Profile, Second Edition (SSP-2; Dunn, 1999) is a 34-item parent-report measure designed to assess behaviors associated with atypical responses to sensory stimuli across seven domains in children aged birth to 14. The paper and pencil measure takes approximately 10 minutes to complete by a parent/caregiver respondent. Each item on the SSP-2 is measured on a 5-point Likert scale (score values range from 1 [*almost never*] to 5 [*almost always*] and a "0" option for *does not apply*), with higher scores indicating more severe impairment. Domain scores are assessed broadly for sensory processing (14 items) and behavioral responses associated with sensory processing (20 items), as well as within the four subcategories of seeking/seeker (7 items; *touches people and objects more than same-aged children*), avoiding/avoider (9 items; *interacts or participates in groups less than same-aged children*), sensitivity/sensor (10 items; *struggles to complete tasks when music or TV is on*), and registration/bystander (8 items; *bumps into things, failing to notice objects or people in the way*). Summed scores for these two broad domains and four subdomains fall individually into five possible categories (as compared with the general population) with a possible range of scores from 0 to 170: *(much) less than others, just like the majority of others*, and *(much) more than others*.

The SSP-2 comprises of the items that demonstrated the highest discriminative power of atypical sensory processing among all the items from its predecessor and longer version, The Sensory Profile (SP; Dunn, 1999), from which norms were established and standardized from a sample of 1,791 children (898 males and 893 females). While the total scale score is a good indicator of overall sensory dysfunction, the individual domain scores have demonstrated promising internal and external validity, with internal consistency alphas ranging from .79 to .93 across all domains and test-retest reliability alphas ranging from .93 to .97. Internal validity correlations through factor analysis for individual domains ranged from .25 to .76 and were all significant at $p < .01$. Early studies have also found discriminant validity to be greater than 95% in identifying children with and without sensory modulation difficulties (McIntosh et al., 1999). Finally, confirmatory factor analyses (CFA) have found good construct validity and goodness of fit for the SSP-2 across settings (Dunn, 1999) and moderate results for versions adapted to other cultures and in other languages; e.g., a 7-factor model of a Malay version (SSP-M; Ee et al., 2016) which yielded a comparative fit index (CFI) of .92—a comparison of the original model to the independent, translated model (Bentler, 1990)—and a root mean square approximation of error (RMSEA) of .05.

CHAPTER III: Results

Data Entry and Preparation

Data were entered into the Statistical Package for the Social Sciences (SPSS) Version 26.0 software and were cross checked for accuracy. Primary and ancillary analyses were run using the PROCESS macro add-on (Hayes, 2013; Models 1 and 3). Primary and ancillary variables of interest included: child developmental status (dichotomous predictor; coded as 0 for TD and 1 for ASD), child verbal language ability (dependent variable; verbal ability composite standard score), child visual motor integration (continuous moderator; VMI full form), and parent-report of child sensory processing (continuous moderator; total sensory score).

Power Analyses.

An a priori analysis with a multiple regression design was conducted using G*Power software (Faul et al., 2009) to calculate the necessary sample size for yielding adequate power for the current analyses. Based on previous literature, two potentially confounding demographic variables—child gender (dichotomous variable; coded 0 for male and 1 for female) and chronological age (continuous variable; entered in months)—were entered as covariates for this a priori power analysis (Bellini, 2006). Therefore, a total of six variables (developmental status, verbal language ability, visual motor integration, sensory processing, gender, and chronological age) were entered as predictors in the power analysis. Because the variables of verbal language ability, visual motor integration, and sensory processing have not been examined together in a sample of young children with and without autism, Cohen's F^2 effect size was set at .20, a high medium effect size, based on previous research with similar constructs and statistical models (Cohen, 2003; Shoener et al., 2008). With an alpha set at .05 and the power level at .80, a minimum of 52 participants was determined to be necessary for the planned analyses to be adequately powered.

Following testing of all hypotheses, a post hoc power analysis was completed using G*Power (Faul et al., 2009) in order to assess achieved power with the present study. Again, with a multiple regression design, the six predictor variables (developmental status, verbal language ability, visual motor integration, sensory processing, gender, and chronological age) were entered. The effect size (f^2) was calculated using the R^2 from the overall model ($R^2 = .721$), $f^2 = 2.58$ and the total sample size ($N = 22$) was also entered with the alpha level set at .05. Based on these parameters, the power level was determined to be very good (power level = .999), which suggests that the present study was sufficiently powered despite a lower than anticipated final *N*. However, due to the unequal status subgroup sizes (e.g., TD = 14; ASD = 8), there presents a meaningful and increased risk for Type II error worth noting. Therefore, in addition to significant values, confidence intervals were reported in subsequent analyses and sizes and directions of Beta weights (β) of the indirect effects were attended to where applicable.

Missingness, Outliers, and Assumptions of Multiple Regression

Data were assessed for missingness, outliers, and possible violations of the assumptions of multiple regression prior to all statistical analyses in the present study. Given that all participants completed demographic questionnaire, eligibility screeners (e.g., SCQ and ABC), Differential Abilities Scales, Second Edition (DAS-II), Beery–Buktenica Developmental Test of Visual–Motor Integration, Sixth Edition (Beery VMI), and the Short Sensory Profile, Second Edition (SSP-2), no missingness was detected. Outliers were also assessed using box-and-whisker plots and, following literature recommendations, bootstrapping was used in subsequent analyses as a robust method to outliers (Field, 2013; Hayes, 2013). No outliers were found in the current sample. Finally, the data were screened for the remaining violations of the assumptions of multiple regression: linearity, homoscedasticity, independence, normality, and multicollinearity.

Linearity

This assumption posits that the association between the independent (IV) and dependent (DV) variables must be linear. Data were examined using a probability-probability plot (P-P plot) and scatter-plot graphing to identify a best fitting line—a process that ensures that the data do not plot quadratically or cubically—as well as assess the linearity of the relations between the residuals and predicted values. With a categorical predictor variable, data were assessed by developmental status group (TD = 0, ASD = 1) between all predictor (e.g., visual motor integration and sensory processing) and the outcome (e.g., verbal language ability) variables. Based on visual inspection, all data points appeared linear, randomly and evenly dispersed around estimates within the status groups. Therefore, this assumption was met.

Homoscedasticity

This assumption relates to the variance of the residuals being held constant across all IV values (Field, 2009) and is again tested graphically by creating partial plots for each IV in relation to each DV by status group. This assumption was met based on data not following a funneling pattern and appearing evenly dispersed around a best fit line with no apparent outliers.

Independence

Positing that errors of estimation are statistically independent from one another, this assumption requires that a residual from one data point is not related to a residual of another data point (Field, 2009). The Durbin-Watson test conducted to explore the serial relation between the residuals, through which residual dependence is indicated by values of less than 1 or greater than

3. Results from this test determined that values were independent, and that this assumption was not violated (Cohen, 2003; Field, 2009).

Normality

This assumption holds that residual distribution within the data are normally distributed (Field, 2009). Field further recommends separate examination when there is a categorical predictor, as was the case in the present study (e.g., TD and ASD developmental status groups). Using graphical visual inspection of both a histogram and a P-P plot, the histogram revealed a normal distribution of residuals and a bell-shaped curve and the P-P plot demonstrated a pattern of *z*-scores that held closely along the diagonal line. Therefore, this assumption was met.

Multicollinearity

This occurs when there is elevated covariance between two predictor variables (Field, 2009) and was assessed through correlation analyses (see Table 3) and collinearity metrics (e.g., the variance inflation factor [VIF] and tolerance statistics). Findings indicated that predictors were not correlated ($r > .80$), VIF values ranged from 1.04 to 1.09 (threshold requirement is less than 10), and tolerance values ranged from .916 to .961 (threshold requirement is greater than .20; Field, 2009). As such, this final assumption was also met.

Data Analytic Plan

In the present study, I proposed hypothesized relations between the variables of developmental status (TD vs. ASD), verbal language ability (DAS-II), visual motor integration (Beery VMI), and sensory processing (SSP-2) through a multiple moderation analysis. Preliminary (including descriptive and correlational analyses), primary, and ancillary analyses are discussed in subsequent sections. Primary and ancillary analyses were run using template Models 3 and 1, respectively, from the macro add-on for PROCESS (Hayes, 2013). For primary analyses of multiple moderation, the model was specified to include developmental status (TD vs. ASD), language ability (verbal ability composite standard score), visual motor integration (full VMI standard score), and sensory processing (total sensory score).

Statistical Analyses: Descriptive, Correlational, Primary

Descriptive Analyses

Descriptive statistics comprise of group means, standard deviations, independent samples *t*-tests, and effect sizes and are provided to illustrate the statistical differences between the two developmental status groups (TD vs. ASD) across all entered variables of interest. All results are presented in Table 2 below. To further maximize the power of the independent samples *t*-tests, Field (2009) recommends using the bootstrap resampling method to obtain bias-corrected and accelerated (BCa) confidence intervals at 95% based on 5000 resamples. Effect sizes were reported using Cohen's *d*, which included medium to very large effect sizes (i.e., Cohen's *d* > 1) across the groups. There were significant status group differences for all study variables except expressive language ability (DAS-II), visual perception (Beery VMI), sensory seeking (SSP-2), and sensory registration (SSP-2).

Table 2.
Descriptive Statistics for Study Variables by Status Group

	Status			BCa 95% Confidence Interval for *t*-test		
	ASD (*n* = 8)	TD (*n* = 14)				
Variable	*Means (SD)* [*Range*]		*t*	*Lower*	*Upper*	*Cohen's d*
DAS-II SS	102.6 (*12.1*) [89, 124]	120.9 (*16.9*) [103, 159]	2.66 *	.226	1.85	1.039
Receptive	48.12 (*7.94*) [33, 57]	61.07 (*12.2*) [45, 90]	2.68 *	.229	1.86	1.042

Expressive	54.88 (*11.9*) [37, 74]	61.43 (*13.4*) [44, 90]	1.15	-.414	1.42	.5038
VMI Full	102.5 (*8.65*) [89, 114]	114.1 (*15.4*) [91, 132]	2.27 *	.065	1.56	.8127
Visual	107.6 (*14.5*) [78, 121]	106.7 (*13.4*) [89, 131]	-.149	-1.01	.879	-.0676
Motor	84.0 (*23.1*) [45, 117]	109.9 (*17.7*) [80, 134]	2.96 *	.330	1.91	1.1205
SSP Sensory	37.50 (*10.6*) [22, 53]	16.86 (*7.48*) [5, 27]	-5.35 **	-2.17	-.951	-1.558
Behavioral	47.75 (*19.3*) [19, 78]	25.79 (*10.1*) [9, 39]	-3.53 *	-2.00	-.516	-1.259
Seeking	16.13 (*6.06*) [6, 26]	11.64 (*5.59*) [0, 21]	-1.69	-1.60	.169	-.7171
Avoidance	24.63 (*9.21*) [10, 38]	13.14 (*4.56*) [7, 21]	-3.30 **	-2.26	-.423	-1.343
Sensitivity	26.38 (*9.38*) [13, 41]	16.14 (*5.72*) [4, 26]	-3.19 *	-1.95	-.411	-1.182
Registration	19.63 (*14.7*) [3, 49]	13.86 (*10.3*) [1, 34]	-1.08	-1.39	.443	-.4774

Note. *N* = 22; BCa = bias-corrected and accelerated confidence intervals; DAS-II SS = Differential Abilities Scales, Second Edition Verbal Ability Cluster Standard Score; Receptive = DAS-II Verbal Comprehension Subtest *T*-Score; Expressive = DAS-II Naming Vocabulary Subtest *T*-Score; VMI Full = Beery–Buktenica Developmental Test of Visual–Motor Integration, Sixth Edition Full Form; Visual = VMI Visual Perception; Motor = VMI Motor Coordination; SSP Sensory = Short Sensory Profile, Second Edition Sensory Processing; Behavioral = SSP Behavioral Responses Associated with Sensory Processing; Seeking = SSP Seeking/Seeker; Avoidance = SSP Avoiding/Avoider; Sensitivity = SSP Sensitivity/Sensor; Registration = SSP Registration/Bystander.

* $p < .05$

** $p \leq .001$

Correlational Analyses

Preliminary bivariate correlational analyses were also conducted to evaluate for assumption violation, isolate the influence of potential covariates on key study variables, and to identify significantly correlated demographic variables (e.g., child gender and child chronological age) that were controlled for in subsequent analyses. Pearson's bivariate correlations were used to examine the relations between study variables and are provided in the correlation matrix below (see Table 3). Significant correlations were found between status and DAS-II verbal standard score as well as status and SSP-2 total sensory score. Additionally, because the proposed covariates of child chronological age and child gender were not found to be correlated with any other study variable in the present sample, these variables were not controlled for in subsequent analyses.

Table 3.
Pearson's Bivariate Correlations among Study Variables

Variable	1	2	3	4	5	6	7	8
1. Chronological Age								
2. Child Gender	.232							
3. Child/Parent Ethnicity	.122	-.077						
4. Parent Education	.215	.312	-.374					
5. Annual Family Income	-.033	.307	-.269	.218				
6. Developmental Status	.180	-.245	.116	.017	.065			
7. DAS-II Verbal SS	.316	.248	-.232	.089	-.178	-.512*		
8. VMI Full Form	.202	.204	.375	.187	-.220	-.400	-.009	
9. SSP-2 Total Sensory	.416	.105	.223	.019	-.083	.767**	-.217	-.190

Note. $N = 22$; Chronological Age = in months; Developmental Status = TD vs. ASD; DAS-II Verbal SS = Differential Abilities Scales, Second Edition Verbal Ability Cluster Standard Score; VMI Full Form = Beery–Buktenica Developmental Test of Visual–Motor Integration, Sixth Edition Full Form; SSP-2 Total Sensory = Short Sensory Profile, Second Edition Total Sensory Processing Score.
* $p < .05$
** $p \leq .01$

Primary Tests of Moderational Relations

The PROCESS macro add-on for SPSS 26 (Hayes, 2013) was used to evaluate the overall conceptual moderated moderation model, which produced 95% confidence intervals for indirect effects. For the present study, I specified a model predicting verbal language ability using PROCESS template Model 3. The statistical diagram of Model 3 is presented below in Figure 2. My dichotomous focal predictor was developmental status (TD vs. ASD), with continuous primary (visual motor integration; M_1) and secondary (sensory processing; M_2) moderators. PROCESS Model 3 automatically evaluates interaction terms between the three variables (status and VMI; status and sensory processing; VMI and sensory processing), and the three-way interaction model (status, VMI, and sensory processing) when simultaneously entered. These moderators (visual motor integration; M_1 and sensory processing; M_2) were also later evaluated individually with ancillary analyses. Lastly, bootstrapped estimates of the conditional indirect effects, a nonparametric resampling procedure, was used to further assess the statistical significance of these indirect effects and to maximize statistical power (Preacher et al., 2007). Bootstrapped estimates are provided at a default setting based on 5000 resamples (Hayes, 2013).

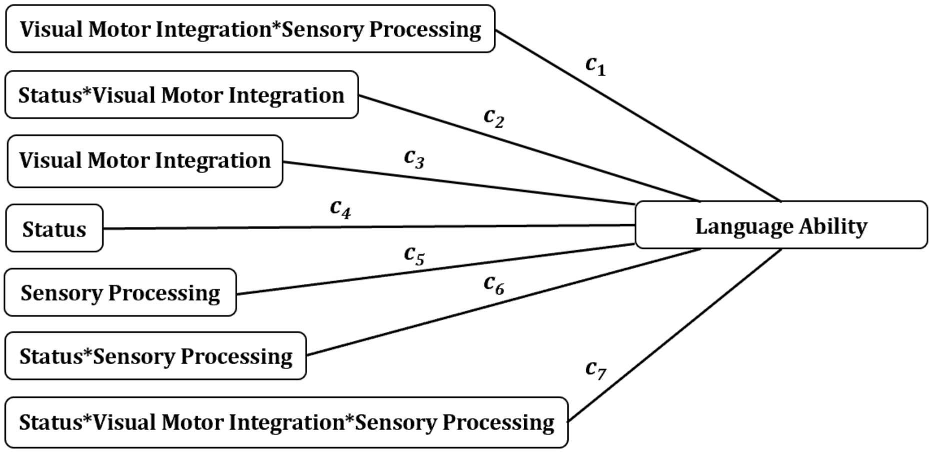

Figure 2. Statistical diagram of the effects of developmental status on language ability through visual motor integration and sensory processing.

Results by Hypothesis

Combined results from descriptive analyses and from this moderated moderation (Hayes, 2013; PROCES Model 3) are presented individually by hypothesis, and together in Figures 3 and 4 and Tables 2 and 4.

Hypothesis 1A: Language ability by developmental status

Child developmental status (TD = 0, ASD = 1) would predict language ability, such that children with ASD were predicted to have lower language ability composite scores. Following the prediction, the relation between status (X) and language ability (Y) was significant for overall verbal composite score: $t(20) = 2.66$, $p = .015$, $CI_{95} = .226$ to 1.85. Within individual subtest performance, receptive language was significant [$t(20) = 2.68$, $p = .015$, $CI_{95} = .229$ to 1.86] but expressive language was not [$t(20) = 1.15$, $p = .253$, $CI_{95} = -.414$ to 1.42].

Hypothesis 1B: Visual motor integration by developmental status

Child developmental status (TD = 0, ASD = 1) would predict visual motor integration scores, such that children with ASD were predicted to have lower visual motor integration scores. The relation between status (X) and visual motor integration (M_1) was significant [$t(20) = 2.27$, $p = .035$, $CI_{95} = .065$ to 1.56], as was the individual subtest of motor coordination [$t(20) = 2.96$, $p = .008$, $CI_{95} = .330$ to 1.91]. However, the subtest of visual perception was nonsignificant: $t(20) = -.149$, $p = .883$, $CI_{95} =-1.01$ to .879.

Hypothesis 1C: Sensory processing by developmental status

Child developmental status (TD = 0, ASD = 1) would predict total sensory processing scores, such that children with ASD were predicted to have higher sensory processing scores.

Overall, the hypothesized relation between status (X) and sensory processing (M_2) was supported, with significant findings for: overall sensory score [$t(20) = -5.35$, $p < .001$, $CI_{95} = -2.17$ to $-.951$], behavioral responses to sensory [$t(20) = -3.53$, $p = .002$, $CI_{95} = -2.00$ to $-.516$], avoidance [$t(20) = -3.30$, $p = .001$, $CI_{95} = -2.26$ to $-.423$], and sensitivity [$t(20) = -3.19$, $p = .005$, $CI_{95} = -1.95$ to $-.411$]. However, scores for both seeking [$t(20) = -1.69$, $p = .107$, $CI_{95} = -1.60$ to $.169$] and registration [$t(20) = -1.08$, $p = .292$, $CI_{95} = -1.39$ to $.443$] were nonsignificant.

Hypothesis 2: Status and language moderated by visual motor integration

Scores on the task of visual motor integration (W) would moderate the relation between child developmental status (X) and language ability score (Y). Controlling for sensory scores, children with lower scores on visual motor integration were predicted to yield lower language ability scores and this effect was expected to be even more severe for children with autism. For this first interaction, the conditional effect of status (X) and visual motor integration (W) when sensory (Z) is set to zero was nonsignificant: $p = .16$, $B = -4.41$, $CI_{95} = -10.78$ to 1.95.

Hypothesis 3: Status and language moderated by sensory processing

Sensory processing (Z) was also predicted to uniquely moderate the relation between child developmental status (X) and language ability scores (Y). Controlling for visual motor integration performance, children with higher sensory processing scores were predicted to yield lower language ability scores and this effect was expected to be even more severe for children with autism. While nonsignificant, the conditional effect of status (X) and sensory (Z) when visual motor integration (W) is set to zero trended toward significance: $p = .07$, $B = -17.43$, $CI_{95} = -37.25$ to 2.38.

Hypothesis 4: Language moderated by visual motor integration and sensory processing

Given previous literature on the two moderators of interest, visual motor integration (W) and sensory processing (Z), were also predicted to moderate language outcome when controlling for status (X). While this hypothesis was not supported (p = .23, B = -17.43, CI_{95} = -.13 to .034), the negative valence of the coefficient suggested that the directionalities of variables were following previous literature on these constructs and predictions for the present study. Status group differences across the two moderators of motor and sensory were then explored further via scatterplot in Figure 3. In this figure, fit lines by status group suggested some interesting trends: negative correlations for the ASD group, for example, VMI scores increased as sensory scores decreased. In contrast, positive correlations for the TD group's VMI scores increased as sensory scores increased. These two variables were explored further in ancillary analyses as separate moderations.

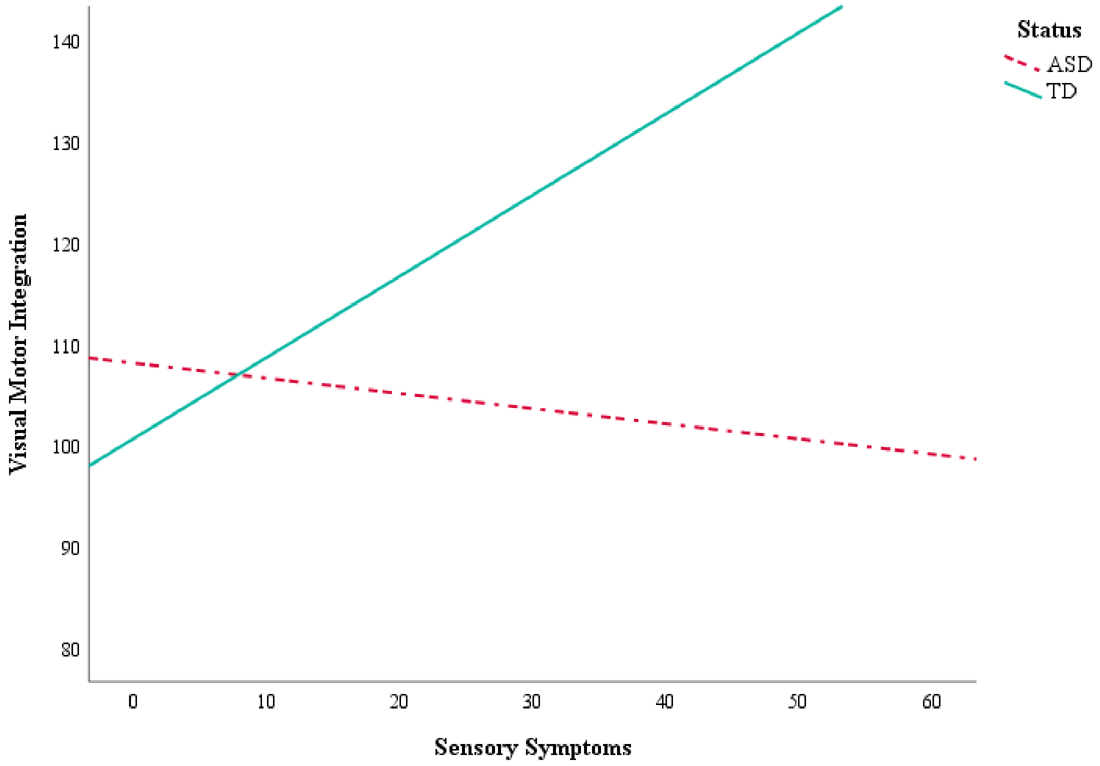

Figure 3. Scatterplot of the total sample displaying the negative trend between visual motor integration and sensory by status group.

Hypothesis 5: Status and language moderated by visual motor integration and sensory processing

Lastly, with the full model, it was predicted that performance on the task of visual motor integration (W) and sensory processing total score (Z) would moderate the relation between child developmental status (X) and language ability score (Y). Specifically, it was expected that the most impacted language ability scores would be demonstrated by children with an autism diagnosis and both lower scores on the visual motor integration task and higher sensory processing challenges. Overall, 72% of the variance in language ability was accounted for by the key variables in this model. However, in this final test of the full three-way moderation model interaction, results were nonsignificant: $p = .09$, $B = .15$, $CI_{95} = -.031$ to .33. All results are listed in Figure 4 and Table 4 below. Also included in Table 4 are effect sizes that were calculated for each path using the f^2 statistic described by Aiken, West, and Reno (1991). Cohen (2003) suggests effect size interpretations for small, medium, and large as .02, .15, and .035, respectively. Based on these guidelines, effect sizes in the present sample ranged from medium (.12) to very large (4.69).

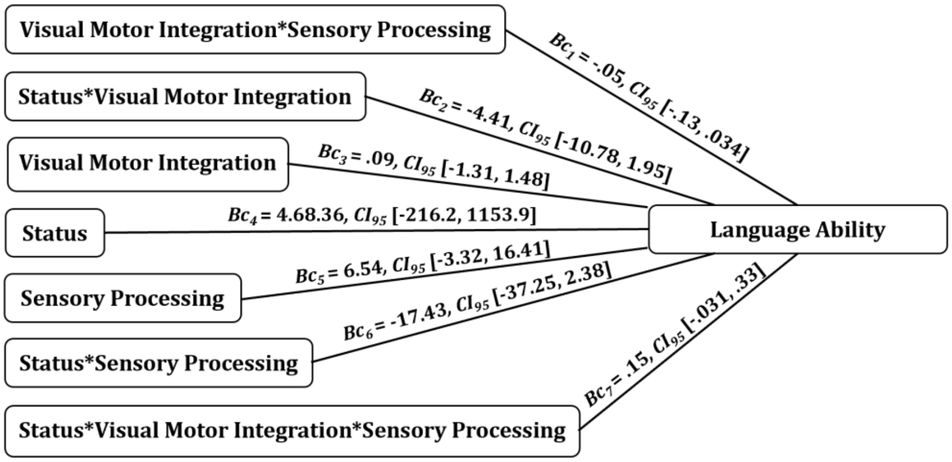

Figure 4. Moderated moderation of visual motor integration and sensory processing on the relation between developmental status and language ability, including unstandardized path coefficient values and 95% confidence intervals.

Table 4.
Simple and Conditional Effects of Status on Language Ability through Visual Motor Integration (M_1) and Sensory Processing (M_2)

Effect	*B*	*SE*	*p*	f^2	*95% CI*	
					Lower	*Upper*
Status → Language	468.36	314.57	.16	.59	-217.2	1153.9
VMI → Language	.09	.64	.89	.12	-1.31	1.48
Sensory → Language	6.54	4.53	.17	.59	-3.32	16.41
Status → VMI → Language	-4.41	2.92	.16	2.95	-10.78	1.95
Status → Sensory → Language	-17.43	9.09	.07	2.09	-37.25	2.38
VMI → Sensory → Language	-.05	.038	.23	4.69	-.13	.034
Status → VMI → Sensory → Language	.15	.083	.09	.64	-.031	.33

Note. *N* = 22; Developmental Status = TD vs. ASD; Language = Differential Abilities Scales, Second Edition Verbal Ability Cluster Standard Score; VMI = Beery–Buktenica Developmental Test of Visual–Motor Integration, Sixth Edition Full Form; Sensory = Short Sensory Profile, Second Edition Total Sensory Processing Score.

Post-hoc Analyses: Ancillary Tests of Individual Moderational Relations

Due to lack of significant findings across interaction hypotheses in the present study, ancillary tests of moderational relations were conducted using Model 1 of the PROCESS macro add-on for SPSS 26 (Hayes, 2013). These analyses examined the effects of visual motor integration and sensory on the relation between status and language as separate moderators (see Figures 5 and 6). Once again, 95% confidence intervals for the indirect effects were produced. Additionally, bootstrapped estimates of the conditional indirect effects, a nonparametric resampling procedure, was used to further assess the statistical significance of these indirect effects and to maximize statistical power (Preacher et al., 2007). Bootstrapped estimates are provided at a default setting based on 5000 resamples (Hayes, 2013).

Ancillary Moderation of Visual Motor Integration

PROCESS Model 1 was used to evaluate the additive and interaction effects of developmental status (dichotomous predictor) and visual motor integration (VMI Full Form; continuous moderator) on language ability (dependent variable). All variables were simultaneously entered. Results in this first moderation suggested that 58% of the variance in language ability was accounted for by the variables in this model. There was a significant simple effect of visual motor integration on language (p = .04, B = -.540, CI_{95} = -1.06 to -.018). However, the simple effect of status on language (p = .602, B = -34.61, CI_{95} = -172.57 to 103.35) and the interaction between status and visual motor integration on language (p = .92, B = .067, CI_{95} = -1.25 to 1.39) were both nonsignificant.

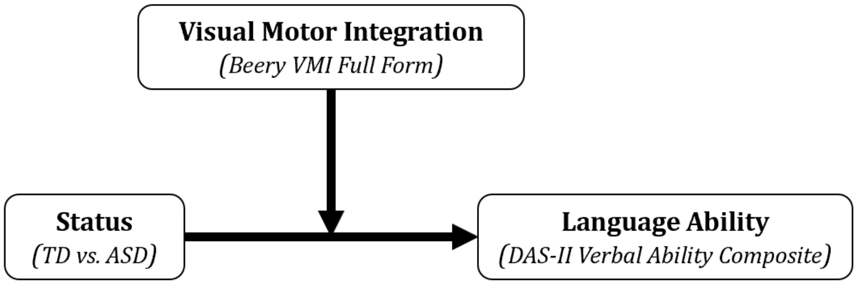

Figure 5. Moderation model evaluating the individual conditional effect of visual motor integration on the relation between developmental status and language ability.

Ancillary Moderation of Sensory

PROCESS Model 1 was also used to evaluate the additive and interaction effects of developmental status (dichotomous predictor) and sensory (SSP-2 Total Sensory Score; continuous moderator) on language ability (dependent variable). All variables were again simultaneously entered. Results in this second moderation suggested that 45% of the variance in language ability was accounted for by the variables in this model. The simple effects of sensory on language ($p = .48$, $B = .439$, $CI_{95} = -.858$ to 1.74) and of status on language ($p = .47$, $B = -17.78$, $CI_{95} = -69.29$ to 33.74), as well as the interaction between status and sensory on language ($p = .68$, $B = -.324$, $CI_{95} = -1.96$ to 1.31) were all nonsignificant.

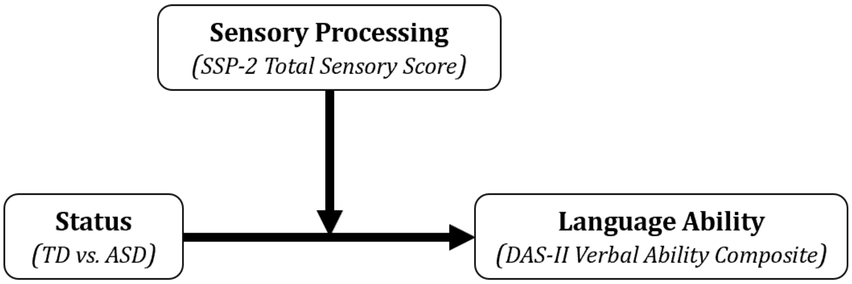

Figure 6. Moderation model evaluating the individual conditional effect of sensory on the relation between developmental status and language ability.

Because findings from these individual moderations were altogether nonsignificant, these interactions were each further examined using the Johnson-Neyman technique (Johnson & Fay, 1950) to evaluate the area of significance for the conditional effects of the predictor (language) at mean and +/- 1SD mean values of each individual moderator (visual motor integration and sensory). Findings from these probes revealed significant status group (TD vs. ASD) differences for children with visual motor integration full form standard scores of 119 and below ($p < .05$) and for children with total sensory scores of 25 to 36 ($p < .05$). Given that VMI standard scores were as high as 132 and total sensory scores ranged from 5 to 53, many from the present sample did not meet these cutoffs. These thresholds for clinical significance across the two constructs of interest are presented below in Figure 7.

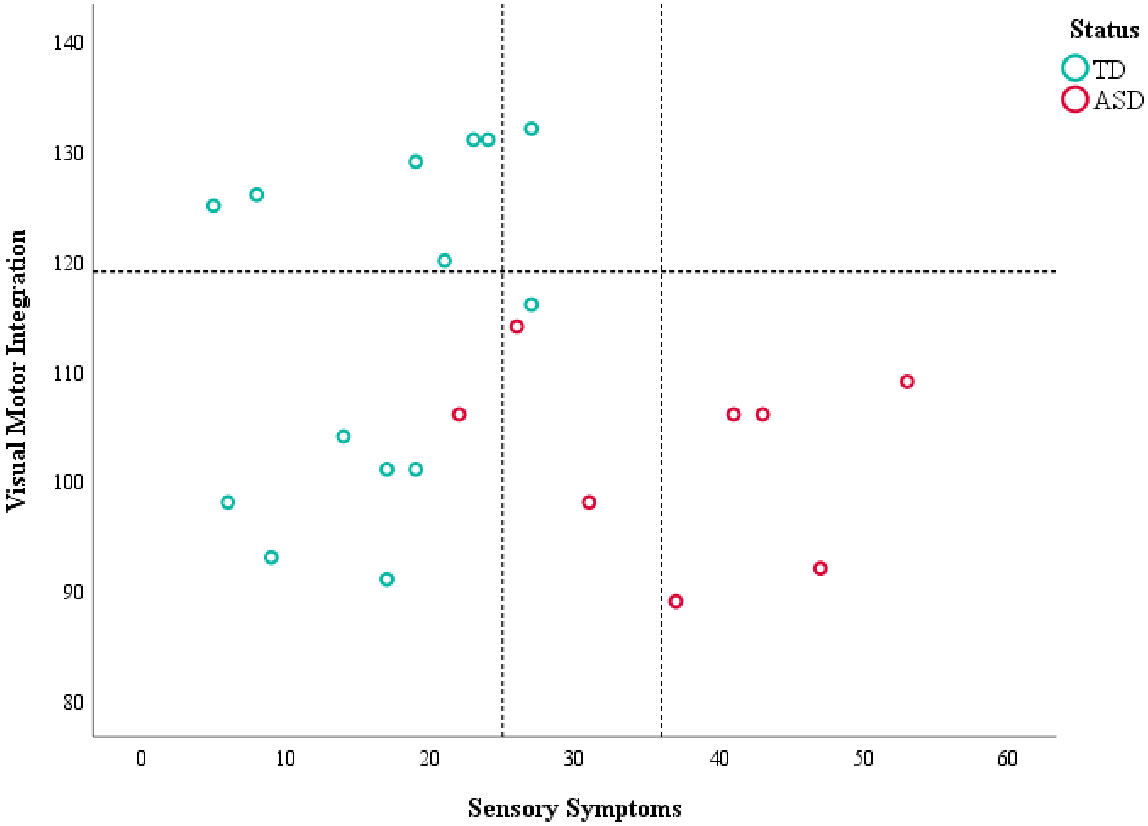

Figure 7. Scatterplot of the total sample by status group displaying the thresholds for clinical significance across visual motor integration scores and sensory symptoms. Note: VMI full form standard scores of 119 and below ($p < .05$) and total sensory scores of 25 to 36 ($p < .05$).

CHAPTER IV: Discussion

The current study sought to address a gap in the literature by exploring the relation between visual motor integration, sensory processing, and language ability in children with autism and in children with typical development between the ages of 3:0 and 9:6 years. Specifically, the constructs of visual motor integration and sensory processing were examined as moderators of the relation between child developmental status (TD vs. ASD) and language ability score. In the overall conceptual model of moderated moderation, I hypothesized that children with autism, atypical sensory processing, and impaired visual motor integration would have the most impacted language ability scores. While this hypothesis was not supported in the present study, there were significant findings with other proposed hypotheses (Hypotheses 1A, 1B, and 1C), a notable trending significance for the moderation of sensory on the relation between status and language (Hypothesis 3), and further meaningful findings within ancillary analyses of individual moderations. These findings were reviewed in subsequent sections, along with a discussion of clinical implications of these results, strengths and limitations of the present study, and proposed directions for future research.

Interpretation of Results

Autism and Language Ability

Findings from the current study indicated that children with ASD demonstrated lower language ability composite scores than their TD peers and this effect was large (f^2=.59), supporting *Hypothesis 1A*. Compared to the TD group, ASD children also performed significantly lower on the subtest of receptive language, but there were no significant group differences for expressive language subtest performance. This mirrors previous literature on the highly variable types and severity of language impairment in ASD populations, particularly for younger children when language skills are still developing (APA, 2013; LeBarton & Iverson, 2013; Pickles et al., 2004; Tager-Flusberg & Kasari, 2013). It is also important to note that, like much prior research of children with autism (Tager-Flusberg & Kasari, 2013), current study inclusion criteria was limited to children with average to above-average verbal ability and still produced significant group differences.

Autism and Visual Motor Integration

Hypothesis 1B was also supported in that children with ASD performed worse on the task of visual motor integration compared to the TD group. This effect was also large (f^2=2.95) and is encouraging for future research. There were also significant status group differences for the motor coordination subtest (i.e., TD significantly outperformed ASD), but not with the subtest of visual perception. These findings are mostly consistent with previous literature that have described children with ASD as having significant challenges with visual motor integration (Green et al., 2016; Hannant, 2018), as well as fine motor skill and motor coordination (LeBarton & Iverson, 2013; Libertus et al., 2014). However, these results did not indicate significant visual perception impairment for the ASD group as has been the case with other studies (Beery et al., 2010; Samuelson & Smith, 1999). Lack of significance for this latter relation may have been due to having enrolled a highly verbal sample of children. Previous studies that have examined visual perception in children with ASD and higher verbal ability have found similar nonsignificant results when compared to children with lower verbal ability (Abdelaziz et al., 2018). Moreover, Perry and Saffran (2017) also proposed that assessment of visual perception and language skills in children may be dependent on the timing of acquisition of these skills. In other words, a single assessment may be insufficient for detecting meaningful differences with skills that develop over time.

Autism and Sensory Processing

Children with autism in the current sample also demonstrated significantly higher overall sensory processing differences than the TD group, therein supporting *Hypothesis 1C* and the effect was large (f^2=2.09). This follows previous literature suggesting that sensory processing challenges are present in about 90 to 95% of individuals with autism (Baker et al., 2008; Tomchek & Dunn, 2007). Significant group differences were also found for the sensory subscales of behavioral responses to sensory processing, avoidance, and sensitivity such that children with ASD were reported to have more sensory impairment in these domains than the TD group. However, reported scores for both sensory seeking and sensory registration were not significantly different across the two status groups. Interestingly, these mixed results also follow previous studies on sensory differences in autism that have not only reported consistently high sensory challenges, but also highly varied findings on sensory subtype and severity for children with autism (Robertson & Baron-Cohen, 2017; Woo et al., 2015). In her review paper, Haigh (2018) suggested that this variability may be due to challenges with comparing differing forms of sensory assessment (e.g., paper and pencil vs. physiological) and with the perpetuating challenges with drawing causal conclusions within sensory systems (i.e., which mechanism precedes which response).

Testing Visual Motor Integration as a Moderator of the Relation Between Developmental Status and Language Ability

This was the first of my hypotheses that, to my knowledge, has not previously been investigated together in a younger population sample. Specifically, I predicted that children with lower scores on visual motor integration would demonstrate lower language ability scores, and this effect would be more severe for children with autism (*Hypothesis 2*). Prior research posits that targeted intervention for motor skill development may support language acquisition and development in children (MacDonald et al., 2013), and that this relation would be more impactful for children with autism than TD (Houwen et al., 2016). For this hypothesis, the conditional effect of status and visual motor integration on language was not significant. In further ancillary analyses using the Johnson-Neyman technique, significant status group (TD vs. ASD) differences were found for children with visual motor integration full form standard scores of 119 and below ($p < .05$). With VMI scores ranging as high as 132 for an already highly verbal sample (i.e., standard scores as high as 159), half of the TD subjects (i.e., seven of the 14) did not meet clinical cutoffs, while all eight ASD participants met clinical significance. In other words, the TD sample may have consistently performed too well on the tasks of visual motor integration and language such that meaningful group differences could not be detected. In addition to challenges with homogeneity, it is important to remember that risk for Type II error was inflated due to small sample size ($N = 22$) and unequal subgroup sample sizes (i.e., TD = 14; ASD = 8). However, given the medium effect size (f^2=.12), continued investigation of these constructs is encouraged with a larger sample.

Testing Sensory Processing as a Moderator of the Relation Between Developmental Status and Language Ability

Positive associations between severity of sensory challenges and language impairment have been well documented in the literature (Brock et al., 2012), but prior research also suggests that the nature of sensory subtype and severity across the lifespan in ASD populations remains varied (Watson et al., 2011). While my prediction that children with autism and higher sensory scores would have the most impacted language scores, *Hypothesis 3* was not supported. However, findings were trending in the expected direction and the effect size was large (f^2=.59) for this association Further ancillary analyses using the Johnson-Neyman technique revealed significant status group (TD vs. ASD) differences for children with total sensory scores of 25 to 36 ($p < .05$). Within this highly verbal sample whose sensory raw scores ranged from 5 to 53 (i.e., on a questionnaire whose total sensory subscale values range from 0 to 70), only one TD and two ASD participants met this sample-specific clinical threshold (i.e., value cutoffs for clinical significance for the VMI and SSP-2 with this specific sample; see Figure 7) which severely limited the possibility of detecting meaningful group differences. Challenges with previously discussed sample performance homogeneity and possible inflation of Type II error also may have contributed to these nonsignificant findings.

Visual Motor Integration and Sensory Processing

Hypothesis 4 proposed that visual motor integration (W) and sensory processing (Z), would moderate language outcomes after controlling for status (X). It was hoped that this hypothesis would help address a gap in the literature by investigating these constructs with a younger sample. Based on previous research with older children, I hypothesized that visual motor integration and sensory processing would moderate language, contributing unique variance beyond that of status group differences. Ultimately, this hypothesis was not supported. Earlier investigations into the constructs of motor and sensory indicate high variability with regards to the stepwise nature of motor skill acquisition (e.g., certain foundational motor skills preceding/depending on the learning of the next) and the complexities around type of sensory processing differences in children across different ages (Baranek et al., 2013; Ben-Sasson et al., 2009; Jasmin et al., 2009; Leonard et al., 2015). It could be that a single assessment of these constructs is less able to capture differences than would multiple assessments using a longitudinal design. Despite these nonsignificant findings, further exploration into the constructs of motor and sensory identified some interesting differences for the two status groups for motor and sensory. For example, the ASD group demonstrated negative correlations such that increased VMI scores were related to decreased sensory scores (i.e., VMI performance improved as sensory impairment decreased). However, contrary to prediction and prior findings, positive correlations were observed with the TD group in that increased VMI scores were related to increased sensory scores (i.e., VMI performance improved with increased sensory impairment). In other words, these trends suggested that increases in sensory symptoms were related to worsened performance for the ASD group and improved performance for the TD group on the VMI task. Given limitations around small sample size and with narrow thresholds for clinical significance, these results should be interpreted with caution. However, these results still warrant further investigation in future studies due to the very large effect (f^2=4.69).

Testing Visual Motor Integration and Sensory Processing as Moderated Moderators of the Relation Between Developmental Status and Language Ability

To my knowledge, there continues to exist a paucity of research examining the relation between the constructs of motor skills, sensory processing, and language development in young children with autism. This appears to be the case, despite emerging research suggesting the ongoing need for investigation of these critical areas (Duvekot, et al., 2018; Hannant, 2018; Sukhodolsky et al., 2008). I investigated this issue utilizing a three-way interaction model and I predicted that children with autism, lower visual motor integration scores, and higher sensory processing challenges would have the most impacted language ability scores (*Hypothesis 5*). While results suggested that 72% of the variance in language ability was accounted for by the key variables in this model, no significant results were found regarding the proposed conceptual model of moderated moderation. As noted earlier, it is likely that the lack of significant findings was related to the study's small overall ($N = 22$) and unequal subgroup sample sizes for developmental status (i.e., TD = 14; ASD = 8), which further inflated the risk for Type II error. Additionally, the relatively low variability across performance scores with language, visual motor integration, and sensory made detecting clinically significant sample differences difficult. Nevertheless, the effect size of motor and sensory on the relations between status and language was large (f^2=.64), which is promising for future studies with a larger and more adequately powered sample.

Clinical Implications

Retrospective studies like those performed by Heathcock and colleagues (2015) stress the importance of monitoring for individuals at increased risk for autism, as early and reliable diagnosis allows families to access evidence-based early interventions. A better understanding of the underlying challenges experienced by young children on the spectrum will assist in identifying specific areas for more effective and targeted interventions with this population. Research suggest interventions for these children are most impactful when implemented earlier in life (Bhat et al., 2012) because early challenges have a multiplicative effect over time with early delays impacting multiple areas of functioning. For example, difficulties in motor skill development have been associated with challenges in tasks of daily living, school/work performance, and social functioning for children on the autism spectrum (MacDonald et al., 2013; May et al., 2016). Additionally, children with ASD demonstrating a higher frequency of sensory behaviors have been shown to experience pervasive challenges across the domains of social functioning (Ben-Sasson et al., 2009), daily activities (Bar-Shalita et al., 2008), and emotion regulation (Miller et al., 2004).

These under-researched areas of motor development and sensory processing require greater attention. The theory of embodied cognition holds that cognitive development, and arguably language development (Iverson, 2010), are contingent upon the sensorimotor interplay between an individual and their physical environment (Smith & Gasser, 2005). As such, when deficits with motor development are combined with sensory processing challenges, it is conceivable that cascading effects may be observed in an individual's language ability. Moreover, language development in autism populations remains one of the best predictors of adaptive functioning and social skills later in life (Gillespie-Lynch et al., 2012). Thus, a better understanding of these early individual differences is critical for identifying more effective targets for early intervention.

Strengths and Limitations

There were several strengths worth noting regarding the present study. First, to the best of my knowledge, examination of this combination of study variables with young children with autism was designed to address an important gap in current autism literature and may therefore serve as a platform for future empirical endeavors. This study also used a combination of psychometrically sound direct child assessment (e.g., Differential Ability Scales, 2nd Edition and Beery–Buktenica Developmental Test of Visual–Motor Integration, 6th Edition) and parent report (Short Sensory Profile, 2nd Edition) instruments. Additionally, while this was a relatively homogeneous and affluent sample with regards to race/ethnicity, parent education, and family income, these demographic factors were not correlated with and therefore did not overtly influence findings regarding key study variables. Lastly, this study utilized performance-based assessments of language ability and motor skills in lieu of relying on adult report with this young sample.

Despite these important strengths, there were also several limitations with this study. Eligibility criteria for the larger, ongoing study required enrollment of children with average to above average verbal language ability (i.e., verbal composite standard score of 85 and above). While this sampling of children with higher verbal ability is consistent with a large majority of previous research (Tager-Flusberg & Kasari, 2013), the variability of language performance for the current study was limited. Because this was such a highly verbal sample, I also suspect that this may have impacted the limited variability of performance and ratings across other primary study variables (i.e., Beery VMI and SSP-2). By utilizing a cross-sectional design, causal inferences regarding the relations between variables could also not be determined. Additionally, this study comprised of a small overall sample size (*N* = 20) and unequal status subgroups (i.e., TD = 14; ASD = 8), which inflated the risk for Type II error and therefore limited the interpretability of the results. Lastly, it is important to acknowledge the potential limitations associated with utilizing parents as reporters of their child's sensory processing. While the Short Sensory Profile, Second Edition (SSP-2) is a widely used measurement of sensory symptoms and parent-report was necessary for the younger children in this sample, parent-report may not fully capture the breadth and depth of an individual's subjective experience of sensory differences and are further subject to potential reporter bias and halo effects.

Conclusions and Future Directions

Results from this study serve as a pilot for continued research on the important yet under-researched constructs of language and motor development and sensory differences in ASD populations and are promising for further research. This research is particularly important for age groups that have traditionally received less attention from researchers, especially children after 36 months and before later elementary school years (Ben-Sasson et al., 2009; Hannant et al., 2016; Shoener et al., 2008). The present study with children between the ages of 3:0 and 9:6 supported previous findings regarding significant group differences with older children with autism (e.g., ages 7 to 16) across the constructs of language, visual motor integration, and sensory differences (Hannant et al., 2016; Shoener et al., 2008). Specifically, compared to children with typical development, children with ASD in the present sample were found to demonstrate significantly lower performance on tasks of language ability and visual motor integration and to have more sensory symptoms. However, overall conclusions about the moderation of visual motor integration and sensory processing on the relation between status and language ability could not be made given the aforementioned limitations of this study. These included its small sample size, homogeneity of performance across verbal and motor tasks and sensory ratings, as well as unequal status subgroups.

While the overall model findings were nonsignificant, other findings discussed in this study may serve as meaningful avenues for replication and expansion in future research (e.g., subtest/subscale variability across the VMI, SSP-2, and DAS-II). Additionally, future research should include larger samples with equal status subgroups and enroll children with a wider range of language ability. Continued examination of these constructs should also use a longitudinal design to assess for potential causal relations between these variables, as well as establish a better understanding of when to what degree the combination of motor and sensory challenges may impact other functional domains (i.e., language). With this effort in mind, future researchers might also consider exploring further on the current study’s findings such as the statistical trend of sensory on the relation between status and language and thresholds for clinical significance within VMI performance and sensory ratings. Given the large effect sizes found for these relations, I suspect that with more variability in the data (e.g., wider range of verbal eligibility criteria), a larger sample, and equal status subgroups, more significant findings and conclusions could be made. In summary, the relations between motor skill, sensory impairment, and language ability share many common themes in early cognitive development. Therefore, continued research on these constructs is encouraged as they may serve as pivotal targets for early intervention that could have cascading effects on later developmental outcomes.

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