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BRIEF REPORT

Development and pilot testing of an early childhood somatosensory assessment: Somatosensory test of reaching

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Abstract

Thirty-two children (50% female, 59.3% White, 7–60 months), from middle to high socioeconomic status families, participated in pilot feasibility and validity testing of the somatosensory test of reaching (STOR). STOR tested the child's accuracy of reach to visual and somatosensory targets. All children were able to complete the assessment. Statistically significant differences were found between age groups ($p = .0001$), showing developmental trends, and between test conditions ($p < .001$), showing that the ability to reach to visible targets develops before somatosensory targets. STOR also showed a moderate correlation with the Developmental Assessment of Young Children 2nd edition. STOR appears to be a promising tool for assessing somatosensory processing in very young children, and it warrants additional testing in larger participant samples.

KEYWORDS
early childhood, proprioception, somatosensory

1 | INTRODUCTION

In order to function well in daily activities, the body relies on the nervous system to process and integrate information from multiple sensory systems (Ayres, 1972; Bundy et al., 2002). Somatosensory processing is the process of sensory information related to the body (somato-). Somatosensory can be broken into tactile pression (touch, pressure, vibration, temperature) and the subconscious and conscious awareness of the spatial and mechanical status of the musculoskeletal framework (Proske & Gandevia, 2012; Stillman, 2002). Proprioception includes position and movement sense, and sense of force that originate mostly from muscle spindles and Golgi tendon organs (Bastian, 1887; Proske et al., 1988; Schmidt & Lee, 2014; Sherrington, 1906). While some studies consider position sense and movement sense separately (Barrack & Skinner, 1990; Gardner et al., 2000; van Beers et al., 1998; Warner et al., 1996), we consider movement sense within the context of position sense as these two senses are highly interconnected. Movements can be interpreted as changes in joint position, and position sense provides cues about the direction and speed of movement (Chu, 2017). Proprioception provides feedback about the relative spatial relationship between musculoskeletal units of the body to the motor system and thus plays an essential role in motor control and planning. Understanding the impact of the proprioceptive system on the motor system in adults has contributed to the success of targeted proprioceptive interventions for the prevention of recurring falls in the geriatric population (Li et al., 2008; Mehrsheed Sinaki et al., 2005; Sinaki & Lynn, 2002) and rehabilitation of various motor disorders such as stroke and Parkinson's disease (Aman et al., 2014).

Deficits in processing and integrating somatosensory information can severely impact a child's ability to learn new motor skills and develop motor coordination skills (Wong et al., 2012). Children with poor somatosensory processing are often not diagnosed until they are around school age, when they present with significant motor deficits and are referred to pediatric occupational or physical therapists. Children with somatosensory deficits, observed when they are older, have difficulty functioning in their everyday lives (Blanche, Reinoso, et al.,

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2012; Falk et al., 2010; Fatoye et al., 2009; Johnston et al., 1987; Mon-Williams et al., 1999; Schneck, 1991; Weimer et al., 2001), such as with feeding, dressing, and playing. Studies have linked poor proprioception with motor difficulties in older children, including poor balance and postural control (Blanche, Bodison, et al., 2012; Weimer et al., 2001), difficulties with force gradation (Dunn, 1999; Parham & Ecker, 2007), handwriting difficulties (Falk et al., 2010; Schneck, 1991), and poor coordination (Fatoye et al., 2009; Johnston et al., 1987; Mon-Williams et al., 1999). Although studies have shown, in adults and animal models, loss of proprioception can be accommodated by increasing reliance on visual feedback (Bard et al., 1995; Bernier et al., 2006; Bossom & Ommaya, 1968; Ingram et al., 2000; Miall et al., 2018), this process is highly cognitive intensive (Ingram et al., 2000; Miall et al., 2018) and thus results in less efficient movement patterns (Sainburg et al., 1995).

Each year, over 4 million children are diagnosed with developmental dyspraxia or developmental coordination disorder (DCD), which is estimated to affect 2%–8% of school age children. A majority of these children are not diagnosed and referred for services until their motor deficits are affecting their academic performance in elementary school. Studies have shown that over 40% of children with DCD have proprioceptive deficits when they are tested between the ages of 7–11 years old (Hoare, 1994; Macnab et al., 2001). The proprioceptive impairments in these children are likely present at a much younger age and precede the motor deficits, but we do not currently have the tools to assess somatosensory processing accurately at a young age.

Currently, somatosensory processing in children is typically assessed indirectly through clinical observations, or parent reports of the child's behavior or coordination abilities (Blanche, Reinoso, et al., 2012; Chu, 2017). These strategies provide a starting place for understanding a child's challenges, but they lack objectivity and cannot quantify in a reliable or valid manner whether a child's proprioceptive ability is delayed compared to his/her same age peers. For older children, somatosensory processing can be tested using the Sensory Integration and Praxis Test, which was standardized for 4- to 9-year-old children (Ayres, 1989), or the Kinaesthetic Sensitivity Test that was standardized for 5- to -12-year-old children (Laszlo & Bairstow, 1980), though both of these assessments were standardized over 40 years ago. Other methods to assess proprioception can also be done through procedures such as unilateral or contralateral limb position matching with vision occluded, location or direction identification of passively moved limb, and ability to hold limb against gravity with vision occluded (Chu, 2017). However, these tests are not feasible to use with children younger than 4–5 years old due to difficulty in following highly standardized instructions. The lack of objective assessments available to measure somatosensory processing in young children results in a significant knowledge gap in the somatosensory development process, particularly in the early formative years of motor development. The inability to quantify somatosensory deficits in young children limits our ability to provide early and targeted interventions (motor- vs. somatosensory-based interventions) for children with DCD and other motor disorders.

Due to limited assessment tools, little is known about somatosensory development during early childhood. Lack of tools to measure somatosensory deficits in young children may lead to missed opportunities for early intervention when children with poor somatosensory processing are not appropriately identified. To meet this need for objective somatosensory assessments, the purpose of this study is to develop and validate assessments for young children. We acknowledge that proprioception is difficult to isolate from other somatosensory processing (particularly tactile processing) in very young children. Therefore, we examined somatosensory processing as a whole, to provide insights on proprioception processing during early childhood development. We aimed to (1) develop an assessment tool for somatosensory that is feasible to use in children under 5 years of age, (2) determine the reliability and validity of the tool, and (3) examine age-related trends in the development of somatosensory processing. We evaluate our tool using the following criteria: (1) our criterion for determining whether the tool was feasible to use for each age group is that at least 80% of the children in that age group were able to complete the test; (2) we considered the test results reliable if the interrater reliability were high (intraclass correlation > 0.75), test-retest reliability was good (intraclass correlation > 0.75) (Koo & Li, 2016), and there was a significant correlation between our test results and test scores on standardized development assessments (concurrent validity), while controlling for age. (3) We also explored age-related differences in our test results using analysis of variance (ANOVA).

2 | METHOD

2.1 | Participants

The protocol for this study was approved by the Virginia Commonwealth University Institutional Review Board. Thirty-two children (ages 7–60 months) were recruited through flyers sent to local daycares, social media posts to local groups, and convenience sampling from the local community [university name blinded]. We divided the children into four age groups (7–12 mo, 13–24 mo, 25–36 mo, and 37–60 mo), with eight children in each group (four females, four males). The children were mostly from middle to high socioeconomic families, with 59.3% of the children were reported to be white. We obtained informed consent from each child's legal guardians. We excluded children with a diagnosis of any neurological, neuromuscular, genetic, or neurodevelopmental disorders. All children who participated in this study were able to sit independently.

2.2 | Somatosensory Test of Reaching (STOR)

Typical position sense assessments require a child to match positions with their arms or hands without vision, requiring understanding of the task, which is not appropriate for young children (Chu, 2017). We took a modified approach and have young children reach for stickers that are in their visual field (visual reach, e.g., on a table in front of them) versus stickers that are outside of their visual field (somatosensory reach, e.g., on their forehead) (Figure 1a). While we would like to examine the development of proprioception, it is difficult to completely isolate the contribution of proprioception in sensorimotor tasks. In this study, we control for the confounding factor of motor ability using the visual

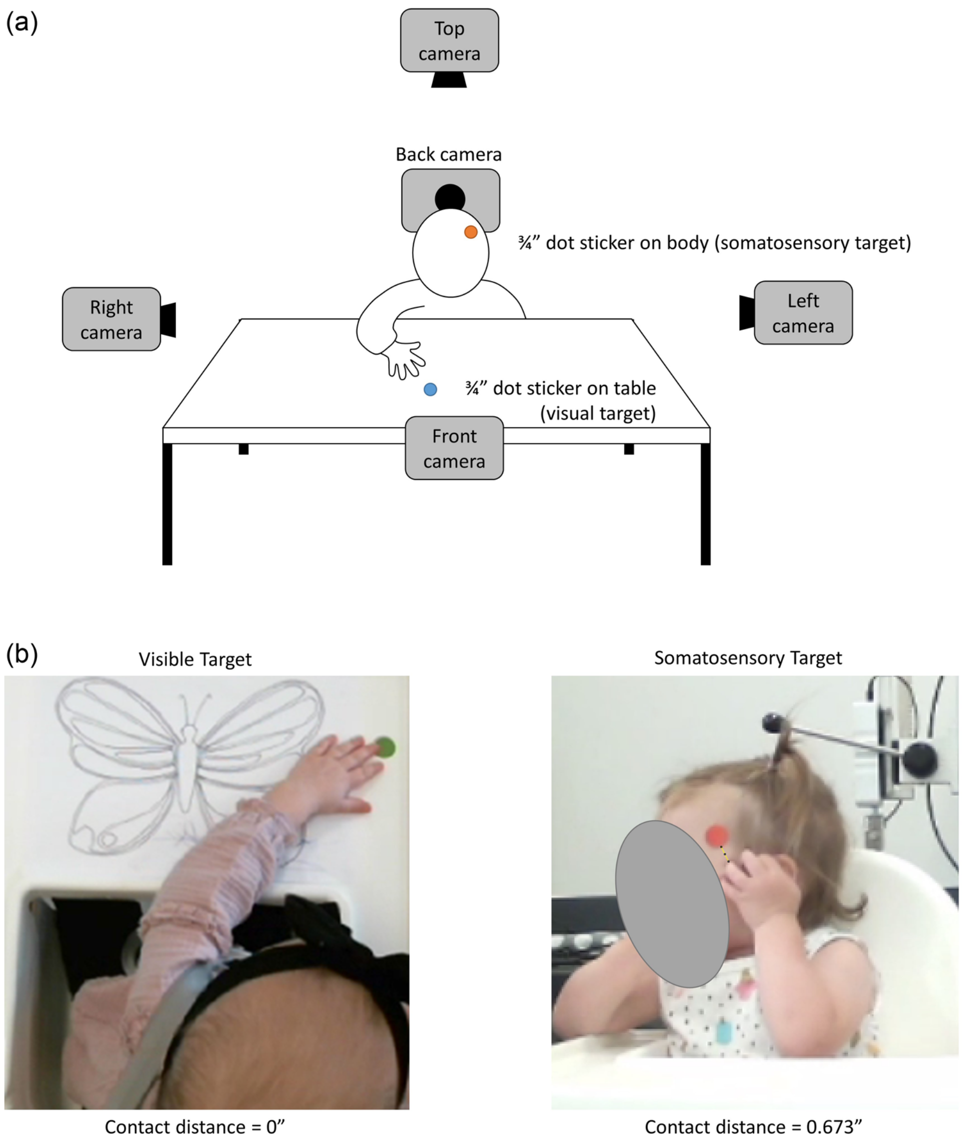

FIGURE 1 Study setup. (a) Setup showing the camera locations relative to the child. Sticker locations are for illustration purposes (*the two stickers are not placed at the same time). (b) Calculating contact distances in FIJI. Reaching for a visible target (left)—the distance is 0, if the child's finger is in contact with the sticker. Reaching for a somatosensory target (right)—the yellow line represents the shortest distance from the closest finger to the edge of the sticker. The image scale is set using the diameter of the dot sticker (standard length = ¾ inch), and the contact distance is calculated to be 0.673 inch.

reach task, but factors other than proprioception, such as tactile ability, also contribute to the child's ability to reach for a target on their body that they cannot see. Therefore, we refer to the reach to stickers outside their visual field as somatosensory reach instead of proprioceptive reach.

Children were seated at a child-sized chair in front of a child-sized table. Younger children were seated at an Ikea Antilop highchair, if preferred by the child's guardians. Cameras were placed around the child to capture the view from the top, left, right, front, and back. The video feeds were synchronized using software on the data collection computer. Standard ¾ inch dot stickers (PARLAIMJ ¾ inch round color dots) were used as targets for reaching. All children began with reaching for visible targets. Dot stickers were placed one at a time, and children were encouraged to get the stickers. Children were given the option to use the stickers they peel to decorate a picture. Successful completion was defined by the child completing three trials of reaching for the sticker without any physical prompts. If a child required physical prompts to reach to the target, the trial was repeated. Following the visual reach task, children were encouraged to play "sticker peek-a-boo" (somatosensory reach). Children were encouraged to close their eyes, and one sticker would be placed somewhere on their head that was not visible to them (e.g., forehead, side of cheek). The stickers were placed with firm pressure to allow the child to feel the touch of a sticker placement, but the pressure was not so hard that it would indent the skin. Children were then encouraged to find the hidden sticker. There were also three trials for reaching toward somatosensory targets. Very young children (under 2 years old) often have challenges following directions to close their eyes. For these younger children, toys (or other preferred objects) were used to keep their visual attention on the table when the sticker was placed on their head. If children had long hair that impacted the placement of the stickers, hair would be tied up and out of the way stickers would be placed on the forehead or sides of the head (avoiding the hair, but still not visible to the child). If stickers were stuck to the hair, the trial was excluded from the analysis.

The reach attempts were videotaped, and the video was processed using FIJI is Just ImageJ (FIJI). The time of contact was defined as the first time the child contacted the surface (e.g., table, forehead) at which the sticker was located. The contact distance is calculated as the distance between the closest finger to the edge of the sticker at the time of contact, using the sticker as a size reference (Figure 1b). If the fingertip is on the sticker, the contact distance is recorded as 0. Each video was coded by two trained video coders to determine the interrater reliability of scoring.

In order to control for the confounding factor of motor ability, the visible target was used to provide a measure of the child's reaching abilities. If children were able to reach a visible target, we know that the children's motor abilities were not compromised and able to reach an intended target. The accuracy observed in the reach toward a somatosensory target would be based on the child's ability to integrate somatosensory information to direct his/her reach. This provides us with a proxy to measure proprioception processing in young children. Another confounding factor is whether the child has developed object permanence (whether the child has a concept of objects that are out of sight). In order to control for the development of the cognitive skill of object permanence, we tested all the children with a simple object permanence activity. A preferred toy was covered with a blanket, and the child's response was recorded.

2.3 | Test-retest reliability

To examine test-retest reliability of our assessment, the sticker trials (three visible targets and three somatosensory targets) were repeated during the same study visit in eight participants (age range: 15–58 months, mean age: 28 months, SD: 13.9 months, six females, 62.5% white). Three of these children were also in the main study sample, and five were recruited separately.

2.4 | Standardized assessments

We assessed the child's overall development using the Developmental Assessment of Young Children, 2nd edition (DAYC-2). The DAYC-2 is a reliable and valid assessment from birth to 5 years old in the following domains: adaptive behavior, cognitive, social-emotional, physical, and communication. The parents also completed the Sensory Profile, 2nd edition (SP-2) toddler form (7–35 months) and child form (3–14 years). The SP-2 is a parent report measure that examines the following sensory domains: general, auditory, visual, touch, movement, body position, and oral sensory. Since the SP-2 primarily measures responses to sensory stimuli via parent report, we do not anticipate a correlation between our results that measure sensory discrimination and SP-2 scores that measure sensory modulation, as these are different constructs. The SP-2 provides scores in four quadrants (seeking, avoiding, sensitivity, and registration). The registration quadrant score measures the degree to which the child misses sensory input. While the registration quadrant score is most closely related to our assessment, it is not specific to somatosensory processing.

2.5 | Statistical analysis

All statistical analyses were calculated with the Statistical Package for the Social Sciences (SPSS, Version 26, IBM Corp., New York, USA). To determine the feasibility and usability of our assessments, we tabulated the number of children who completed the assessment in each age group. We calculated the intraclass correlation coefficient (ICC) between two raters to determine the interrater reliability, and the two sets of trials within 24 h to determine test-retest reliability. We used general linear model (GLM) to examine the correlation between the somatosensory contact distance and the DAYC-2 domain and total raw scores, while moderating for the effect of age group. We also examined the correlation between the somatosensory contact distance with the SP-2 registration quadrant score while moderating for the effect of age group. We repeated the GLM analyses with the visual reach accuracy. We used a two-way ANOVA to examine the developmental trends in the contact distances with the reach condition (visual, somatosensory) and age group (7–12 mo, 13–24 mo, 25–36 mo, and 37–60 mo) as dependent factors.

3 | RESULTS

3.1 | Feasibility of assessment

We were able to complete the assessment with 26 children (81.25% of the participants that participated in this study). Three children (9.4%) had one trial excluded due to the sticker stuck in the hair for the somatosensory targets. All children as young as 7 months old reached toward our visible targets, the colorful ¾ inch dot stickers. However, when the stickers were out of view (somatosensory targets), four of the eight children in the youngest age group (7–12 months) did not reach for the stickers, and these children were aged 7–9 months. These children initially tried to reach for the stickers when it was in their field of vision (e.g., when the sticker was peeled and moved toward them), but once the sticker was out of view, they sometimes turn to look for the sticker, but give up the search when they cannot see the sticker. Then, they often return their attention to the toy on the table or just tap the table. Two of the children (7 and 8 months) ignored some stickers and attempted to reach for less than half of the somatosensory targets. Two older children (aged 10 and 11 months) in the youngest age group and all children in the 3 older age groups attempted to reach toward all the somatosensory targets presented to them. Despite not reaching for the somatosensory targets, all of the children in the youngest age group demonstrated object permanence, as they were all able to retrieve objects that were hidden under a visible barrier. As the ability to recognize the existence of a somatosensory target is an emerging skill between the ages of 7–9 months, we determined that our assessment was most feasible for use with children aged 10 months and older.

3.2 | Reliability and validity

We demonstrated high interrater reliability among our coders (average ICC(2,1) = 0.954, SD = 0.059) for our main study participants. In our test-retest group of participants, we found good test-retest reliability for both the visible targets (ICC(2,1) = 0.81) and the somatosensory targets (ICC(2,1) = 0.806).

Using general linear model, while controlling for the effect of age group, the somatosensory reach accuracy showed a significant correlation with the cognitive ($F(1, 18) = 4.415$, $p = .05$) and physical ($F(1,18) = 11.944$, $p = .003$) domain raw scores of the DAYC-2 (full model adjusted $r^2 = 0.677$). The correlations with other DAYC-2 domain and total raw scores were not significant ($p > .05$). Separate correlations between the somatosensory reach accuracy and the DAYC-2 physical domain raw score (adjusted $r^2 = 0.495$) and cognitive raw score (adjusted $r^2 = 0.223$) showed moderate correlations. The visual reach accuracy did not show any significant correlation with DAYC-2 domain or total raw scores after controlling for the effect of age group (adjusted $r^2 = 0.254$, $p > .05$). The correlation with the SP-2 registration quadrant score was not significant, when controlled for the effect of age group for both the somatosensory reach accuracy ($p = .99$) and visual reach accuracy ($p = .79$).

3.3 | Developmental trends

We found a significant difference in contact distance between the visible and somatosensory targets ($F(1,52) = 14.052$, $p < .001$) and age group ($F(3, 52) = 4.684$, $p = .006$), but there was no significant interaction between the different targets and age ($F(3, 52) = 1.867$, $p = .147$). The results were presented graphically in Figure 2, with full ANOVA statistics reported in Table 1. We found a sharp drop in contact distance from the 7–12 months group to the 13–24 months group, showing that the accuracy of reach to visual targets drastically improves in the first year of life. However, the contact distance to somatosensory targets remains high and variable from 7–24 months and shows a gradual drop through the two older age groups.

4 | DISCUSSION

4.1 | Determining STOR age range

While we were able to conduct the assessment with all the children who participated in the study, we observed that children under 10 months of age do not consistently reach for targets that are not within their visual field. Although these children (7–9 months) demonstrated object permanence by removing a blanket barrier to uncover a preferred toy, they may not have fully developed their concepts of objects or self yet. The barrier itself (blanket) may serve as a reminder that their preferred object is under the barrier. We have also tested some infants with a rigid barrier to eliminate the shape conforming ability of the blanket (i.e., using a box to cover the preferred object), and these infants were also able to remove the box. However, when the object (sticker) is placed on top of their heads, some of these infants attempted to turn their head to look for the sticker but abandoned the task when the sticker is nowhere to be found. This shows that the ability to recognize the presence of objects on their body without vision develops after object permanence, at around 10 months. We also observed that children continue to improve in their accuracy to reach for somatosensory targets through our oldest age group (up to 60 months). Based on these observations, we believe that this assessment would be most appropriate for children 10–60 months of age. Future studies may further expand the age range to older children to determine if there are further improvements in reach accuracy in later childhood years.

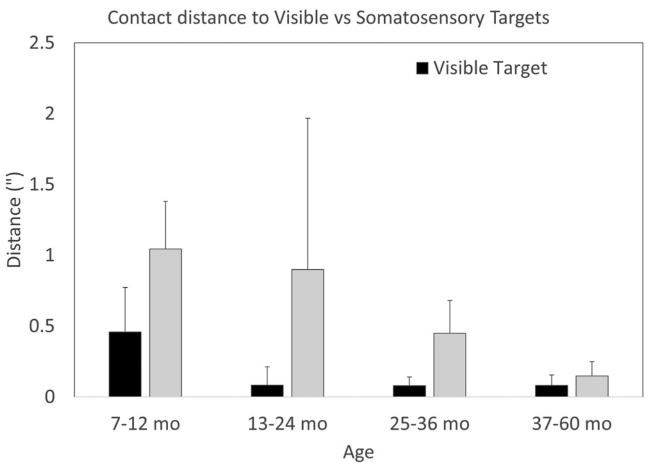

FIGURE 2 Mean and standard deviation (error bars) of the contact distances for each age group. Contact distances was defined as the distance between the closest finger to the edge of the target sticker

4.2 | Reliability and validity of STOR

We had high interrater reliability for STOR. We also demonstrated good test-retest reliability in a smaller group of children. Comparing our test with standardized developmental assessments (DAYC-2), our test scores were significantly correlated ($p < .05$) with the DAYC-2 physical and cognitive domain scores while controlling for the age factor. This demonstrated that our test was capturing differences in development related to motor and cognitive areas beyond a mutual relationship with age, demonstrating good criterion validity when compared to the DAYC-2, particularly the physical and cognitive domain. At the same time, the correlations were below 0.8 (Rönkkö & Cho, 2020), showing that our assessment has some discriminative ability

TABLE 1 Details of the two-way analysis of variance (ANOVA) examining the developmental trend

Two-way ANOVA results examining the developmental trends					
Dependent variable: Reach accuracy					
Source	**Type III sum of squares**	**df**	**Mean square**	***F***	**Significance**
Corrected model	6.563[a]	7	0.938	4.384	.001
Intercept	9.358	1	9.358	43.754	.000
Condition (visual vs. somatosensory)	3.005	1	3.005	14.052	.000
Age group	3.005	3	1.002	4.684	.006
Condition × Age Group	1.198	3	0.399	1.867	.147
Error	11.122	52	0.214		
Total	25.592	60			
Corrected total	17.685	59			

[a] $R^2 = 0.371$ (adjusted $R^2 = 0.286$).

from the DAYC-2, and our test measured a different construct that was not captured in the DAYC-2. We did not observe a strong correlation between the visual reach accuracy and the DAYC-2 scores, likely due to most of the children beyond 12 months of age making close to perfect reaches in the visual target conditions, and reached a ceiling effect. On the contrary, our test showed an insignificant correlation with the SP-2 registration quadrant score ($p = .99$). While the SP-2 measures sensory processing, it is not designed to assess developmental trends. The SP-2 treats the whole age range specified for a caregiver form as an entire group (toddler: 7–35 months, child: 3–14 years) and does not differentiate age-related changes within that group. Furthermore, the SP-2 captures parent's perception of differences in sensory processing based on observed behaviors related to sensory input. The questions on the registration quadrant ask about how frequently the child misses sensory input (e.g., not respond to touch, ignore people coming into the room, ignore sounds). While the registration quadrant most closely relates to our assessment construct (sensory discrimination), there could be other many reasons why a child fails to respond to sensory input, including sensory regulation and differences in volition, and it is not specific to somatosensory processing. Our assessment will be able to capture specific information related to somatosensory processing, and allow us to examine developmental trends.

4.3 | Developmental trends

Our assessments showed that the ability and accuracy of reach toward a somatosensory target is developed from infancy through toddlerhood. This development is different from simple development of motor skills to reach, as accuracy of reach to visual targets improves dramatically from the 7–12 mo group to the 13–24 mo group and holds steady through 60 months. Yet, we found that the average contact distance to a somatosensory target drops steadily with age throughout our study age range. Our study lays the foundation for developing standard norms to compare and identify children who may be delayed in the ability to process somatosensory information.

4.4 | Study limitations and future directions

Our study presents a novel, developmentally appropriate method to assess somatosensory development in very young children. A limitation of our test is the need for multiple cameras to conduct the test. Future studies will examine the critical angles that are needed and if the test can be simplified with fewer cameras. We have plans to automate the calculation of the fingertip distance to the sticker using computer vision technology in order to simplify the analysis process to allow this methodology to be developed into a clinical assessment. Another limitation of our study is that different parts of the head and face are innervated differently (Corniani & Saal, 2020), which could impact the child's ability to perceive the location of the somatosensory targets placed on different parts of the head. Future studies would need to more closely examine the location of target placement based on innervation patterns and its impact on reach accuracy in order to standardize the target placement for the assessment. Despite these limitations, our methods are found to be feasible, reliable, and adequate in criterion validity for measuring somatosensory processing during development. This was a feasibility study with a small sample size, resulting in limited generalizability of the results until the research has been replicated with larger samples. Future validation studies will examine the STOR's ability to detect differences between typically developing children and those with conditions that would put them at higher risk of sensory processing challenges. Results from a larger sample study of typically developing children can also be used to establish normative data for somatosensory processing in early childhood.

5 | CONCLUSIONS

This study highlights the development of the STOR as a tool for assessing somatosensory processing during early childhood. Since much of motor development occurs in the first few years of childhood, it is important to be able to compare proprioceptive performance against developmental benchmarks during early childhood. If the proprioceptive impairments can be identified early, intervention could be provided prior to the development of significant motor delays, minimizing the cumulative and compounding impact of poor perceptual skills on motor learning in a developing nervous system. Targeting interventions for proprioceptive deficits in a young child will minimize the need for future interventions needed to correct for erroneous motor patterns learned from an ineffective feedback system.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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