Measuring Change in Somatosensation Across the Lifespan

MeSH TERMS
- aging
- perception
- proprioception
- sensation
- touch

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OBJECTIVE. The study aim was to determine natural variability in somatosensation across age groups using brief measures. We validated measures in a community-dwelling population as part of the National Institutes of Health (NIH) Toolbox for Assessment of Neurological and Behavioral Function (NIH Toolbox; http://www.nihtoolbox.org).

METHOD. Participants included community-dwelling children and adults ($N = 367$, ages 3–85 yr) across seven sites. We tested haptic recognition, touch detection–discrimination, and proprioception using brief affordable measures as required by the NIH Toolbox.

RESULTS. Accuracy improved from young children to young adults; from young to older adults, the pattern reversed slightly. We found significant differences between adults and older adults. One proprioception test (kinesthesia; $p = .003$) showed gender differences (females more accurate). We provide expected score ranges for age groups as a basis for understanding age-related expectations for somatosensory perception.

CONCLUSION. The age-related patterns of somatosensory perception from this study refine decision making about performance.

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The National Institutes of Health (NIH) Toolbox for Assessment of Neurological and Behavioral Function (NIH Toolbox; http://www.nihtoolbox.org) was charged to develop brief, cost-effective, simple-to-administer, comprehensive assessment tools that could be used across the lifespan (in people aged 3–85 yr) as a "common currency" for measuring sensory, motor, cognitive, and emotional functions in population- and condition-based studies. The NIH Toolbox assessments are designed to provide valid and reliable tools that researchers and practitioners can use to evaluate areas of function that would otherwise require a test administrator with specialized expertise.

Somatosensory function in particular (part of the "sensory" function of the NIH Toolbox) is important for studies of development and aging because sensation affects daily life function, relationships, and health outcomes (Hane, Henderson, Reeb-Sutherland, & Fox, 2010; Hirabayashi & Iwasaki, 1995; Nevalainen, Lauronen, & Pihko, 2014; Parush, Sohmer, Steinberg, & Kaitz, 2007). *Somatosensory function* refers to the detection, discrimination, and recognition of touch sensation and proprioception. These sensations arise from sensory receptors in skin, joints, tendons, muscles, and viscera (Dinse, Tegenthoff, Heinish, & Kalisch, 2009; Kandel, Schwartz, Jessell, Siegelbaum, & Hudspeth, 2013). Researchers have shown that somatosensory cortices integrate touch with other senses, highlighting the importance of the somatosensory system in organizing information for functional use (Hsu, Kuo, Chiu, Jou, & Su, 2009; Keysers, Kaas, & Gazzola, 2010).

Borstad and Nichols-Larsen (2014) outlined four levels of somatosensory measurement: *detection* (noticing stimuli), *discrimination* (distinguishing among stimuli), *scaling* (grading stimuli), and *object recognition* (knowing what the object is by touch). Detection is not directly associated with changes in functional use of sensation; sensory receptor density diminishes after age 40, but people do not lose tactile sensory processing until age 65 yr (Stevens, Alvarez-Reeves, Dipietro, Mack, & Green, 2003). Somatosensory discrimination affects quality of movement (Blennerhassett, Matyas, & Carey, 2007; Johansson, 1996); hand function (Tremblay, Wong, Sanderson, & Coté, 2003); and balance (Hirabayashi & Iwasaki, 1995), which is associated with falls (Lord & Ward, 1994). Scaling and object recognition are dependent on location because of receptor density across body sites; for example, researchers have reported 7% to 53% impairments across body sites in people who have had a stroke (Yekutiel & Guttman, 1993).

Somatosensory processing also enables people to experience pleasure and satisfaction (Hill, Fisher, Schmid, Crabtree, & Page, 2014), learn and adapt (Hane et al., 2010; Nevalainen et al., 2014), process the touch experiences of others (Keysers et al., 2010), and take action (Dijkerman & de Haan, 2007). Hill et al. (2014) reported on the importance of touch sensation to performance of valued activities after stroke, highlighting the relationship between somatosensation and quality of life. Hane et al. (2010) related low-quality touch in infant caregiving to inhibition and aggressive play in preschoolers.

Many studies in the literature have documented the performance of various populations with conditions and frequently compared them with the performance of peers without conditions to illustrate the need to address particular neurological or behavioral factors in intervention. The NIH recognized that there was insufficient information about the general population as the proper metric for larger cohort studies and for comparison across conditions using the same measures. To be responsive to these needs, the NIH Toolbox created normative data on community-dwelling populations to document how performance can be expected to look across ages (3–85 yr), thus providing baseline evidence for multiple comparisons in future large-scale studies.

By measuring somatosensation across age bands, we examined how to discriminate between typical changes associated with development and aging and patterns that may be markers of risk. Researchers have reported that touch and proprioceptive perception patterns in children ages 4–8 yr get more accurate (Ayres, 1989; Elliott, Connolly, & Doyle, 1988) and that spatial resolution (scaling) is lower in younger children than older children (Bleyenheuft, Cols, Arnould, & Thonnard, 2006). Young adults are better at recognizing raised letters and textures than older adults (Manning & Tremblay, 2006). Others have reported that two-point discrimination and haptic discrimination diminish in adults age 65 yr and older (Kalisch, Kattenstroth, Kowalewski, Tegenthoff, & Dinse, 2012; Lederman & Klatzky, 2009; Schumm et al., 2009; Stevens et al., 2003) and were significantly less accurate for people who tend to fall (Melzer, Benjuya, & Kaplanski, 2004). Diminishing proprioception and sensitivity across adulthood have also been documented (Laszlo & Bairstow, 1980; Ribeiro & Oliveira, 2007; Stevens et al., 2003; Wickremaratchi & Llewelyn, 2006). However, no studies have illustrated precise changes across the lifespan using common measurements.

In this article, we measure somatosensation across the lifespan by asking participants to interact with objects and the environment as part of the NIH Toolbox. The study aims were to determine whether age affects somatosensation by using the brief tests of the NIH Toolbox and to provide comparative age-related data. We hypothesized that the pattern reported from the brief, functional somatosensation tests would be consistent with that reported from detailed somatosensation testing.

Method

Design

We designed functional measures of touch perception based on the NIH Toolbox standards that would be applicable and sensitive across the lifespan, cost-effective, brief, and simple to administer when testing a community-dwelling population (Gershon et al., 2010). After review and initial testing (see Dunn et al., 2013, for details), we included measures of tactile detection and discrimination, proprioception, and haptic object recognition.

Participants

We recruited a convenience sample of community-dwelling children and adults ($N = 409$, ages 3–85 yr) from 8 testing sites across the country using brochures and recruitment posters in each community. Consistent with the NIH Toolbox, we included anyone from the community who could complete testing and excluded people incapable of following instructions given in English or by Spanish translators, unable to provide informed consent, those with incomplete forms ($n = 30$), a person who was not willing to provide his age ($n = 1$), and younger children (i.e., 3–4 yr old) who could not complete testing ($n = 11$). Therefore, our total sample was 367 participants (146 [40%] male, 221 [60%] female; Table 1). For a subset, we conducted validity testing (n = 181; 75 [41%] male, 106 [59%] female; see Table 1). All participants provided informed written consent. Parents provided written consent; children aged 7–17 yr also provided assent.

Procedures

We tested participants at testers' home facilities (in eight cities). To establish fidelity across sites, we created a testing manual with instructions, forms, illustrations, and pictures of testing protocols. We held a conference call to review the manual with testers at each site, and then each site provided a videotape of testers administering the measures. Researchers at the primary site (Kansas City) reviewed the videos for accuracy and provided feedback and additional review as needed before actual testing began. Participants rotated among testing stations to complete all measures during one session.

The following sections provide test statistics for measures already developed. Other measures were adapted or designed for the NIH Toolbox.

Measures: Proprioception

Brief Kinesthesia Test. The Brief Kinesthesia Test (Ayres, 1972, 1980, 1989) measures upper-limb movement and position. After occluding the participant's vision, the tester moves the participant's finger and arm in space to place the fingertip on a specific location on a table. The tester asks the participant to remember the location, moves the finger back to the starting position, and asks the participant to reproduce the movement. For each hand, there is a short-, medium-, and long-distance item. The tester records the distance between the actual target and the response location in centimeters (accuracy) and the time to execute the movement for each of the six items.

Table 1. Age Categories and Number of Participants

Group	Age, yr	Total, n (%)[a]	Male, n	Female, n
Full Sample (N = 367)				
1	3–6	29 (8)	11	18
2	7–12	42 (11)	24	18
3	13–20	26 (7)	9	17
4	21–39	46 (14)	12	34
5	40–54	42 (13)	15	27
6	55–64	36 (10)	12	24
7	65–74	61 (17)	22	39
8	75–85	85 (23)	41	44
Subset for Validity Testing (n = 181)				
1	3–6	29 (16)	11	18
2	7–20	54 (27)	24	30
3	21–39	42 (26)	12	30
4	40–64	36 (22)	17	19
5	65–85	20 (9)	11	9

[a]Percentages may not total 100 due to rounding.

Wrist Position Sense Test. The Wrist Position Sense Test (Carey, Oke, & Matyas, 1996) assesses a person's capacity to recognize wrist position. The standardized test has high test–retest reliability (rs = .88 and .92) and good discriminative validity (Carey et al., 1996). The tester occludes the participant's vision of hand and wrist by placing them in a boxlike apparatus. The forearm and hand are positioned in separate splints for stability, and the tester moves the hand to a defined wrist angle. The participant then moves a protractor stylus on top of the box to match the hidden hand position. The score is the difference in degrees between actual and response position for 10 trials (brief version).

Clinical Test of Wrist Position. For the Clinical Test of Wrist Position (Carey et al., 1996), the tester manually moves the participant's dominant wrist to five flexion–extension test positions with vision occluded. For each position, the participant selects a wrist position on a photograph, and the tester records the number correct out of the five trials.

Measures: Touch Detection and Discrimination

Tactile Discrimination Test. The Tactile Discrimination Test (Carey, Oke, & Matyas, 1997) is a standardized measure that uses standard texture stimuli and a three-alternative forced choice. The test has norms, high test–retest reliability, and good discriminative properties (Carey et al., 1997). We used a brief version of this test (10 trials, each using both hands) and calculated the area under the curve (AUC) score, which accounts for chance responses.

Bottom of Foot Test. The Bottom of Foot Test was adapted from testing in the National Health and Nutrition Examination Survey project (Centers for Disease Control and Prevention, 2013; http://www.cdc.gov/nchs/nhanes.htm). We used six Semmes–Weinstein nylon monofilaments (Morgan, 2013; Tomanick, 1987) ranging from 2.83 marking number (mN; target force = 0.07 g pressure) to 6.65 mN (target force = 300 g pressure) applying standard protocols. We tested bottom of big toe, little toe, and instep. We added a "false-positive" trial by asking for a response without touching the foot. The tester reported the smallest accurate filament (Weinstein, 1993), no response, or false positive.

Measures: Haptic Object Recognition

Brief Manual Form Perception Test: Method 1. The Brief Manual Form Perception (MFP) Test was adapted from Ayres (1972, 1980, 1989). The original test involved the participant feeling one shape out of view and selecting a picture of that shape on a poster depicting many shapes. Our Method 1 followed this touch-input and visual-output approach. The tester occluded the participant's vision before the participant felt a shape in one hand and pointed to a picture of that shape on a poster depicting many shapes. The tester recorded the number correct out of six trials.

Brief Manual Form Perception Test: Method 2. Our Brief MFP Test Method 2 followed a touch-input and touch-output approach. The tester occluded the participant's vision. For four items, participants felt one shape and attempted to select a matching shape from among three shapes in a bag. For the fifth item, participants found a matching pair from among three shapes in each of 2 bags (one for each hand). For the sixth, final item, participants found a matching pair from among five shapes in each bag. The tester recorded the number correct for each trial.

Brief Manual Form Perception Test: Method 3. Our Brief MFP Test Method 3 used coin matching. However, it was too easy for participants, so we removed it.

Data Analysis

We used descriptive statistics and graphing to characterize performance by age. Table 1 shows eight age categories for the total sample and five categories for the subgroup to ensure adequate sampling within each category. Because our distributions were not uniform, we used the means within the Kruskall–Wallis nonparametric test with follow-up testing (Mann–Whitney rank-sum tests) to identify significantly different age groups and to determine any gender effects.

Results

Demographics

We evaluated responses of 367 community-dwelling participants (40% male; see Table 1). Ages ranged from 3.2 to 85.9 yr. Most of the sample was right-handed (87%). Ethnic distribution included White American (49%), Black/African-American (27%), Australian (21%), and Asian (2%); 25% said they were Latino or Hispanic. Participants self-reported arthritis (24%), diabetes (18%), hypertension (27%), and psoriasis (5%). Participants rated their health as (and parents rated children's health as) *excellent* (33%), *very good* (28%), *good* (28%), *fair* (9%), and *poor* (1%). (Percentages may not total 100 due to rounding.) We calculated the expected range of performance (i.e., ±1 standard deviation) reflecting the middle part of the bell curve (Table 2).

Proprioception

Brief Kinesthesia Test. During feasibility testing, we identified that the two short-distance items did not fit in a one-dimensional model factor model, so to improve psychometrics and decrease testing time, we used a four-item version that included the medium and long distances. Confirmatory factor analysis for the four-item version yielded a good fit for a 1-factor model (comparative fit index = 0.966, root-mean-square area of approximation = 0.090, standardized root-mean-square residual = 0.028, χ^2 [N = 367] = 9.06, p = .01). Increased time for respondents to complete testing did not improve the model. Figure 1 illustrates age-based distributions. The median total score was 24.1 cm (range = 6.5–66.1 cm). There is clear variation in scores across age categories, with poorer performance in young children (median = 24.1 cm) compared with young adults (8.5 cm) and older adults (12.8 cm). Females were more accurate in kinesthesia (p = .003).

Wrist Position Sense Test. The median average error score was 9.5° (for the dominant hand). Young children had the greatest error (median = 23.9°). Young adults showed the least error (median = 7.1°), and older adults showed a relative increase (median = 9.7°).

Clinical Test of Wrist Position. Scores were variable across age ranges with poor scale resolution and high variability;

Table 2. Expected Range of Somatosensory Scores by Age Group

Age Group, yr	BKT, Cm (66.1 Cm Max)	CTWP Score	BWPST, Degrees	BTDT, AUC	BMFPT Method 1 Score (6 Points Max)	BMFPT Method 2 Score (30 Points Max)
3–6	13.10–41.34	0.72–3.20	10.02–46.27	4.36–51.93	2.37–5.02	9.21–21.02
7–12	7.19–18.85	1.55–4.25	5.31–19.21[a]	25.21–72.70[a]	3.51–5.71	6.10–17.67
13–20	7.06–16.01	2.56–4.60	—	—	4.24–5.85	6.71–9.06
21–39	5.39–11.23	2.31–4.71	4.98–10.74	40.42–89.36	4.28–6.13	5.90–10.25
40–54	5.13–12.81	2.73–4.79	5.27–11.54[a]	31.06–79.71[a]	4.40–6.14	5.94–11.56
55–64	5.40–12.15	2.22–4.45	—	—	4.19–6.03	6.47–11.19
65–74	6.17–12.95	1.80–4.16	5.34–14.19[a]	34.37–75.56[a]	3.38–5.94	6.68–11.43
75–85	8.59–19.27	1.44–3.79	—	—	2.51–5.23	6.54–14.32

Note. — = Age groups were combined for the test. AUC = area under the curve; BKT = Brief Kinesthesia Test; BMFPT = Brief Manual Form Perception Test; BTDT = Brief Tactile Discrimination Test; BWPST = Brief Wrist Position Sense Test; CTWP = Clinical Test of Wrist Position; max = maximum.
[a]Subgroup (n = 181) took these tests; some age groups were collapsed to retain necessary group size for analysis.

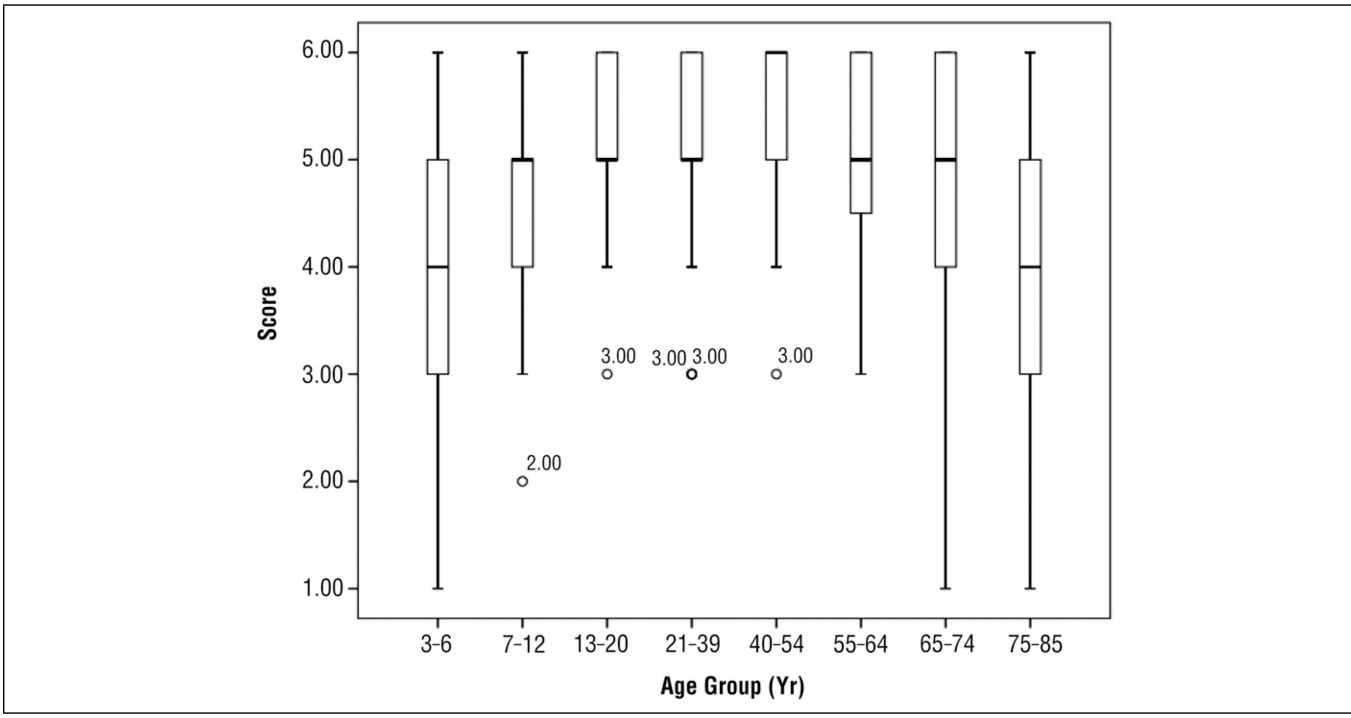

Figure 1. Distribution of scores according to age group for the Brief Kinesthesia Test. Each age band illustrates (from bottom to top) minimum, first quartile, median, third quartile, and maximum score. Outliers are plotted as individual points.

a general trend was apparent (median = 2 out of 5 for young children, 3 out of 5 for children, 4 out of 5 for adults, and 3 out of 5 for older adults). This method of testing wrist position may not be sensitive enough to detect subtle changes.

Touch Detection and Discrimination

Brief Tactile Discrimination Test. For the dominant hand, scores ranged from –15.80 (indicative of below-chance performance) to 100 (maximum AUC score) with a median score of 55.0 AUC. Inspection of boxplots suggests an inverse U shape, with lowest scores in young children (median = 29.2 AUC), highest scores in young adults (median = 75.6 AUC), and lower scores in older adults (median = 58.2 AUC).

Bottom of Foot Test. There was not a useful age-related pattern; children and young adults had a median filament

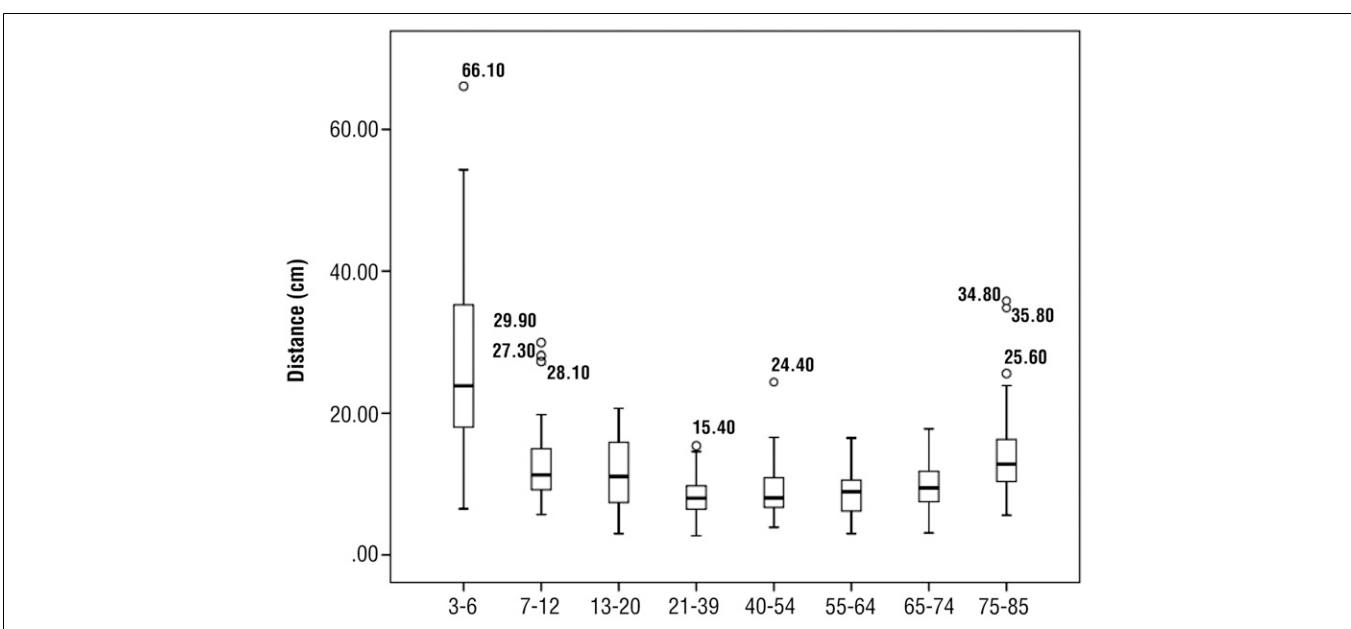

Figure 2. Distribution of scores according to age for Brief Manual Form Perception Test Method 1 (maximum score possible = 6). Each age band illustrates (from bottom to top) minimum, first quartile, median, third quartile, and maximum score. Outliers are plotted as individual points.

of 3.61 mN; young children (4.33 mN) and older adults (4.53 mN) were less sensitive.

Haptic Object Recognition

Our Brief MFP Test Method 1 (Figure 2) shows a pattern of poorer performance for young children (median = 4), best performance in young adults (median = 6), and greater variability for older adults (median = 5) and very old adults (median = 4). Method 2 yielded a U-shaped age trend.

Age-Related Patterns

We found an overall age effect in sensory performance across age categories for most of the sensory measures using the Kruskal–Wallis test with correction for 14 comparisons ($p < .004$). In post hoc analyses using the Mann–Whitney *U* test (four comparisons, $p < .0125$), we found significant differences between young children (3–4 yr) and both children and young adults for all measures except foot touch detection. Young adults were more accurate for kinesthesia, clinical wrist position, Brief MFP Test, and foot touch detection when compared with older adults.

Discussion

We recruited community-dwelling people for this study. We included participants who self-reported no relevant health conditions and could complete the demands of testing, reflecting the requirements of the NIH Toolbox; therefore, we did not screen for neurological function. These data inform us about the performance range we might expect from community-dwelling members and represent the range of persons in the general population. The age-related differences were evident across measures; inspection of graphs indicated a U-shaped relationship, with the least accuracy in young children and older adults.

Patterns of Somatosensory Perception Across the Lifespan

We found increasing accuracy from childhood to adulthood, and some reduced accuracy for older adults using brief tests of functional touch perception. Our age-related score distribution is consistent with previous literature from more detailed laboratory measures (Bleyenheuft et al., 2006; Donat, Ozcan, Ozdirenç, Aksakoğlu, & Aydinoğlu, 2005), suggesting that our brief functional measures reflect basic somatosensory processing.

Somatosensory Performance in Children. Young children (3–4 yr) had the most varied and least accurate performance across all measures, which likely reflects expected developmental trajectories (Hane et al., 2010; Nevalainen et al., 2014). Testing demands are likely to have affected results. For example, consistent with their development, the youngest children attended to tasks for shorter periods of time and may have misunderstood specific instructions (e.g., "pick the odd one") even though we included practice items on every test. In addition, although each measure was designed to be brief, completing all tests in one testing session was more challenging for young children. Children improved accuracy as they got older, which is consistent with somatosensory cortex maturation (Bleyenheuft et al., 2006) and with other more detailed somatosensory testing showing marked improvement in accuracy and touch exploration strategy by age 10–11 yr (Ayres, 1989). Systematic exploration strategies accounted for most of the improvement in performance based on observation notes.

Our findings can serve as a reminder to be careful about deciding when a particular performance is out of expected ranges. Perhaps further consideration of the impact of sensory perception and the role of cognitive development on all children's functional behaviors is warranted before deciding that a particular child has a problem.

Somatosensory Performance in Adults. We found that older adults (those older than age 70) were less accurate than young adults in foot touch detection, kinesthesia, and haptic recognition; we did not find consistent changes for older adults on wrist position sense and texture discrimination. Although others have reported that women's decline in accuracy and speed for exploration of unfamiliar objects is greater than men's (Kalisch et al., 2012), we found a gender difference only for brief kinesthesia, and women were more accurate. Some researchers have demonstrated both neural changes in proprioception specifically (Goble et al., 2012; Goble, Lewis, Hurvitz, & Brown, 2005) and plasticity of the somatosensory cortex more globally in older adults, findings that may represent a compensatory mechanism to counterbalance cortical degeneration (Pellicciari, Miniussi, Rossini, & De Gennaro, 2009). Perhaps the range of touch responses in older adults reflects these nervous system changes. These findings suggest that natural variability exists in somatosensory functions across adult age groups that affects our interpretations when evaluating early changes or reduced sensory perception in disease states.

Use of Expected Somatosensory Performance Ranges for Assessment Across the Lifespan

We report expected patterns of performance for age groups in this study. Researchers and clinicians can use these findings to make age-related decisions about performance of people in vulnerable populations such as those with diabetes or stroke. Without data on the general population, it can be tempting to assume that people with conditions that affect somatosensation automatically perform poorly on these tests. With the data from this study, it is possible to introduce more considered interpretation of assessment results to guide making appropriate plans. For example, if an older adult has diabetes, it would be important to check expected ranges from this study before assuming somatosensory processing is impaired related only to diabetes.

Borstad and Nichols-Larsen (2014) offered additional structure with levels of somatosensory perception, and Hill et al. (2014) linked these sensory experiences to valued activities in daily life for those who have had a stroke. Additionally, it may be important for occupational therapy practitioners to consider population-based interventions for declining somatosensory–perceptual accuracy because these perceptual changes affect routines of daily life such as cooking, hygiene, and dressing.

Limitations of the Study

We used a convenience sample of participants based geographically on testing sites. To determine somatosensory performance standards, we would need to create a randomized sample. The NIH Toolbox required use of simple-to-administer, time-efficient, and cost-effective testing methods across the lifespan; these tests would not suffice for a thorough study of somatosensation. The literature provides a vast array of sensory tests designed for detailed assessment of different sensory modalities for detection, discrimination, scaling, and object recognition, although few have been sufficiently validated or studied for lifespan effects. Rather, these tests are appropriate in studies that want to include somatosensory data as part of a larger study. We provide the first examination of somatosensory expectations across the lifespan using NIH Toolbox components. Future studies will need to validate our findings with additional samples to assess usefulness for screening or measuring change.

Implications for Occupational Therapy Practice

The results of this study have the following implications for occupational therapy practice:

- The NIH Toolbox tests may be useful for occupational therapy practitioners interested in evaluating somatosensory perception.
- Touch perception varies across age bands; clinicians and researchers must consider age-related expected patterns of performance.
- In general, touch perception is highest in young adults and adults and is lower in young children and older adults.
- Touch perception is variable in young children (3–6 yr old); additional assessment of the impact of sensory perception on functional behavior is needed to determine whether there are somatosensory perception problems for children in this age range.
- The Brief MFP Test may be best suited to children older than age 10.
- The data from this study can be used to make age-related decisions about performance of people in vulnerable populations (e.g., those with diabetes, stroke).

Conclusion

It is possible to evaluate somatosensation in a community-dwelling population across the lifespan using easy-to-administer, cost-effective, time-efficient testing methods. This study, the first to examine the topic, provides initial testing guidelines and results about somatosensory processing that can be used to gauge performance when testing vulnerable populations for risk. ▲

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