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Somatosensory and Motor Research

Publication details, including instructions for authors and subscription information:

<http://www.informaworld.com/smpp/title-content=t713393866>

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To link to this article: DOI: 10.1080/08990220600816440

URL: <http://dx.doi.org/10.1080/08990220600816440>

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Age-related changes in tactile spatial resolution from 6 to 16 years old

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(Received 6 February 2006; accepted 20 April 2006)

Abstract

The aim of this study was to determine age-related changes in tactile spatial resolution from 6 to 16 years old. Two hundred and twenty-two healthy children (105 boys and 117 girls) were assessed. The tactile spatial resolution threshold was determined using a classic set of JVP domes with a procedure adapted for children. Preadolescence appears to be an important step in tactile spatial resolution since children aged between 6 and 9 years old had a worse tactile spatial resolution than older children. Both peripheral and central explanations for this improvement of tactile spatial resolution with age are considered. The authors suggest that cortical maturational processes are likely to explain the better results of older children.

Keywords: *Tactile sensitivity, children, spatial resolution, skin properties, cortical maturation, normative data*

Introduction

The measurement of tactile sensitivity, though widely studied and documented during the last century, is still debated in the literature. Among the multiple aspects of tactile sensitivity, the tactile spatial resolution, requiring information treatment at a high cortical level, has been described as highly related to patient's functional capacities or subjective sensations (Van Boven and Johnson 1994b; Krumlinde-Sundholm and Eliasson 2002).

The measurement of tactile spatial resolution is a complex challenge since it requires testing the transmission of an acute spatial neural image evoked by a stimulus (Johnson 2001). For years, the two-point discrimination (TPD) test was used to study tactile spatial resolution. However, this conventional test does not measure spatial resolution as non-spatial cues are not controlled (Johnson and Phillips 1981; Johnson et al. 1994; Van Boven and Johnson 1994b; Craig and Johnson 2000). Cues are considered as spatial if they are based only on the exact location of active neurons and are not affected by changes in impulse rates (Johnson and Phillips 1981). In the 1990s, a new tactile spatial resolution test, named the grating orientation task (GOT) was created (JVP domes, Stoelting Co.,

Wood Dale, IL). In the GOT, the stimulus is appropriate since the neural image is issued only from spatial cues (Johnson et al. 1994). Furthermore, measures obtained with the GOT are consistent with measures obtained with more complex stimuli such as embossed letters or Braille characters, which can only be resolved by spatial cues (Johnson and Phillips 1981). Consequently, the GOT has been considered an objective and valid test of tactile spatial resolution (Craig and Johnson 2000; Gibson and Craig 2002).

The GOT has been studied in adulthood and elderly people showing a decrease in performance with ageing (Sathian et al. 1997; Tremblay et al. 2003; Vega-Bermudez and Johnson 2004). However, this test has never been used to characterize spatial resolution during childhood. Previous studies reporting data for tactile spatial resolution during childhood were based on a gap detection task or on a TPD test (Gellis and Pool 1977; Stevens and Choo 1996). Gellis and Pool (1977) reported that children had worse TPD when compared with young adults (20–29 years old) which performance peaked at 30 years old. However, they constituted only two groups of children (0–9 years old and 10–19 years old) which was enough to compare children to adults

but not to characterize developmental changes during childhood. The same drawback can be directed to the study of Stevens and Choo (1996) with an age group comprising children from 8 to 14 years old.

The aim of the present study was to determine developmental changes of tactile spatial resolution from 6 to 16 years of age.

Material and methods

Subjects

This study was authorized by the Ethical Committee of the Université catholique de Louvain, Faculty of Medicine in Brussels, Belgium. Children and parents gave their written informed consent.

Two hundred and twenty-two healthy Belgian children (105 boys and 117 girls) were assessed. All children were free from disease or injury that could affect the tactile sensitivity of their hands. Children were aged between 6 and 16 years old (mean age, 10.9) and were classified into five age groups as described in Table I. The children were categorized in the different age groups as follows: children from 6 to 7.9 years old were comprised in the 6–7 years old group, children from 8 to 9.9 were comprised in the 8–9 years old group, and so forth.

Test description

Handedness of each child was determined by writing hand preference (Waldron and Anton 1995). The children were seated comfortably in a quiet place with the dominant forearm placed on a table in a supine position. The index finger lay on the table and was immobilized on the support using double-sided adhesive tape applied to the nail (Sathian and Zangaladze 1996). The positions of the other fingers were determined by the subjects according to their comfort preferences. Some subjects kept all five digits extended, while others flexed the remaining digits (Tremblay et al. 2003). Each subject was instructed how to perform the test and was blindfolded before starting.

The tactile spatial resolution threshold was measured with the GOT using the JVP domes

(Stoelting Co.) on the index finger of the dominant hand. This test consists of a set of eight different hemispherical plastic dome gratings having equidistant bar and groove widths: 0.35, 0.50, 0.75, 1.00, 1.20, 1.50, 2.00, and 3.00 mm. Each dome was applied perpendicularly to the skin for 1–2 s. Manual application of approximately 1–2 mm of skin perpendicular deformation was used (Van Boven and Johnson 1994a; Van Boven et al. 2000). The bars and grooves were aligned randomly in one of the two orthogonal directions (i.e., with the grooves parallel or with the grooves transverse to the long axis of the finger). Blindfolded children were required to identify the stimulus orientation before the stimulus was removed. The examiner was particularly attentive to avoid any shearing stress between the skin and the grating which could distort the measure as SAI afferents are ten times more sensitive to dynamic than to static stimuli (Johnson et al. 2000) and as the movement across the bars produces different discharge rates than movement along the bars (Goodwin and Morley 1987; Vega-Bermudez et al. 1991).

The original procedure described by Van Boven et al. (2000) has been adapted for children in order to reduce the duration of the test. Indeed, the original procedure, lasting 30–60 min (Sathian et al. 1997), was too demanding for children. The adapted procedure reduced the duration of the test to 15 min, allowing the children to stay concentrated during the entire test. In the adapted procedure, the largest grating (3 mm) was initially applied for ten consecutive trials using a randomized orientation of the bars. The answer of each trial was recorded, giving the probability of correct answers for the dome. The next smaller grating (2 mm) was applied following the same procedure and so forth. The test was stopped when the probability of correct answers for the grating reached 50%. The validity of this procedure was verified in a group of ten young adults since no significant difference was found between the scores obtained from the original and from the adapted procedure.

The tactile spatial resolution performance was determined by the Tactile Acuity Grating (TAG) score (Med Core 2003) which is a simple linear interpolation estimate of the 75% correct grating width. A lower TAG score means a better tactile spatial resolution performance:

$$\text{TAG score} = g_{\text{below}} + \frac{0.75 - p_{\text{below}}}{p_{\text{above}} - p_{\text{below}}} (g_{\text{above}} - g_{\text{below}})$$

where g = grating width of a probe, p = probability of correct answers, above = grating width that results in a score closest to but above 75% correct, and below = grating width that results in a score closest to but below 75% correct.

Table I. Characteristics of subjects.

Age groups	Boys			Girls		
	<i>n</i>	Mean age	SD	<i>n</i>	Mean age	SD
6–7	22	7.2	0.76	22	7.3	0.75
8–9	22	8.4	0.33	34	9.2	0.55
10–11	20	11.1	0.50	21	11.2	0.54
12–13	20	13.2	0.46	20	12.8	0.60
14–16	21	14.8	0.92	20	15.5	0.95
	105			117		

Data analysis

Non-parametric tests were conducted as the distributions of the thresholds were not normal. A Mann–Whitney Rank Sum test was first applied to test a gender effect. A Kruskal–Wallis test was then used to test a global age effect and Mann–Whitney Rank Sum tests were conducted to identify age group(s) significantly different from the others.

Results

No significant difference was observed across genders for the tactile spatial resolution. Consequently boys and girls were treated together.

The tactile spatial resolution performance improved with the age until 10–11 years old and then stabilized. The median threshold and inter-quartile range are reported in Table II.

ANOVA on ranks (Kruskal–Wallis test) showed a significant global age effect ($p < 0.001$). The 6–7 years old children were less sensitive than the children above 10 years old (all $p < 0.012$). The same observation was reported for the 8–9 years old group, statistically different from the children above 10 years old (all $p < 0.021$). The 6–7 years old performance was not significantly different from that of the 8–9 years old group ($p = 0.894$). No significant differences were reported between the 10–11 years old, the 12–13 years old, and the 14–16 years old group (all $p > 0.711$). Consequently, as shown on Figure 1, the children were pooled in a first age group of 6–9 years old ($n = 100$) and a second group of 10–16 years old ($n = 122$). The difference between these two groups was highly significant ($p < 0.001$).

Discussion

The purpose of this study was to determine the gender and age-related changes in tactile spatial resolution in children from 6 to 16 years old. No gender difference was observed in tactile spatial resolution which improved significantly at the age of 10 (see Figure 1).

The only age effect reported for the GOT in the literature concerns adults and elderly who experience

a worsening in performance with age (Sathian et al. 1997; Goldreich and Kanics 2003; Tremblay et al. 2003; Vega-Bermudez and Johnson 2004). Indeed, subjects about 20 years old present thresholds (ranging from 0.73 to 1.17 mm) similar to those of our children from 12 to 16 years old (Van Boven and Johnson 1994a). Afterwards, the values of the thresholds progressively worsen. In a sample of 18 subjects (19–36 years old), Vega-Bermudez found a mean GOT value of 1.21 mm (Vega-Bermudez and Johnson 2004). In a group of sighted subjects (mean age 42), Van Boven et al. (2000) found a mean GOT threshold of 1.46 mm. Finally, older adults present a major worsening in the GOT task since people of 60–71 years old have a mean threshold of 2.7 mm, and people of 74–95 years old present a mean threshold of 3.4 mm (Tremblay et al. 2003). This global worsening of performance during adulthood has been clearly highlighted in both sighted and blind subjects (Goldreich and Kanics 2003). This worsening with age is consistent with previous studies on gap detection and thresholds of orientation in two planes (Stevens et al. 1996) and TPD (Gellis and Pool 1977).

The step observed in our study between 6–9 and 10–16 years old could be explained by some changes in the skin conformance around the age of 10. Skin conformance, measured as the slope of the function relating conformance to groove width, is correlated with young adults' tactile spatial resolution performance (Vega-Bermudez and Johnson 2004). Subjects with greater skin conformance had better GOT performance (Vega-Bermudez and Johnson 2004). However, such a link has not been investigated in children and adolescents and there is no evidence in the literature that children from 6 to 9 have worse skin conformance than teenagers

Table II. Tactile spatial resolution thresholds (mm).

Age groups	<i>n</i>	Thresholds (mm)		
		25%	50%	75%
6–7	44	1.12	1.31	1.83
8–9	56	0.97	1.23	2.11
10–11	41	0.73	1.09	1.42
12–13	40	0.78	1.00	1.30
14–16	41	0.71	1.10	1.28

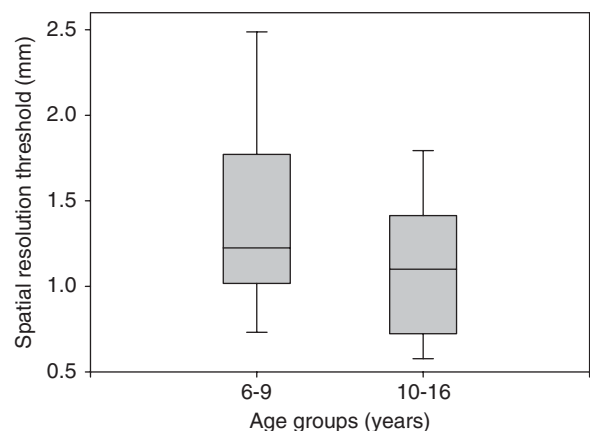


Figure 1. Box plots showing the tactile spatial resolution thresholds for the two different age groups (6–9 and 10–16 years old). Horizontal bars outside the box indicate the 10% and 90% limits; the box indicates the 25% and 75% limits; and the horizontal bar inside the box indicates the median of the distributions.

or adults. The step around 10 could also be explained by skin hydration. A recent study has shown that the degradation of tactile spatial resolution occurring with age was partially restored after hydration of the skin with a moisturizer (Lévêque et al. 2000). An improvement in skin hydration around 10 would be consistent with the sweat function—underdeveloped in prepuberal children—that increases at the onset of puberty (Inoue et al. 2004). However, this potential improvement in spatial resolution due to an increase in skin hydration has not been investigated in children. As the tactile spatial resolution threshold in humans corresponds closely to the SAI afferent mean spacing, the density of SAI afferent innervations is closely related to the spatial resolution performance (Van Boven and Johnson 1994a). A decrease in receptor density has been reported with ageing (Bolton et al. 1965; Bruce 1980; Besné et al. 2002) and is a potential explanation for the worse performance by the elderly in grating orientation tasks (Tremblay et al. 2003; Vega-Bermudez and Johnson 2004). A modification in the receptor density or organization around the age of 10 could thus explain the improvement in tactile spatial resolution performance. However, this is not congruent with embryonic studies on Merkel cells (Kim and Holbrook 1995) showing a decrease in receptor density from fetal age to senescence.

As highlighted above, it seems difficult to fully explain the improvement of spatial resolution observed around 10 years old by a change in skin and/or tactile receptor properties. Alternatively, the explanation could be found in the maturational process of the underlying cortical mechanisms. Recent studies have assumed that changes in the underlying cortical mechanisms play a major role in older adults' decline in spatial resolution tasks (Vega-Bermudez and Johnson 2004) and in the enhancement of spatial resolution in blind people (Van Boven et al. 2000). It has been now widely demonstrated that tactile spatial resolution recruits activity not only in somatosensory but also in visual cortical areas (Zangaladze et al. 1999; Sathian and Zangaladze 2001, 2002). Both somatosensory and visual systems are encountering changes around the age of 10–11 years old. Anatomical post-mortem studies focused on myelogenesis suggest that maturation of the somatosensory cortex is completed by about the onset of puberty (Yakovlev and Lecours 1967). The visual system, even if partly considered as mature by the age of 4 years old (Allison et al. 1984), shows clear developmental changes afterwards in some components of visual evoked potentials reflecting intracortical maturation (Allison et al. 1984). This late maturation is for instance evidenced in tasks implying visual hyper-acuity which is not mature before the age of 10–14 years old (Skoczenski and Norcia 2002). Magnetic resonance imaging investigations have also reported

maturational cortical changes by using the spin-lattice relaxation time (T1) as an anatomical reference. By 11 years, T1 significantly decreases in the cortical grey matter to reach the range of values for young adults (Steen et al. 1997) indicating that cortical grey matter becomes mature at this age.

In conclusion, some important changes appear in tactile spatial resolution during preadolescence. The step in tactile spatial resolution is most probably linked to cortical maturational processes. Nevertheless, further investigations are needed to clearly understand and define the underlying mechanisms. This study also provides normative data during childhood. Such data could be used as reference for the measurement of tactile spatial resolution in impaired children.

Acknowledgements

This study was supported by a grant from the Fonds de la Recherche Scientifique Médicale (FRSM).

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