Somatosensory and Motor Research, March 2010; 27(1): 9–14

ORIGINAL ARTICLE

Relationship between tactile spatial resolution and digital dexterity during childhood

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(Received August 2009; accepted 9 October 2009)

Abstract
The aim of this study was to determine whether tactile spatial resolution and digital dexterity performance are associated during childhood. A total of 104 healthy children (52 boys and 52 girls) were assessed. The tactile spatial resolution threshold was determined using an enlarged set of JVP domes with a procedure adapted for children. Digital dexterity was tested with the Purdue Pegboard Test. While tactile spatial resolution and digital dexterity improved with age following a parallel evolution, no correlation was found between the scores of the children for both tests. We suggest that central maturational processes are responsible for a global refinement of sensory and motor function between the ages of 4 and 10 years, reaching the range of adult values at this age.

Keywords: *touch, tactile spatial resolution, dexterity, children, development*

Introduction

The ability to draw, assemble small pieces to make a model airplane, or create objects with papier mâché develops slowly in young children. These activities are actually dependent on the ability to manipulate objects, which is not innate and evolves with age (Forssberg et al. 1991, 1992, 1995; Gordon et al. 1992). Many factors are likely to contribute to the manipulation of objects: cognition, perception, sensory function, coordination of movement (Eliasson 1995). In young children, the manipulation of small objects is thought to rely primarily on the afferent feedback of information from mechanoreceptors of the pulp of the fingers (Forssberg et al. 1991). One can therefore hypothesize that digital dexterity could be dependent on the ability to employ central sensory information. One of the sensory modalities frequently assumed to be associated with digital dexterity is tactile spatial resolution (Tremblay et al. 2002, 2003). The aim of the current study was to test this relationship in normal children, since both sensory abilities and digital dexterity evolve during childhood (Tiffin and Asher 1948; Gardner and Broman 1979; Bleyenheuft et al. 2006; Arnould et al. n.d.).

Digital dexterity, defined as “the ability to make rapid, skillful, controlled manipulative movements of small objects, where the fingers are primarily involved” (Fleishman and Ellison 1962, p. 96), can be measured reliably using the Purdue Pegboard Test (PPT; Tiffin and Asher 1948; Mathiowetz et al. 1985). The sensitivity of this test highlights potential dysfunctions, even in children (Gardner and Broman 1979; Duqué et al. 2003; Bleyenheuft et al. 2007).

The transmission of an acute spatial neural image evoked by a stimulus can be tested by measuring the tactile spatial resolution (Johnson 2001). The Grating Orientation Task (GOT) is an objective and valid test of tactile spatial resolution (Craig and Johnson 2000; Gibson and Craig 2002), since the neural image is issued only from spatial cues (Johnson and Hsiao 1994). It is not affected by changes in impulse rates, but only on the exact location of active neurons (Johnson and Phillips 1981). Moreover, GOT thresholds are consistent

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ISSN 0899–0220 print/ISSN 1369–1651 online
DOI: 10.3109/08990220903471831

with complex stimuli that can only be resolved by spatial cues, for example, Braille characters (Johnson and Phillips 1981).

The PPT and the GOT have been studied in children (Tiffin and Asher 1948; Gardner and Broman 1979; Bleyenheuft et al. 2006; Arnould et al. n.d.). Both tests show an increase in performance between the ages of 6 and 10 years, after which a stabilization in the performance is observed. A causal relationship between tactile spatial resolution and digital dexterity, however, has never been studied in children. In older adults, such a relationship has been highlighted, and an inferior tactile spatial resolution of some older individuals was found as an explanation for their substandard dexterity (Tremblay et al. 2003). We hypothesized that a potentially poor performance in GOT of younger children could parallel and partly explain their limitations in digital dexterity.

Material and methods

Subjects

This study was approved by the Ethical Committee of the Université catholique de Louvain. Written informed consent was obtained from parents of the test subjects.

A total of 104 children between 4 and 17 years old (mean age: 10.3 years) and who did not present with a hand disease or injury were enrolled (description, Table I).

Test description

Two tests were presented to the dominant hand of each child. First, the tactile spatial resolution threshold was measured with the GOT using JVP domes (Stoelting Co., Wood Dale, IL, USA). Digital dexterity was then assessed using the PPT.

Table I. Subjects.

			Purdue score (*n*)		JVP score (mm)	
Age group (years)	*n*	mean age (years)	mean	SD	mean	SD
4	5	4.6	8.1	1.4	5.7	2.2
5	11	5.5	10.1	1.06	4.2	1.92
6	10	6.3	11.3	1.32	1.8	0.66
7	8	7.2	12.7	1.14	1.6	0.81
8	9	8.3	13.8	1.28	1.4	0.58
9	7	9.3	13.8	0.96	1.5	0.76
10	7	10.5	16	1.25	1	0.43
11	11	11.2	15.7	1.38	1	0.23
12	8	12.3	16.2	1.48	0.9	0.3
13	6	13.4	17	1.72	1	0.5
14	8	14.2	16.7	1.64	1	0.53
15	8	15.3	16.2	1.23	1.1	0.35
16	4	16.2	16	1.93	1.1	0.53
17	2	17	16	1.41	1.1	0.25
Total	104					

Tactile spatial resolution

The GOT took place in a quiet room where children were first instructed on the sequence of the test. The task was then clearly demonstrated. The subjects, blindfolded, were sitting with their forearm lying in a supine position on a table with the index finger fixed on the support using adhesive tape applied to the nail (Sathian and Zangaladze 1996).

An extended set of 11 different hemispherical JVP domes presenting gratings with equidistant bar and groove widths (0.35, 0.50, 0.75, 1.00, 1.20, 1.50, 2.00, 3.00, 3.5, 4, and 4.5 mm) was applied on the index finger of the children. Each dome was normally applied to the skin for 1–2 s such that it provided a skin deformation of about 2 mm (Van Boven and Johnson 1994; Van Boven et al. 2000; Bleyenheuft and Thonnard 2007). A random presentation of the bars and grooves, along or across the longitudinal axis of the index finger, was applied for 10 consecutive trials with the largest grating (4.5 mm). The next smallest grating (4 mm) was subsequently applied using the same procedure and so forth. In this adapted procedure (Bleyenheuft et al. 2006), subjects were required to identify the orientation of the grooves before the stimulus was removed, as originally recommended by Van Boven and Johnson (1994). When the probability of correct answers for one grating reached 50%, the test was stopped, and the threshold was calculated with the TAG score as a simple linear interpolation estimate of the 75% correct grating width (Med Core 2004). The TAG score was thus calculated as

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

where

- g grating width of a probe
- p probability of correct answers
- above the grating width that results in a score closest to but above 75% correct
- below the grating width that results in a score closest to but below 75% correct.

The lower the TAG score was, the better the tactile spatial resolution performance.

Digital dexterity

The PPT (Tiffin and Asher 1948; Lafayette Instrument Model 32020) was used to measure digital dexterity (Mathiowetz et al. 1986). Within 30 s, children had to pick up some pins (length: 2.5 cm; diameter: 2.5 mm) from a cup, one at a time and place as many as possible into holes of a board (diameter: 3 mm). Before starting the test, subjects were given the chance to practice with four pins. They subsequently performed the test 3 times with the dominant hand. The score was determined as the average number of pins picked up and placed in 30 s during the three trials.

Data analysis

Spearman correlations were conducted to test age effects in PPT and GOT. The relationship between the *z*-scores of both tests was also tested with a Spearman correlation.

Results

Age effects

Table I presents the mean and SD of each age bracket for PPT and GOT results. As expected, the results of the PPT were highly correlated with age ($r = 0.815$; $p < 0.001$). This evolution showed a clear increase in performance until the age of 10. Afterwards, the scores tended to stabilize (Figure 1A).

As presented in Figure 1B, children also showed an increase in the TAG score that was highly correlated with age ($r = -0.635$; $p < 0.001$), with values decreasing (improvement) with age until the age of 10. Older children showed stable values around 1 mm. Unexpectedly, the youngest children (4 and 5 year olds) presented with very high scores. For some of them, an accurate threshold estimate could not be calculated.

Correlation between digital dexterity and tactile spatial resolution

To exclude age effects, all results were converted into *z*-scores. The correlation of PPT *z*-scores and JVP *z*-scores was not significant ($r = 0.061$; $p = 0.6$; Figure 2).

Discussion

The aim of this study was to test whether the poor performance in digital dexterity of young children was associated with deficiencies or immaturity in tactile spatial resolution.

Digital dexterity

As expected, we observed a gradual improvement of digital dexterity with age, similar to previous studies (Costa et al. 1964; Gardner and Broman 1979; Wilson et al. 1982; Arnould et al. n.d.). As previously described, the performance on the PPT increased until stabilizing at the age of 10 years (Costa et al. 1964; Arnould et al. n.d.). One hypothesis to explain this evolution is the parallel development of digital dexterity and the corticospinal

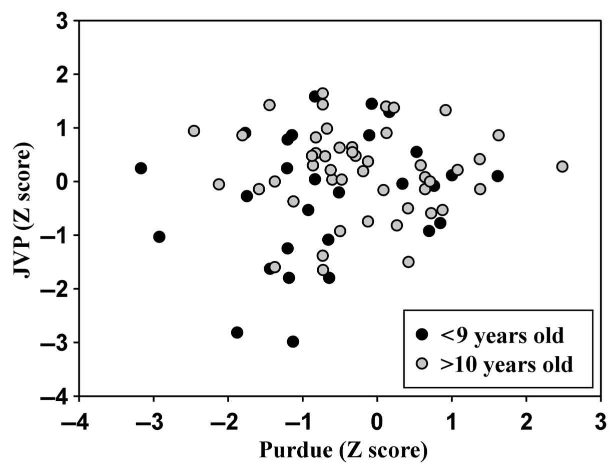

Figure 2. Correlation between PPT and tactile spatial resolution performance represented as *z*-scores. Each dot represents one child.

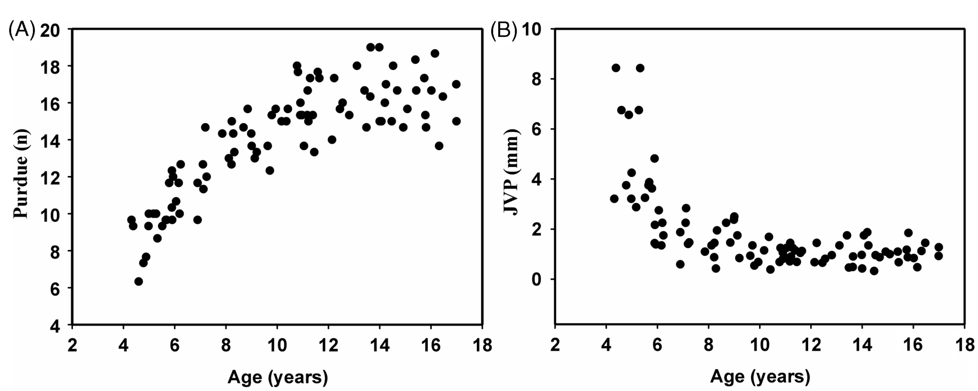

Figure 1. The evolution of rough scores with age for (A) the Purdue Pegboard Test and (B) JVP dome scores. Each black dot represents one child.

tract (Müller and Hömberg 1992; Arnould et al. n.d.). The corticospinal tract, which is crucial for dexterity (Porter and Lemon 1993; Duqué et al. 2003; Lang and Schieber 2003, 2004; Bleyenheuft et al. 2007), undergoes a maturation process until the age of 10 years, as shown by transcranial magnetic stimulation studies (Müller et al. 1991; Nezu et al. 1997; Heinen et al. 1998; Fietzek et al. 2000).

Tactile spatial resolution

Tactile spatial resolution also increased in performance until the age of 10 years with a subsequent stabilization. This is consistent with a previous study that hypothesized that this stabilization reflected the maturation of the underlying cortical process (Bleyenheuft et al. 2006), since both visual and somatosensory systems applied in tactile spatial resolution tasks (Zangaladze et al. 1999; Sathian and Zangaladze 2001, 2002) go through changes around 10–11 years of age.

The youngest children in our study had extremely high thresholds in the GOT. An accurate threshold estimate could not even be calculated in some of the subjects. Despite the adapted procedure (Bleyenheuft et al. 2006), the GOT is a demanding task. The results obtained here could be explained by a lack of attention in the younger subjects (Davidson et al. 2006). Another explanation could lie in an immaturity of the somatosensory cortex, which would be unable to correctly transmit the acute spatial neural image evoked by the stimulus that is required in the GOT (Johnson 2001). This is consistent with a previous study that used somatosensory evoked potentials to show a prolonged maturation of afferent somatosensory central pathways, which do not reach adult values until 5–7 years (Müller et al. 1994).

The relationship between tactile spatial resolution and digital dexterity

A strong relationship has been established between digital dexterity and tactile spatial resolution in ageing people (Tremblay et al. 2003). It was therefore surprising to observe an absence of this correlation in children. One can argue that many components are required in order to have a good performance in digital dexterity. Tactile spatial resolution is most likely one of these components, but the representation of the movements thanks to an accurate internal model is crucial too (Flanagan and Wing 1997; Blakemore et al. 1998; Kawato 1999; Witney et al. 2004). In ageing people, it is possible that the decrease in dexterity is due to perturbations of tactile spatial resolution, while other components of dexterity such as planning of the movement remain intact. This decrease in tactile spatial resolution could be due to the SA1 decrease in density encountered with age (Tremblay et al. 2003; Vega-Bermudez and Johnson 2004), since grating orientation information is conveyed and determined by SA1 fibres (Johnson and Hsiao 1994; Blake et al. 1997; Yoshioka et al. 2001) that are known to prune with age (Besné et al. 2002). The tactile spatial resolution in young children, while clearly immature, is not the only component perturbed. In fact, during childhood and especially before the age of 6, prehension studies have highlighted major perturbations in precision grip (Forssberg et al. 1991, 1992, 1995; Gordon et al. 1992). Children do not use internal models but instead rely on feedback information. This improves after 6 years, but it is still not similar to adults until the age of 10 (Forssberg et al. 1992, 1995). Thus, the age at which children are able to use internal models to plan a fine movement closely matches the age at which digital dexterity performances stabilize. The acquisition of the ability to anticipate the fine gesture could therefore be more determinant to perform digital dexterity tasks than acquiring the sensory abilities. Alternatively, some other factors like cognition, perception, or coordination of movement may contribute to the manipulation of objects (Eliasson 1995).

Alternately, it can also be hypothesized that both digital dexterity and tactile spatial resolution are influenced by other factors. Skin hydration, for instance, has been shown to play a major role in tactile spatial resolution, since the degradation of tactile spatial resolution in older people is partially restored after hydration of the skin with a moisturizer (Lévêque et al. 2000). First, skin hydration could have an effect on digital dexterity performance and could therefore influence the results of both tests in elderly subjects. In children, skin hydration improves around age 10 because the sweat function that is underdeveloped in prepubescent children increases at the onset of puberty (Inoue et al. 2004). This hypothesis, however, should be tested on children and older people by modifying the skin hydration between two evaluations of tactile spatial resolution and digital dexterity.

Second, the rather parallel evolution of the performance on both tests during childhood showed an improvement between 4 and 10 years of age, and the subsequent stabilization could also be explained by a change in the concentration abilities of the children. It has been shown that attention is highly correlated with age. Attention abilities already show an increase in 3–5 year olds, but it is not until around age 6 that an important stage in the development of different components of attention begins

(Klenberg et al. 2001). It has also been reported that concentration abilities improve rapidly from 6 to 10 years, and the improvements become less prominent during the teenage years (Rebok et al. 1997). This evolution of attention abilities closely matches that of our results in both tests and could explain their parallel evolution. This is supported by some findings in the literature suggesting that dexterity can be accounted for by attentional demands (Strenge et al. 2002).

Finally, this parallel change could also be explained by cortical maturation. In fact, after 10 years, the cortex reaches a global level of maturity as highlighted in magnetic resonance images while using the spin–lattice relaxation time (T1) as an anatomical reference (Steen et al. 1997). These authors showed maturational cortical changes in T1, which significantly decreases in the cortical grey matter during childhood and reaches the range of young adult values by the age of 11. This indicates that cortical grey matter becomes mature around this age.

In conclusion, we suggest that while young children present a very poor tactile spatial resolution performance, it cannot explain their poor digital dexterity. Alternatively, we suggest that components such as central planning of movements studied by analysis of forces in precision grip are responsible for this poor performance of younger children in digital dexterity. This central planning of movement is actually not fully developed until the age of 10 (Forssberg et al. 1992, 1995).

Declaration of interest: The authors report no conflict of interest. The authors alone are responsible for the content of the paper.

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