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Integration of tactile input across fingers in a patient with finger agnosia

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ABSTRACT

Finger agnosia has been described as an inability to explicitly individuate between the fingers, which is possibly due to fused neural representations of these fingers. Hence, are patients with finger agnosia unable to keep tactile information perceived over several fingers separate? Here, we tested a finger agnosic patient (GO) on two tasks that measured the ability to keep tactile information simultaneously perceived by individual fingers separate. In experiment 1 GO performed a haptic search task, in which a target (the absence of a protruded line) needed to be identified among distracters (protruded lines). The lines were presented simultaneously to the fingertips of both hands. Similarly to the controls, her reaction time decreased when her fingers were aligned as compared to when her fingers were stretched and in an unaligned position. This suggests that she can keep tactile input from different fingers separate. In experiment two, GO was required to judge the position of a target tactile stimulus to the index finger, relatively to a reference tactile stimulus to the middle finger, both in fingers uncrossed and crossed position. GO was able to indicate the relative position of the target stimulus as well as healthy controls, which indicates that she was able to keep tactile information perceived by two neighbouring fingers separate. Interestingly, GO performed better as compared to the healthy controls in the finger crossed condition. Together, these results suggest the GO is able to implicitly distinguish between tactile information perceived by multiple fingers. We therefore conclude that finger agnosia is not caused by minor disruptions of low-level somatosensory processing. These findings further underpin the idea of a selective impaired higher order body representation restricted to the fingers as underlying cause of finger agnosia.

1. Introduction

Finger agnosia, the inability to recognize one's own fingers or fingers in general, has been frequently investigated throughout the last century. These studies were often performed in the context of the Gerstmann's syndrome (finger agnosia, agraphia, acalculia and left/right disorientation, e.g. Benton, 1961; Carota, Di Pietro, Ptak, Poglia, & Schnider, 2004; Gerstmann, 1930; Mayer, Martory, Pegna, Landis, Delavelle, & Annoni, 1999; Roux, Boetto, Sacko, Chollet, & Tremoulet, 2003; Stengel, 1944; see for overview: Lebrun, 2005; Rusconi, Pinel, Dehaene, & Kleinschmidt, 2009). More detailed and specific investigations targeting the mechanism underlying finger agnosia are less frequently reported (Ettlinger, 1963; Kinsbourne & Warrington, 1962; Poeck & Orgass, 1969), which is unfortunate since Benton observed already in 1961 that the four disorders that constitute Gerstmann's syndrome did not mutually associate very well (for similar critics see Critchley, 1966). Indeed, finger agnosia might be of interest when it comes to explaining the cognitive representations of the body and as such has gained renewed interest in recent years (Anema et al., 2008; Haggard & Wolpert, 2005).

In 1944, Stengel suggested that a spatial mechanism might be the underlying deficit. Based on a thorough investigation of a patient who showed a general loss of spatial orientation, constructional apraxia and Gerstmann's syndrome, the author proposed that finger agnosia is "the inability of the patient to relate in space objects which form part of an organised whole to each other and to himself according to the rules acquired by experience" (Stengel, 1944, p. 760). There appears to be an inability to judge the relative positions of the fingers, more than there is an inability to recognize a finger *per se*. Indeed, the fact that finger agnosia patients also exhibit "toe agnosia" is consistent with the idea of a more general rather

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than a finger specific disorder (e.g. Mayer et al., 1999; Stengel, 1944; Tucha, Steup, Smely, & Lange, 1997). However, these observations are incompatible with Gerstmann's definition of finger agnosia. The author defined finger agnosia as being primarily a specific type of autotopagnosia, or a loss of body orientation restricted to the fingers, "...as though the optic-tactile-kinesthetic image pertaining to the fingers were split off from the total body..." (Gerstmann, 1957, p. 867). This idea was taken even further by Benton who proposed a concept of a distinct "finger schema" (Benton, 1959). Kinsbourne and Warrington's (1962) performed perhaps one of the most thorough investigations of finger agnosia. They confirmed and expanded Stengel's hypothesis (1944) that finger agnosia is a problem in recognizing the serial order of the fingers. Whereas most tests of finger agnosia remain rather explicit (e.g. name the touched finger, touch the indicated finger, indicate the touched finger on a drawing of the hand) Kinsbourne and Warrington used tasks targeting implicit concepts of serial order. The authors tested finger agnosia patients on a variety of haptic tasks. Twelve finger agnosic patients with Gerstman's syndrome and 20 control cases completed tasks in which information of relative finger position and knowledge of finger boundaries was essential for correct performance. For example, patients were instructed to determine the number of fingers that was in between two simultaneously touched fingers, which requires knowledge about the relation of the two fingers to the rest. Typically, finger agnosia patients responded with "three fingers in between" irrespective of the actual number of fingers. Another task investigated the ability to discriminate between finger positions on basis of tactile features of a specific, uncommon object. Patients' fingers were moulded around an object, after which they had to pick out the corresponding object out of 4 models, without looking at the object in their hand. All tested finger agnosia patients were unable to perform this task. Also, in a task which tested knowledge of finger boundaries, patients were unable to discriminate between two simultaneously applied touches, targeted on one or two fingers. Patients erroneously responded with "two" when the two touches were applied to one finger and vice versa. The authors interpreted the results as if tactile information cannot be processed in terms of the local position of the finger and patients are unable to determine to which finger tactile input belongs. Thus, the ability to comprehend the serial order of the fingers is not only lost, the fingers seem to be "fused" together into a single representation and individuating between them is no longer possible.

Nevertheless, even though the exact mechanism is still poorly understood there appears to be a general agreement of finger agnosia being a disorder in the "individuation of the fingers" (Haggard & Wolpert, 2005; Haggard, Kitadono, Press, & Taylor-Clark, 2006; Kinsbourne & Warrington, 1962; Stengel, 1944). Haggard and Wolpert (2005) discussed finger agnosia as part of body representation disorders and categorized it as a "pathology of segmentation". The authors related finger agnosia to autotopagnosia, a more general body mislocalisation disorder. In both disorders the knowledge about the body part categories is preserved, but the unique position of these categorical elements within the overall spatial organisation of the body is lost.

A recent study conducted by some of the current authors (Anema et al., 2008) investigated finger agnosia within a theory of dissociable representations of body image and body schema (Dijkerman & de Haan, 2007). Finger agnosia was studied in three patients with lesions affecting the angular gyrus by asking them to localise a touched finger using three different response modes. They were required to either reach to point towards the touched finger on their own hand, on a drawn map of a hand, name the targeted finger. The results revealed that these patients performed normally when reaching towards the touched finger on their own hand but failed to indicate this finger on a drawing of a hand or to name it. Similar defects in the perception of other body parts were not observed. The findings provide converging evidence for finger agnosia being a disorder of higher-order selective perceptual differentiation.

As described above, finger agnosia appears to be a problem in individuating between the fingers which originates in a collective fusion of the representation of the fingers and leads to the inability to accurately attribute (here) tactile information to the finger receiving that information. When exploring objects for haptic object recognition tactile input to the fingers needs to be combined with proprioceptive information of the location of those fingers (Lederman & Klatzky, 1987; Overvliet, Anema, Brenner, Dijkerman, & Smeets, in press). It could therefore be expected that it is problematic for patients with finger agnosia to integrate all the information accurately into a stable percept. Thus, separation might not just be important for identifying the fingers, but may also be critical for recognizing objects by touch. Interestingly, finger agnosic patients are not known for impairments in haptic recognition of common objects used in daily life and to our knowledge no study has reported (or even investigated) such impairments. However, it could be hypothesised that minor disruptions in more early somatosensory processes contribute to the inability to explicitly distinguish between the fingers, without functionally hampering haptic object recognition. Perhaps the impairment arises at the processing level at which proprioceptive input about the individual fingers is combined with tactile stimulation.

In order to investigate this claim, we tested a patient (GO, see also Anema et al., 2008) with finger agnosia on two haptic tasks that measured the ability to keep separate tactile information simultaneously perceived by individual fingers and have been published earlier by (Benedetti, 1985, 1988; Overvliet, Mayer, Smeets, & Brenner, 2008). The haptic search task published by Overvliet et al. (2008) used two different finger configurations, either fingers stretched and placed on several tangible line segments (line segments condition) or fingers bent rather awkwardly in order to be aligned on one tangible continuous line (continuous line condition) (see Fig. 2). The participants were required to lift the finger under which they did not feel (a part of) a line. The results of Overvliet et al. (2008) study showed that healthy participants have faster response times in the continuous line condition, as compared to the line segments condition. This task additionally tests the integration of somatosensory information perceived over several fingers into a coherent percept. The authors therefore concluded that the alignment of the fingers in the continuous line condition allowed the participants to integrate the input perceived over the fingers into one object, which led to faster detection of the target. This effect can only be achieved if tactile input to various fingers is distinguished from each other and subsequently, in combination with proprioceptive input about the position of the fingertips, integrated into one percept. The second experiment used the paradigm of Benedetti (1985). GO was asked to judge the location of a (target) touch on the fingertip relatively to the location of a second (reference) touch to the neighbouring finger tip. The two fingers (middle and ring finger) were stimulated simultaneously and the position of the target finger was rotated around the reference finger in a frontal plane (fingers uncrossed, fingers on top of each other, exceedingly crossed over). By testing GO with these haptic experiments we investigated her ability to process and keep separate simple features perceived by the fingers, and to subsequently integrate them using proprioceptive information regarding the positions of the fingertips.

We reason that if GO can still perform these tasks, she can still keep tactile information that is perceived over multiple fingers separate, albeit on a low processing level. Consequently, the suggested "fusion of the fingers" must arise selectively at a higher processing level.

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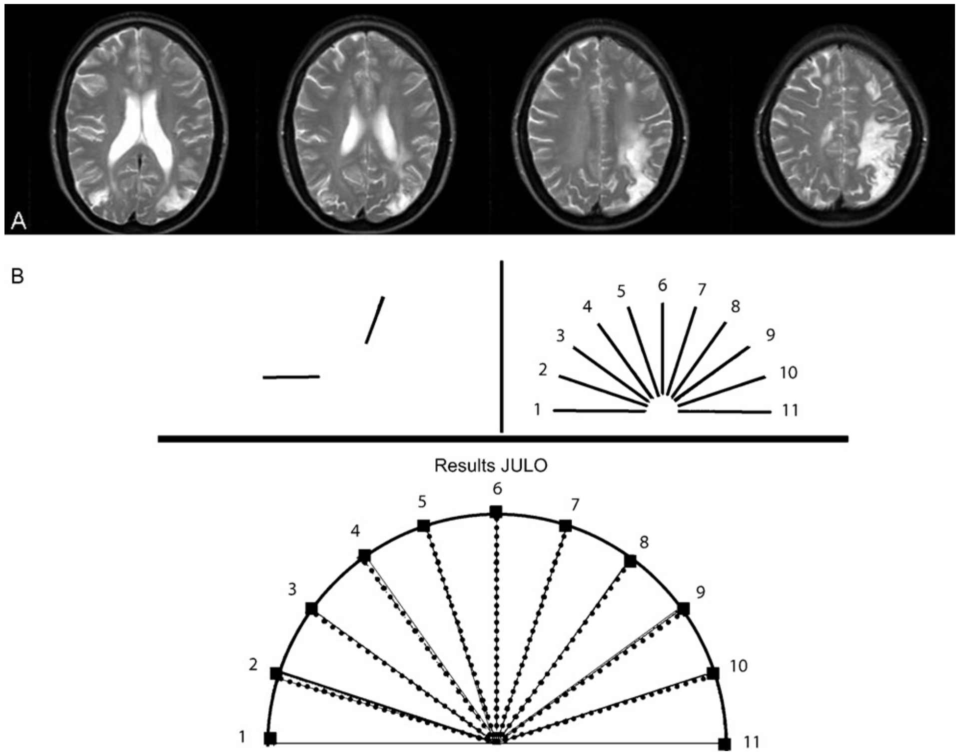

Fig. 1. (A) A T2/FLAIR scan of the finger agnosia patient GO; it shows a lesion in the left parieto-occipital cortex, including the angular gyrus. (B) Results of Visual Judgement of Line Orientation test (JULO); line segments, such as presented in the upper left panel, have to be matched to one of 11 possible line orientations (upper right panel). Results of 3 trials per orientation.

2. Material and methods

2.1. Case description

GO is a 52 years old right-handed woman who had suffered a left hemisphere watershed infarction in the parieto-occipital region including the angular gyrus (see Fig. 1). Shortly after the stroke she exhibited a mild right-sided hemiparesis and reported problems concerning concentration and memory capacity. Furthermore, right hemispheric damage was observed on the boundaries between the supply area of the cerebral medial artery (CMA) and the cerebral posterior artery (CPA) resulting in a minor left distal hemiparesis, which was dissolved on admission.

A neuropsychological examination four weeks after admission revealed impairments in writing, mental arithmetic and spatial orientation (left/right dissociation, mental rotation, and visual perception/construction). As she exhibited several symptoms of Gerstmann's syndrome (acalculia, agraphia and left/right disorientation; Gerstmann, 1930), GO was subsequently tested on finger agnosia, which indeed was observed. GO scored 8 out of 10 when she had to name the fingers of a drawn hand, 6 out of 10 when she had to name her own fingers, and 5 out of 10 when she had to name her fingers in response to an unseen touch. In contrast, localizing and naming other body parts such as shoulder, knee, and hip was unimpaired (10 out of 10). No memory or language impairments were found.

About twenty months later when the experimental data were collected, she reported minor residual complaints regarding cognitive functions such as agraphia and acalculia, although these could no longer be confirmed on formal testing. Also, GO reported to experience some problems with her right hand in terms of dexterity as was shown by difficulties handling scissors with her right hand. When tested on finger agnosia she still exhibited finger identification difficulties both when naming her own fingers (6/10) in response to unseen touch as well as indicating fingers on the map of a hand (4/10). Overall, the errors GO made were mainly in response to the three middle fingers and both hands were equally affected. See Anema et al. (2008) for more elaborate test results of finger agnosia with patient GO.

To re-assess her visual perception performance we tested GO on the Judgement of Line Orientation (JULO). In this task GO was required to visually judge the orientation of a line. Although GO made significantly more errors (10/15 correct) than was expected on the basis of her age, gender and education, she never selected a line further than 1 response option (18° of angle) away from the target. As such, GO was still able to judge the spatial relation between the orientation of visual stimuli, albeit at a somewhat reduced level of accuracy (see Fig. 1B).

Finally, in order to check whether GO's somatosensory function was intact, both her pressure sensitivity and her joint position sense (proprioception) were tested. Pressure sensitivity measures (with Von Frey hair applications) appeared to be different between the left (0.02 g target force) and right hand (0.04 g), but they were within the normal range (mean = 0.04 g/SD = 0.12 g). Joint position sense was clinically tested at the upper phalanx of the right thumb and appeared to be intact (24/24).

GO's performance was compared to that of healthy control participants without history of psychiatric or neurological illness (see for further details Methods sections in Experiment 1 and 2). Participants received a small payment for their participation and they gave written informed consent before the start of the study. This study was approved by the Utrecht Ethical Medical Board and has been conducted in according with the declaration of Helsinki.

2.2. Experiment I

2.2.1. Control participants

GO's performance was compared to that of 10 healthy controls reported in Overvliet et al. (2008). To control for aging effects on somatosensory processing, we added five participants in the control group that were age matched to GO (mean age = 59; range 59–62). The mean age for the entire control group was 40 (range 23–62). All healthy participants, of which two stated to be left handed, had no history of psychiatric or neurological illness. The use of already published data of healthy participants in a single case study, as well as a combination of younger and age matched participants in one control group has been published earlier by Bukach et al. (2006: experiment 4).

2.2.2. Experimental set-up

Participants were seated at a table and a screen with a curtain was placed between the apparatus and the participants in order to prevent visual input of the stimuli. The three middle fingers of both hands were positioned on the apparatus which consisted of six force sensors, designed to have pieces of ZY®-TEX2 Swell paper (Zychem Ltd., Cheshire, England) attached to them. The stimulus items were horizontal lines with a line width of 1.4 mm, which protruded about 1 mm from the surface of the swell paper. Each separate sensor could be accurately positioned to fit the hand size and stimulus positions. The sensor measured whether a finger was in contact with the stimulus. The fingers were always separated to prevent them from touching the neighbouring fingers, which could give additional information, as well as to prevent them from touching a neighbouring sensor (see Fig. 2).

2.2.3. Procedure

We included two different search conditions. In the first condition, the stimulus consisted of separate 2 cm line segments that were positioned under the participants' finger pads (index, middle and ring finger of both hands). In this condition, the hands were in a comfortable (natural), though stretched position (Fig. 2A). The target stimulus was a piece of swell paper without a line segment. In the second

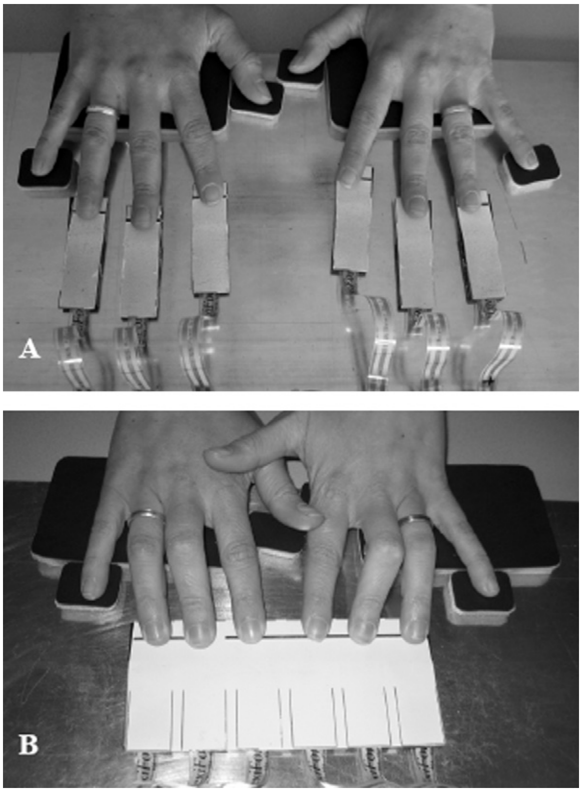

Fig. 2. The setup of experiment I. In the upper panel (A) a subject is performing the haptic search task with line segments (the target (no line) is below the middle finger of the left hand) and in the lower panel (B) a subject is performing the haptic search task in the continuous line condition (the target is below the middle finger of the right hand).

condition a continuous 14.5 cm line was used instead of line segments. A 2 cm gap in this line served as the target. In this condition, the participants had to adjust their finger positions to the line (Fig. 2B).

Each condition was tested in a separate block of 40 trials. In 25% of the trials the stimulus did not contain a target. Both blocks were repeated twice and presented in an ABBA design. Before each trial, the participant was asked specifically to position the fingertips on the sensor to prevent her from misplacing the fingers. When the fingers were in the correct position, participants lifted the fingers and maintained that position, while the experimenter placed the next stimulus on the sensors. The experimenter started each trial by presenting a 4500 Hz tone. As soon as participants heard the tone they had to lower the fingers onto the stimulus. Moving the fingertips over the line stimuli was allowed as long as the fingers remained on the sensors. Participants were instructed to lift the finger under which the target (no line) was positioned as soon as it was detected (target present trial). For trials in which the target was absent (all fingers were presented with a line; target absent trial), participants were instructed to lift all the fingers as soon as they detected the absence.

2.2.4. Design and data analyses

On both target present and absent trials, the reaction time was defined as the time from when the first finger contacted the sensor until a finger was lifted. We excluded trials on the basis of three different parameters. First, trials with reaction times shorter than 100 ms were discarded as they were considered physiologically implausible. Second, trials with reaction times longer than 2 SD above the mean of the participant in question (either control or GO) were excluded as they were considered outliers. Third, trials in which participants lifted the wrong finger were also excluded from the analyses. Next, for each condition (separate line segments, continuous line) the median search time was computed for the remaining trials. After these initial analyses, the data was further statistically analysed in two steps. At first the data of the healthy control group was tested on significant effects between the line segments and continuous line conditions. This involved a 2 (target condition: *target absent*, *present*) × 2 (line condition: *continuous line*, *separate line segments*) × 2 (group: *student controls*, *age matched controls*) Repeated Measures Anova with both *target condition* and *line condition* as within subject factors and *group* as between subjects factor. Only significant effects are reported.

Second, it was tested whether GO exhibited a similar benefit of the continuous line condition as compared to the line segments in detecting a target, or detecting the absence of a target. For each of the four conditions GO's scores were tested against that of the healthy controls using Crawford and Garthwaite's test for abnormality scores in single case studies (Crawford & Garthwaite, 2002).

3. Results

3.1. Accuracy

GO showed a larger proportion of errors as compared to the control group. GO had on average 25% errors (for line segments: 78% correct, 14% false positives, no false negatives, and 8% wrong finger; and for the continuous line: 71% correct, 11% false positives, 4% false negatives and 14% wrong finger). The percentage of errors was considerably higher than in healthy controls (line segments: 13.5%; continuous line 14.5%, respectively). Errors were always made by GO at targets presented to the right hand, either the middle or the ring finger. False positives may have been caused by reduced tactile sensitivity of GO on the right hand. Moreover, when testing GO, we noticed that she experienced difficulties maintaining her right hand fingers on the small strips of swell paper. Chi-square calculations on the proportion of false positives revealed that these values did not differ significantly between the line segments (22%) and the continuous line condition (39%; $\chi^2 < 3.84$). Similar results were found for the proportion "wrong finger" (line segments = 35% and continuous line = 48%; $\chi^2 < 3.84$).

The interim analyses of the accuracy scores reveal a relatively large number of mistakes on the trials in which the target was positioned underneath one of the right hand fingers. Two observations can provide insight in this outcome. As is described above in Section 2.1, GO's right hand is less sensitive to touch as compared to her left hand, although within normal range. Also, the left sided lesion lead to minor but persistent motor problems with her right hand as was reported by GO (see Section 2.1). Indeed, while testing, GO exhibited difficulties maintaining the awkward position of the right hand fingers on to the stimuli. Since her finger agnosia affected both hands and to keep our measurements as valid as possible we excluded (post hoc) the right hand trials in the RT analyses.

3.2. Reaction time

Data of the controls and GO are plotted in Fig. 3. The ANOVA on the healthy control subject reaction times showed a significant main effect of target condition ($F(1,13) = 12.83$, $p < 0.01$): reaction times were faster when the target was present (2011 ms) than when the target was absent (2694 ms). More importantly, a main effect of line condition was observed ($F(1,13) = 9.533$, $p < 0.01$) indicating that search time decreased when fingers were positioned on one continuous line (2168 ms) as compared to the positioning on line segments (2537 ms). Furthermore this effect did not differ between groups (interaction $F(1,13) < 1$). These results are in line with the earlier results of Overvliet et al. (2008). However, the age matched control group was overall slower as compared to the younger subjects (age matched = 3469 ms; young controls = 1235 ms; ($F(1,13) = 78.29$, $p < 0.01$)). It has been shown many times that older adults are slower in a wide variety of tasks (for tactile tasks: e.g. Ballesteros & Reales, 2004; Cole, Rotella, & Harper, 1998; Overvliet, Wagemans, & Krampe, 2010).

Most importantly, GO's search times showed a similar response pattern to the control group. We compared GO's performance to the age-matched control group using Crawford and Garthwaite's test (Crawford & Garthwaite, 2002) for abnormality scores in single case studies. We did not find any significant differences in reaction time behaviour in neither the line segment nor the continuous line condition. The statistics for the line segments condition were as follows: *target absent*, GO (3744 ms) versus control group (2496 ms; SD = 1614), t (df = 14) < 1 and *target present*, GO (2972 ms) versus control group (1813 ms; SD = 960), t (df = 14) = 1.169. For the

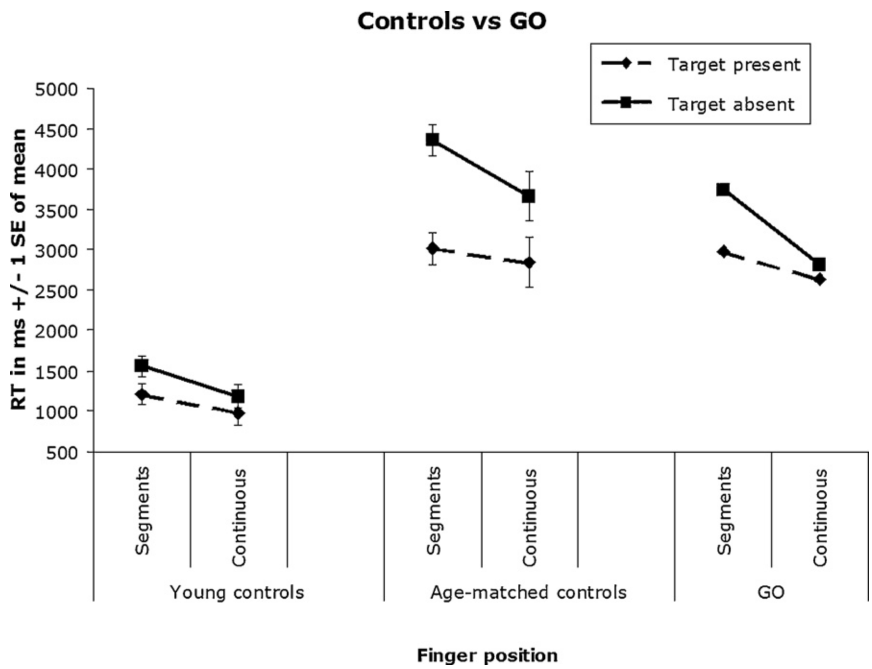

Fig. 3. Results of experiment I for the healthy control subjects, the healthy age matched control subjects and GO separately. The mean and standard errors for the two different conditions for target present (diamond symbol and dotted line) and for target absent (square symbols and solid line) are depicted.

continuous line the statistics were: *target absent*, GO (2806 ms) versus control group (2014 ms; SD = 1407 ms), t (df = 14) < 1, *target present*: GO (2635) versus control group (1597 ms; SD = 1015), t (df = 14) < 1.

3.3. Experiment II

3.3.1. Experimental set-up

Participants were seated at a table opposite the experimenter (see Fig. 4A). During testing either the left or right hand was positioned on top of the table with the palm of the hand downward. To prevent participants from relying on visual feedback, a wooden board was positioned over the participant's hand. The other hand was on top of the board to perform the responses. To enable the fingers to be crossed and manipulated in various orientations we used a similar device as was used in the Benedetti studies (Benedetti, 1985, 1988; see Fig. 4B). The index finger was inserted in a tube and the middle finger was rotated around the index finger. The position of the middle finger was obtained by the experimenter moving this finger and confirmed with a calibrated clinical goniometer (protractor, Medizintechnik KaWe, Germany) and subsequently recorded. As a result, the exact position of the middle finger varied somewhat around the intended target orientations used in the experiment (0°, 45°, 90° and 135°). In tactile trials stimuli consisted of two simultaneously and manually applied simple tactile stimulations, a small 0.5 mm diameter, plastic pin applied on the index finger (reference), and a 5 mm diameter relatively blunt pen like object, further referred to as "ball" applied on the middle finger (target). Responses were made by indicating the perceived position of either the finger relative to the reference finger, or the tactile stimulus ("ball") relative to the pin on a calibrated disk (see Fig. 4B). Responses were made in the frontal plane. The disk itself was positioned on top of the wooden board and this board covered the stimulated fingers. The rotating bar, which was placed on the calibrated disk, could be aligned by means of turning the bar so that the target point correlated with the perceived target position. Two symbols were drawn on this bar, one in the middle indicating the reference stimulus (index finger or .5 mm small pin) and one on the end of the bar indicating the target stimulus (middle finger or 5 mm blunt pin ("ball")). The experimenter recorded the set angle of the bars, of which horizontal was considered to be 0°.

3.3.2. Design and procedure

A 2 (*task:* perceived relative position of ball, perceived relative position of finger) × 4 (*position:* 0°, 45°, 90° and 135°) repeated measures design was used in this experiment. Each position × task condition was presented 4 times, except for the 135° condition that was tested 8 times. Obtaining and maintaining a fingers-crossed position can be difficult for some participants, especially when small differences in positions are requested. Therefore we tested only one crossed condition, that of almost maximally crossed (135°). To correct for differences in the number of trials between crossed and uncrossed finger positions, we added 4 extra trials to the crossed condition. Together this resulted in 40 trials in total. All orientation × task combinations were presented in a random order.

A trial started when the experimenter placed the middle finger in one of four possible target positions (0°, 45°, 90° and 135°). The exact final target position of the middle finger was verified by the experimenter using the goniometer. Next, in a finger condition trial the experimenter asked the participant to judge the orientation of the middle finger with respect to the index finger. In the ball condition trials, two simultaneous above threshold tactile stimulations (5 mm blunt pin on the middle finger and .05 mm sharp pin on the index finger) were manually applied to the fingers by the experimenter for approximately 1500 ms (subjectively controlled by the experimenter) and participants were required to judge the position of the ball with respect to the pin. In both cases responses were made by rotating a bar on a disk (see Fig. 4A). In order to prevent participants from using other reference information, only the 0° position was indicated on the disc. After the response was recorded by the experimenter, the middle finger was returned to the starting position (about −4°) and the response bar was preset to about 0°. Finger condition trials and ball condition trials were randomly interleaved. Prior to testing, participants practiced the task without the stimuli being applied to the fingers, in order to ascertain correct handling of the response device.

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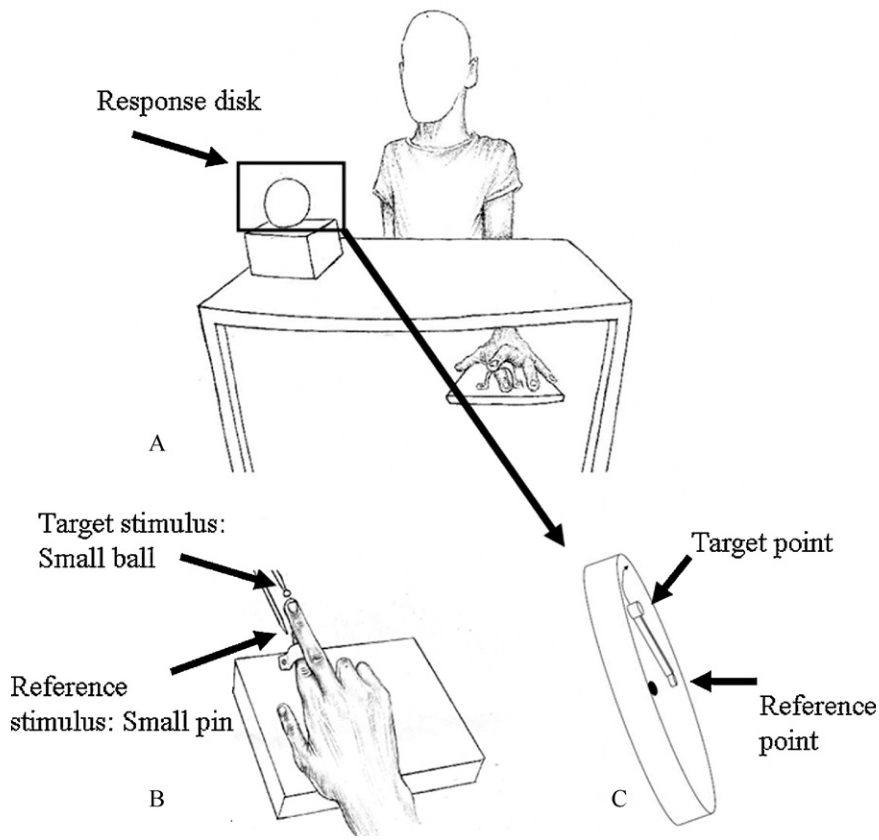

Fig. 4. (A) A schematic drawing of the setup of experiment II. (B) A close up of the hand in experiment II. The middle finger is stimulated by the "ball" and the index finger by a pin simultaneously. (C) The response disc. Note: the bar could be rotated either to the left or right.

3.3.3. *Data analyses*

A 2 × 4 (*task:* perceived relative position of the ball (ball condition), perceived relative position of finger (finger condition); *position:* 0°, 45°, 90° and 135°) repeated measures design was used. Deviations from the target position were calculated by subtracting the target position for each trial (in angular degrees) from the orientation provided by the participant. A 2 × 4 (task × position) repeated measures ANOVA was performed on the averages for each task × position combination.

We used Crawford and Garthwaite's test for abnormality scores in single case studies (Crawford & Garthwaite, 2002) in order to test GO's performance against that of healthy controls. When means are mentioned in the text, standard errors are also given (mean deviation (±SE)).

3.3.4. *Results*

3.3.4.1. Age matched controls. The averaged responses for the different position conditions (when applicable, further referred to as PC 0°, 45°, 90° and 135°) for both GO and the controls are plotted in Fig. 5. Visual inspection of the data suggests that in a fingers crossed position (PC = 135°) healthy controls judge the ball to be at a an uncrossed position (76° ± 2°) whereas they judge the fingers correctly as being crossed (121° ± 6°). The analysis of variance (ANOVA) of the deviations revealed a significant main effect of task (Ball = −10° ± 2.3°; Finger = −0.15 ± 2.3°; $F(1,4) = 12.60$, $p < 0.05$) and of position (PC 0° = 20° ± 2.8°; PC 45° = 11° ± 2.9°; PC 90° = −16° ± 7.7; PC 135° = −36° ± 3.1°; $F(1,4) = 27.69$, $p < 0.05$) as well as a significant task × position interaction effect ($F(3,12) = 10.53$, $p < 0.05$).

The significant interaction was further explored using one sample *t*-tests (test value 0) on the difference between ball and finger judgments for each condition. In the 135° condition, there was a sig-

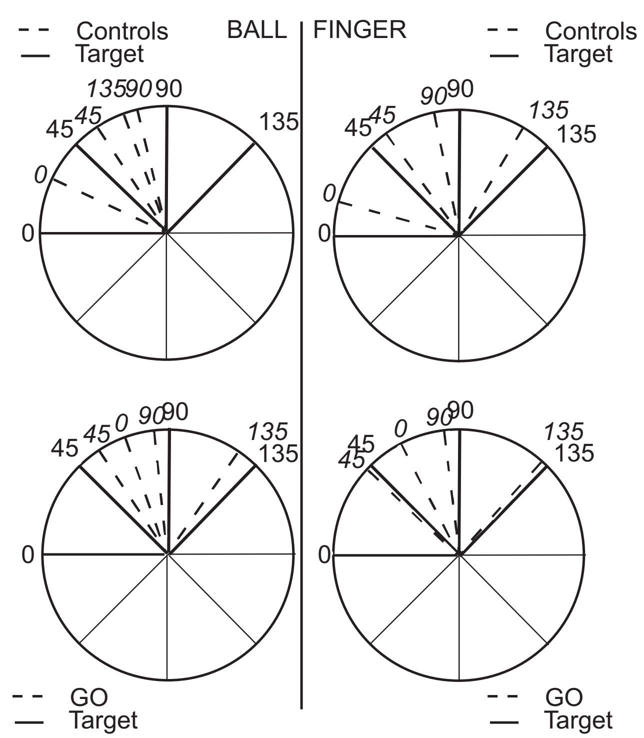

Fig. 5. The average responses in experiment II for both the controls (upper left and right panel) and GO (lower left and right panel). The two left panels are the responses to the tactile stimuli and the right two panels are responses to the finger configuration. The dotted lines represent the answers of the controls and GO and the solid lines the orientation of the stimulus.

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nificant difference in error between the ball and finger judgments (mean difference in error = $-45°$ t (df = 4) = -9.391, $p < 0.0125$), whereas this was not so for the other positions (mean differences in error at PC 0° = 11° ± 9°; PC 45° = 2° ± 8°; PC 90° = $-8°$ ± 5°). These results are a replication of the results of the study by Benedetti (1985).

3.3.4.2. GO. Visual inspection of the data (see Fig. 5) reveals that most aspects of GO's performance on the finger judgement task are within normal ranges. Indeed, for the PC 45°, 90° and 135° we failed to observe significant differences between performance of GO and that of the healthy controls (PC 45°: GO finger = $-2.3°$ ± 14°; control finger = 9.6° ± 12°), t (df4) = -0.872, $p = 0.432$; PC 90°: GO finger = -8.75 ± 10°; control finger = $-11.6°$ ± 22°, $p = 0.913$; PC = 135°: GO finger = $-3.75°$ ± 9°; control finger = $-14.1°$ ± 12°, $p = 0.243$). However, when judging the relative position of the finger in a horizontal position (PC 0°: GO's performance deviated from that of the healthy controls (GO = 62° ± 8°); control = 16° ± 14°, t (df = 4) = 4.516, $p < 0.05$).

Furthermore, visual observation of the ball condition data suggests that she is able to perform the task, except for the horizontal position. However, comparison of her performance in this horizontal position (PC 0°) to that of the healthy controls, failed to confirm a significant difference (GO = 57° ± 3/control = 25° ± 14°, t (df = 4) = 1.982, $p = 0.118$). In fact, the performance of the age matched controls in the horizontal position in the ball condition, yields more error than one would expect from the most "simple" position condition (Ball condition, LH = 41°, NO = 18°, KL = 8°, MT = 20°, MA = 40°; group mean (25.35) differs significantly from 0° t (df = 4) = 3.921, $p < 0.05$).

Her performance in the 45° and 90° conditions was similar as compared to the healthy control participants (PC 45°: GO = 25° ± 15°; control = 12 ± 9°, t (df = 4) = 1.359, $p = 0.246$; PC 90°: GO = $-6.8°$ ± 8°; control = $-20°$ ± 13°, t (df = 4) = 0.916, $p = 0.411$). Most strikingly, her performance in the 135° condition appears to be closer to the veridical orientation compared to the healthy controls. That is, the healthy control subjects judged the ball to be at a 76° position instead of 135° (error of $-59°$ ± 4°), whereas GO was able to perform more accurately in this condition (error of $-11°$ ± 10°). Her lower amount of error was further confirmed by a significant difference between her performance and that of the healthy controls (t (df = 4) = 11.393, $p < 0.001$).

4. Discussion

In two experiments we investigated how a patient with finger agnosia (GO), who is impaired in identifying which finger is touched, performed on two tasks that depended on implicitly keeping separate tactile information applied to different fingers. Despite her inability to distinguish between her fingers, GO was able to distinguish between line segments simultaneously touched by her fingers as she did not significantly differ from healthy controls in a haptic search experiment. Similar to the controls, she benefitted from a position where the fingers were aligned. That allowed her to integrate the perceived line stimuli into one coherent object. Furthermore, in a second experiment, GO was able to judge the position of a tactile stimulus presented to a finger (small ball) relatively to a second stimulus to the adjacent finger (sharp pin). To our surprise, GO performed better than controls in the fingers crossed position.

In order to perform these tasks, tactile information processed by a finger needs to be combined with proprioceptive information about the position as well as other metric properties of that finger. This requires the capacity to distinguish between the fingers, albeit at an implicit level. As such, the suggested fusion of the fingers (Kinsbourne & Warrington, 1962) cannot be explained by a misinterpretation of tactile and proprioceptive information at a lower level. And even so, it seems that GO's finger agnosia is not caused by minor disruptions of low-level somatosensory processing.

A surprising finding in our second experiment might provide further insight on the aetiology of finger agnosia. In experiment II GO was not hampered by the crossed finger condition when judging the spatial position of the tactile stimulus (small ball), relatively to a reference stimulus (sharp pin). In line with Benedetti's observations (1985, 1988) our age matched controls perceived the location of the small ball during a fingers crossed position, as if the fingers were uncrossed. Benedetti explained this illusion by suggesting that the tactile perceptual system is limited and unable to detect the veridical information when the fingers are crossed beyond the borders of functionality.

Our observations can be further explained within an elegant model of somatoperceptual information processing (Longo, Azañon, & Haggard, 2010). In their article the authors describe somatosensory processing along three types of body representations: a superficial schema, a model of body size and shape, and a postural schema. In order to judge the spatial position of the ball relatively to that of the sharp pin, at first one needs to locate the touch on the body surface, which is subserved by the superficial schema. Thus, tactile information is initially coded in a somatotopical map of skin coordinates. Subsequently, the configuration of the joints needs to be calculated and scaled along information about the body size and shape. The rescaling process implies that tactile location is converted from a somatotopic reference frame, to an external one, a sequence that has been demonstrated for the arms and legs (e.g. Azañon & Soto-Faraco, 2008; Overvliet, Azañon, & Soto-Faraco, 2009; Schicke & Röder, 2006; Yamamoto & Kitazawa, 2001). In some cases this remapping process fails, as is the case in the crossed fingers condition in Benedetti's experiment.

In general, uncommon body postures affect basic somatosensory processes in such a way that the sensory information is processed as if the bodily posture was normal. Indeed, Yamamoto and Kitazawa (2001) suggested that the brain has a default condition that assumes that body parts are rarely crossed. In their experiment participants, were required to judge the temporal order of two subsequently applied tactile stimuli (stimulus interval range 0–1500 ms) to the left and right hand, with their eyes closed. Responses were made by lifting the finger of the hand that was tapped first, or in the second half of the experiment, second. The results showed that when crossing the hands, many subjects reported inverted judgments at intervals up to 200 ms. The authors concluded that these speeded temporal order judgments were made before the actual external location of the body part is incorporated in the remapping processes. The judgements are made on basis of a "normal postural situation"; left hand in the left hemifield, right hand in the right hemifield. When more time is separating the two stimuli, the postural schema can be updated with the new postural position (left hand on the right and vice versa) and correct answers are given.

Overall, the results of Benedetti's experiments revealed a very strong influence of this normal posture which Longo et al. (2010) indicated as "canonical posture" or "default posture". Even though healthy controls were entirely aware of their fingers being crossed, they still perceived the tactile stimuli as if the fingers were uncrossed. Therefore it seemed as if there was a "reluctance" to update the postural schema with the crossed fingers position. This illusory feeling of uncrossed fingers is known as the "Aristotle illusion" and already described by Tastevin (1937), who explored the range of this illusion for other body parts (lips, tongue, face, etc.). Recent experiments in our lab, in which participants were

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asked to judge the direction in space of two subsequently applied above threshold tactile stimuli to the finger tips, indeed revealed that crossing fingers always resulted in reversed left/right spatial direction judgements (de Haan, Anema, Nijnens, & Dijkerman, unpublished). In contrast to the above described crossing arms experiments where the reversal effect decreased in strength (more correct answers) for intervals longer than 200 ms, the proportion of incorrect answers in the fingers crossed condition remained even when the interval between the stimuli was as long as 750 ms (stimulus intervals ranged from 15 ms to 750 ms). It appears that remapping from an anatomical representation to a spatial one does not occur, not even in long stimulus intervals. A common explanation for this effect is that in a finger crossed and hands crossed position, there is no functional need for remapping as these positions rarely occur, or remapping is less common and therefore less practiced. However, as GO was able to perform the task with crossed fingers, she clearly showed that a remapping process occurred. The following explanation might provide further insight in this observation.

As is commonly accepted, perception is influenced by common prior knowledge stored in our long-term memory. Therefore, perception with crossed fingers may be biased by built-in prior knowledge about frequent tactile-proprioceptive co-activation, which entails that "fingers are rarely crossed". Possibly, GO's stored knowledge about common somatosensory co-activation with respect to the fingers has become inaccessible as a consequence of her lesion, resulting in a more accurate performance when the fingers were crossed. Perhaps the disruption in accessing knowledge about common somatosensory co-activation is general for the entire body and not merely restricted to the fingers. However, such reasoning needs further investigation.

Some specific aspects of her performance require further discussion. In Experiment II, GO clearly misjudged the positions of both the ball and the finger in the horizontal condition (0°) as being almost above the reference, instead of next to the reference. Surprisingly, performance of the age-matched controls revealed a similar, though smaller, overestimation of the angle required to reach the position of the ball stimulus. GO's performance has a bias in the same direction, but with increased magnitude. Nevertheless, her general performance is not random. This implies that she is able to process tactile information and combine it quite accurately to propropioceptive information unique for the touched finger. Unfortunately, our data cannot provide any insight in the underlying mechanism of the observed results of the horizontal position condition. Benedetti (1985, 1988, 1991) never included a horizontal position condition in his studies, so no comparison of specific outcome for that condition is possible. As such, this can be regarded a new and interesting phenomenon that requires further investigation in healthy controls.

In sum, the observed results suggest that GO, a patient who suffers from finger agnosia, can distinguish between tactile input from different fingers and make comparisons between them, when it does not require explicit identification of the stimulated finger. It seems that GO's finger agnosia is not caused by minor disruptions of low-level somatosensory processing. Furthermore, the fact that her performance with crossed fingers in experiment II is most likely not hampered by prior knowledge about a prototypical finger configuration provides for more insight in the aetiology of finger agnosia. Perhaps finger agnosia is partly caused by a selective impairment in the accessibility or activation of stored perceptual representations of the fingers or of the body in general. However, this hypothesis needs more investigation and as such we conclude that in general our findings further underpin the idea of a selective impaired higher order body representation restricted to the fingers as underlying cause of finger agnosia and are of importance in explaining the cognitive representations of the body.

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