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Haptic shape perception deficit in spatial neglect is improved by Prism Adaptation

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Abstract

Neglect manifestations are typically explored in the visual modality. Although they are less commonly investigated tactile deficits also exist, and the aim of this study was to explore neglect in this modality. A haptic object discrimination task was designed to assess whether or not shape perception is impaired in right brain damaged patients with or without neglect. Each patient's performance on the object discrimination task was assessed before and after a brief period of prism adaptation, a bottom-up rehabilitation technique known to improve neglect symptoms. The results suggest that a haptic deficit – in the form of substantially more left errors – is present only in patients with neglect. Following prism adaptation, the left bias error rates in neglect patients were substantially reduced, and were similar to those observed in patients without neglect. Moreover, the haptic processing of the right side of objects also improved slightly. This finding suggests an expansion of the effects of prism adaptation to the unexposed, tactile modality supporting the cross-modal central effect hypothesis.

Prisms adaptation improves haptic object discrimination in hemispatial neglect.

Introduction

Spatial neglect, described more than a century ago (Anton, 1899; Balint, 1909; Zingerle, 1913; and Babinski, 1914) is characterized by a failure to respond to or orient towards novel or meaningful stimuli positioned on the side opposite the lesion (Heilman, 1985; Halligan *et al.*, 2003; Cubelli, 2017), without any primary sensory or motor deficits (Heilman, 1979; Kerkoff, 2001). A typical space-oriented behavioural disorder biased towards the right occurred, due to the predominance of right hemisphere lesions (Heilman, 1993; Vallar & Calzolari, 2018). Spontaneous recovery is frequent in the first 2-3 weeks following stroke (Hier *et al.*, 1983; Stone *et al.*, 1992; Cassidy *et al.*, 1998). Nevertheless, about 30% of patients still exhibit deficits three months post stroke, resulting in a chronic disorder (Levine *et al.*, 1986; Cassidy *et al.*, 1998; Cherney & Halper, 2001). The challenge to find rehabilitation methods that can alleviate neglect symptoms is all the more difficult given the wide range of clinical features observed in patients (see for review, Bisiach & Vallar, 1988). Neglect is most often depicted as a visual disorder affecting, for example mental imagery tasks (Bisiach & Luzatti, 1978; Rode *et al.*, 2001, 2007), and inducing debilitating effects on everyday life activities (Frassinetti *et al.*, 2002; Mizuno *et al.*, 2011) like wheelchair driving (*e.g.* Jacquin-Courtois *et al.*, 2008), and walking (Turton *et al.*, 2009). In the sensory domain, auditory (*e.g.* Bisiach *et al.*, 1984; Pavani *et al.*, 2004; Jacquin-Courtois *et al.*, 2010; Gutschalk & Dykstra, 2015), olfactory (Bellas *et al.*, 1988) and somatosensory (Maravita *et al.*, 2003; Dijkerman *et al.*, 2004) deficits remain much less studied and may appear less disabling than visual deficits (Gainotti, 2010). In the tactile modality, in the absence of vision, patients show a lack of awareness of tactile inputs delivered to the side of the body opposite the brain lesion, *i.e.* tactile neglect. These manifestations occur when stimulating skin mechanoreceptors, *i.e.* when stimuli are applied to the body surface, such as during tactile perception or pressure sensitivity tasks (Maravita *et al.*, 2003; Dijkerman *et al.*, 2004; Serino *et al.*, 2007), and during upper limb proprioceptive tasks, resulting in a position sense deficit (*e.g.* Vallar *et al.*, 1993). Deficits have also been reported when patients are engaged in a manual search task in extrapersonal space (De Renzi *et al.*, 1970; Chédru, 1976; Beshin *et al.*, 1996; Revol, 2000). In their seminal paper, De Renzi *et al.* (1970) asked right brain damaged patients to find a marble placed in the lateral arm of a maze hidden behind a

35 curtain. They found that neglect patients were slower and often missed the marble when it was
36 placed in left space, suggesting a supramodal disorder of space representation (De Renzi *et al.*,
37 1970). This error cannot be accounted for by a tactile or kinaesthetic perception impairment
38 because the left part was properly explored in blindfolded neglect patients (Villardita *et al.*,
39 1987). Even healthy controls may exhibit left errors in this task (Beshin *et al.*, 1996). So called
40 “tactile line bisection” tasks have also been used with neglect patients, but have failed to detect
41 any evidence of neglect phenomena (Fujii *et al.*, 1991; Hjaltason *et al.*, 1993), probably because
42 of the use by patients of a counting strategy (*e.g.* Hatta & Yamamoto, 1986; McIntosh *et al.*,
43 1999).

44 Haptic perception relies on the stimulation of mechanoreceptors through object
45 manipulation, in order to identify an object or one of its components (*e.g.* size, shape, *e.g.*
46 Gibson, 1962). Some haptic tasks, focusing on haptic orientation, have been developed in order
47 to explore haptic impairments in unilateral neglect (Gentaz *et al.*, 2002; Rousseaux *et al.*, 2015).
48 To our knowledge, no information is available about whether haptic shape perception (or
49 object-based perception) is perturbed in unilateral neglect. McIntosh *et al.*, (2002) performed a
50 related study trying to investigate part of this question with a haptic spatial judgement in
51 peripersonal space. In a blindfolded neglect patient, they used a haptic circle-centering task and
52 found a rightward shift compared with the true centre (McIntosh *et al.*, 2002). However, this
53 task can be viewed as a two-dimensional analogue of the visual bisection task, and the bias
54 observed could be ascribed to the perception of either the shape or the size of the circle, to the
55 computation of its centre, or to the proximal component of the pointing movement required to
56 indicate the centre (Girardi *et al.*, 2004). The first aim of our study was therefore to specifically
57 test for the existence of haptic neglect in right brain damaged patients, using a newly developed
58 haptic shape discrimination task. In order to perform the task it is necessary to integrate
59 information from the distal parts of the body touching the object with information about the
60 position of the body segments in space. Thus, the task depends on spatio-temporal integration
61 of tactile and kinaesthetic inputs (Gentaz *et al.*, 2008). This reconstructed representation of the
62 stimulus shape could be impaired in neglect patients. We asked our patients to perform this task
63 with their right healthy hand in order to exclude any primary somatosensory deficits, *e.g.* a
64 tactile deficit, or motor deficits. Using the right hand, connected to the left hemisphere, we can
65 ensure that any deficits can be attributed to impairment in high level processing of haptic signals,
66 in particular spatial cognition functions located in the right hemisphere.

67 Twenty years ago, rehabilitation using Prism Adaptation (PA), a visuo-motor adaptation
68 with glasses inducing a rightward optical deviation of the visual field and modifying visuomotor

69 transformations, was shown to improve unilateral neglect (Rossetti *et al.*, 1998) and related
70 aspects of spatial cognition (Jacquin-Courtois *et al.*, 2013; Michel, 2016; Rossetti, Nijboer, &
71 Kitazawa, 2019). Several studies using this bottom-up strategy have shown an improvement of
72 hemispatial neglect in visuo-motor tasks, but also in non-motor and non-visual tasks, suggesting
73 an expansion of prism adaptation to sensory, motor and cognitive systems (Rossetti *et al.*, 2004;
74 Rode *et al.*, 1999; 2001; Tilikete *et al.*, 2001; Jacquin-Courtois *et al.*, 2010; Angeli *et al.*, 2004;
75 Watanabe & Amimoto, 2010). The second aim of our study was to test whether this procedure,
76 known to act on higher-level cognitive processes, could also improve haptic shape
77 discrimination in neglect and right brain damaged patients without neglect.

78

79 Material and Methods

80

81 *Patients and right brain damaged controls*

82 Three consecutively enrolled right brain damaged patients with neglect (RBD+, 1 male
83 and 2 females; 66, 38 and 70 years old) participated in this study. The inclusion criteria were:
84 i) one cerebral lesion affecting the right parietal lobe; ii) left neglect; iii) absence of
85 somatosensory deficits in the hands. Four consecutively-enrolled right brain damaged control
86 patients without neglect (RBD-, 1 male and 3 females; 77, 72, 72 and 58 years old) were also
87 included. All patients had no history or evidence of previous neurological or psychiatric
88 disorders, or dementia. All patients were right handed as assessed with the Edinburgh
89 Handedness Inventory (Oldfield, 1971), and gave their informed consent prior the study.

90 The presence of unilateral neglect was assessed using three different tests: i) a scene
91 copying test adapted from Gainotti *et al.* (Gainotti *et al.*, 1972); ii) a star cancellation test
92 (Wilson *et al.*, 1987); iii) a line bisection test where the patient had to mark the center of a 20
93 cm line with a soft pen. The length of the left side of the line was measured to the nearest mm.
94 Marks placed on the right of the true centre yielded positive values while those placed on the
95 left yielded negative values. The inclusion criteria for neglect patients were: at least 2 items
96 omitted in the left part of the drawing in the scene copying test; a rightward line bisection bias
97 larger than 10 mm; and at least 5 omissions in the star cancellation test (Halligan *et al.*, 1990).

98 On the date of data collection all patients had been admitted to a neurological
99 rehabilitation unit for treatment of left hemiplegia. Clinical features and CT-scan data are
100 described in Table 1.

101 CT or MRI allowed us to map lesions of RBD patients. All patients showed a rather
102 extensive unilateral lesion. Aetiology was always vascular, ischaemic in 4 cases and

103 haemorrhagic in the 3 other cases. The RBD⁺ lesions were drawn on a standard MRI template
104 with a 1-mm slice distance (voxels of 1mm³) using MRIcro software (Rorden and Brett, 2000,
105 www.mricro.com). This procedure required us to adapt the standard template to each CT/MRI
106 patient's orientation. Subsequently, each lesion was manually drawn on the corresponding
107 adapted template and, finally backtranslated, in order to return to the parameters of the original
108 MRI template. Figure 1 shows the lesions of each neglect patient, and the lesion overlap of the
109 three RBD⁺ patients as well as that of the four right RBD⁻ patients. Overall, lesions were more
110 extensive in the RBD⁺ group (mean lesion volume 134.94cc±59.03; range 98.46-203.05cc)
111 than in the RBD⁻ group (mean lesion volume 50.75cc±53.21; range 2.23-119.37cc). This is
112 in agreement with larger samples of patients (Hier *et al.*, 1983; Lebovitch *et al.*, 1998; Mancini
113 *et al.*, 2011). In the RBD⁺ group, the maximum overlap was in an area in the white matter on
114 the right parietal lobe. In the RBD⁻ group, the maximum overlap (in 3 out of 4) was more
115 anterior, in the internal capsule and the lenticular nucleus.

116

117 *Neglect patient histories*

118 RBD⁺1, a 38 year-old woman, was admitted to a neurological unit for sudden right
119 cervico-occipital cephalalgia. An MRI scan revealed a subarachnoid haemorrhage with fronto-
120 parietal haematoma, and an aneurysm of the horizontal portion of right middle cerebral artery.
121 After surgery, the patient had left hemiplegia and left visuo-spatial neglect, anosognosia, but
122 no motor or sensory deficits in the left hemibody, nor sensory extinction.

123 RBD⁺2, a 66-year-old man, was hospitalized for a thrombosis of the central artery of the
124 right retina, during surgery he had a stroke. A CT scan showed an ischaemic lesion of the right
125 hemisphere leading to left hemiplegia and left visuo-spatial neglect. The patient did not show
126 any motor or sensory deficits in the left hemibody. The patient exhibited auditory and visual
127 extinction,

128 RBD⁺3, a 70 year-old woman, was admitted to the neurological unit for a sudden onset
129 of left hemiplegia, left lateral homonymous hemianopia and left unilateral neglect. The CT scan
130 revealed a right parieto-occipital haematoma inducing left neglect, left hemianopia,
131 anosognosia, and constructive apraxia. The patient showed no tonic ocular nor cephalic
132 deviation towards the right, no motor or sensory deficits in the left hemibody, nor sensory
133 extinction.

134

135 *Experimental procedure*

136 The patient was seated in a comfortable chair with their right-hand resting on a table
137 and was presented with pairs of objects. A wooden board placed in front of the patient in the
138 midsagittal axis was used to present two objects (4.5 cm diameter; 0.8 cm height) with a 10 cm
139 distance between the centres of each object (see figure 2A). A set of 19 different objects made
140 of thick hard plastic, without any specific texture, was either made with holes or cut in pie shape
141 (see figure 2B). The combination of objects within a pair followed three possible criteria: two
142 identical objects, two objects with a difference on the left (*e.g.* C/A_{inverse}, E_{inverse}/F_{inverse},
143 L/P...see also figure 2A bottom), two objects with a difference on the right (*e.g.*; A/C; E/F, L/E,
144 P_{inverse}/L... see also figure 2A bottom). Objects were randomly presented as followed:
145 top/bottom and then bottom/top (each given object within a pair was presented once in the top
146 position and once in the bottom position). Moreover, for each session and each patient the
147 sequence of the pairs of objects were drawn at random. The blindfolded patient, without visual
148 control performed a haptic discrimination task, had to fully explore the objects successively
149 with his/her right hand. The exploration, performed with the right fingertips (see figure 2A),
150 began either by the top or bottom object in a random order, without any instructed time
151 constraint. The patients was allowed to go back and forth between the two objects. No reference
152 was made to the fact that objects might differ on their left or on their right side. Following this
153 haptic exploration they were requested to verbally report whether the objects were the same or
154 different. This global question enabled the task to be performed without focusing on left vs right
155 issues. The patient never received feedback during the test. The investigator visually ensured
156 that the patient fully explored the objects by two means. First, direct vision of the patient's hand
157 provided a top view perspective. Second, a surveillance camera was added to provide online
158 monitoring of a front-view perspective on the hand and the objects. These were simultaneously
159 displayed on a screen viewed by the experimenter allowing a qualitative assessment of hand
160 movement exploration. As our objects were small and aligned with the midsagittal plane (see
161 figure 2A top) no left object exploration deficit was expected because previous studies revealed
162 a partial exploration on the left hemispace in RBD+ (Karnath and Fetter, 1992; de Renzi *et al.*,
163 1970). This haptic discrimination task was performed twice in two pre-test sessions lasting
164 approximately 45 minutes each, and two days apart. During each session 65 object-pairs were
165 presented, 12 with holes and 53 with pie shapes. In 19 trials, objects were identical, while in
166 the other 46 differences existed either in the left-half side (*e.g.* C/A_{inverse}, E_{inverse}/F_{inverse},
167 L/P...see also figure 2A) or in the right-half side (*e.g.* A/C; E/F, L/E, P_{inverse}/L... see also figure
168 2A). Two days later, a prism adaptation session was administered to the patients. During this
169 period, the subject's head was stabilized in a chin rest, and he/she wore a pair of goggles fitted

170 with wide-field point-to-point lenses inducing a 10° rightward shift of the visual field. The
171 prisms covered a total visual field of 105% in which each monocular field represented 75°,
172 while the central visual binocular field represented 45° (Optique Peter®, Lyon, France). During
173 prism adaptation (PA), patients were requested to point, with fast but comfortable movements
174 with their right hand towards a visual dot, located either to the right or the left of the body
175 midline (10° eccentricity). Fifty pointing movements (i.e. about 2 to 5 minutes) were performed
176 in a pseudo-randomized order towards the two dots (details in Rossetti *et al.*, 1998 or Rode *et*
177 *al.*, 2015). Then the prism glasses were removed. The patient was first asked to point straight-
178 ahead in order to verify the presence of after-effects. We ensured that a minimal 5cm shift was
179 observed between the pre and the post test of adaptation. Then the post-test was performed
180 using the same haptic discrimination task and the same verbal description as during pre-tests.

181 For each haptic discrimination trial, correct responses were given a value of 1 and errors
182 0. For each session, error rates (left half errors and right half errors) were computed as a
183 percentage of the total number of objects explored by each patient. Statistical analyses were
184 conducted with Statistica® 13.1 using non-parametric tests (Mann-Whitney U-test). This
185 statistical analysis was designed to address three main questions: i) are patient's performances
186 different in the two pre-test? ii) does our haptic shape discrimination task detect haptic neglect?
187 iii) does PA improve haptic shape discrimination in unilateral neglect?

188

189 Results

190

191 Qualitative analysis of hand exploration during each test (Pre1, Pre2 and Post PA),
192 monitored by the investigator, revealed no exploration deficit in RBD+ or RBD- patients. Over
193 all patients, errors made for identical objects represented less than 1% of the trials. As they were
194 not informative about left-right asymmetry judgements, they were discarded from further
195 analyses.

196 First, raw data and means for each patient's population and for the two pre-test were
197 reported in figure 3. Left and Right error rates were stable across the two pre-test sessions in
198 RBD+ (Left error rate 25.5 and 23.6 for Pre1 and Pre2 respectively; Mann-Whitney U-test;
199 $Z=0.80$, $p=0.42$; Right error rate 10.8 and 10.3 for Pre1 and Pre2 respectively; Mann-Whitney
200 U-test; $Z=0.44$, $p=0.65$). Stability of results was also observed across the two pre-test sessions
201 for RBD- (Left error rate 14.6 and 13.0 for Pre1 and Pre2 respectively; Mann-Whitney U-test;
202 $Z=0.73$, $p=0.47$; Right error rate 12.0 and 8.3 for Pre1 and Pre2 respectively; Mann-Whitney
203 U-test; $Z=1.46$, $p=0.14$) suggesting test reliability.

204

205 Second, the tactile shape discrimination leads to distinct haptic impairments in patients.
206 The largest effect was a substantial increase in left error rates (as much as 76%) for RBD+
207 patients (Mann-Whitney U-test; $Z=1.98$, $p<0.05$), whereas they behaved like RBD- for the right
208 side differences (Mann-Whitney U-test; $Z=0.53$, $p=0.60$). Unlike RBD+, RBD- patient error
209 rates were evenly distributed across the left and right sides (see Figure 3), suggesting that our
210 shape discrimination task can diagnose haptic neglect.

211 Third, figure 4 shows performance with left as well as right error rates before (Pre1 and
212 Pre2) and after PA for RBD+ and RBD-. After PA, a substantial decrease in left error rates in
213 RBD+ (minus 18%, *i.e.* a relative drop of about 80%) was observed along with a slight decrease
214 (minus 7%) in RBD-. Performance for both groups were no longer statistically different (Mann-
215 Whitney U-test; $Z=0.18$, $p=0.85$) suggesting that RBD+ performances improved to the control
216 level. For the right error rates, RBD+ exhibited a reduction of about 9% while the decrease of
217 about 5% in RBD- without any statistical difference (Mann-Whitney U-test; $Z=0.88$, $p=0.38$).

218

219 Discussion

220 The aim of our study was to assess haptic shape discrimination in right brain damaged
221 patients with or without neglect and to examine the effect of prism adaptation on this task. Our
222 study provides two main new findings. First, three consecutively, included neglect patients
223 exhibited a clearly asymmetric disturbance for haptic shape discrimination, which suggests that
224 haptic neglect may be a common feature in these patients. Second, our results show that prism
225 adaptation can improve haptic discrimination in left neglect patients. In addition, we observe
226 that improvement, although milder, is also observed for right-brain-damaged patients without
227 neglect.

228 Although often thought of as a primarily visual disorder, other sensory modalities, such
229 as somatosensory information, can be also affected (review in Brozzoli *et al.*, 2006). In our
230 original haptic shape discrimination task, patients were asked to evaluate, using their right hand,
231 whether two objects were similar or not, without having to identify them. The error rates were
232 above 10% in right brain damage patients without neglect. The striking result was a
233 substantially higher error rate when differences between objects were on the left-hand side of
234 the objects, up to as much as 76% for these basic shapes, in neglect patients only. Thus,
235 analogous to results found in numerous visual tests in spatial neglect patients (review in
236 Jacquin-Courtois *et al.*, 2013, Rode *et al.*, 2017) a marked lateralized impairment for haptic
237 discrimination was observed. Perception of the spatial properties of an object always involves

238 exploratory movements, depending on the specificity of the touched object (Lederman &
239 Klatsky, 1987). As the haptic system relies on contact between the fingers and the object, one
240 could speculate that our results were due to a tactile misperception, as tactile deficits have been
241 found in neglect patients (*e.g.* Maravita *et al.*, 2004, Dijkerman *et al.*, 2003). However, our task
242 was performed with the right hand, for which tactile perception remains unimpaired (Maravita
243 *et al.*, 2004) due to the integration of the somatosensory inputs in the healthy left hemisphere.
244 Previous studies investigating eye or hand exploratory movements revealed a partially left space
245 exploration in RBD+ (Karnath and Fetter, 1995; De Renzi *et al.*, 1970; McIntosh *et al.*, 2002;
246 Revol 2000). As our haptic-task discrimination task was very close to the sagittal plane, no
247 incomplete object exploration was expected, and nor was it observed. Moreover, our patients
248 were blindfolded, preventing visual cueing effects, known to affect performance (Riddoch &
249 Humphreys, 1983), and thought to be responsible for the rightward bias in the haptic exploration
250 maze test (De Renzi *et al.*, 1970). Taken as a whole, it is unlikely that a disruption of basic
251 sensory-motor mechanisms subserving object exploration account for our results.

252 Since clinical manifestations are observable in non-visual tasks neglect has long been
253 considered as a higher-order disorder of spatial cognition (Bisiach *et al.*, 1981; Rode *et al.*, 2017).
254 The comparison of the two objects entails a spatio-temporal integration of kinaesthetic and
255 tactile inputs generating a representation of the stimulus (Gentaz *et al.*, 2008). Previous studies
256 have shown that neglect patients often exhibit representational neglect: a failure to report details
257 from the left side of mentally visualized images (Bisiach & Luzatti, 1978; Rode *et al.*, 2007).
258 One cannot exclude that the observed haptic spatial orientation deficits (Gentaz *et al.*, 2002;
259 Kerkhoff, 1999, Utz *al.*, 2011) could also be due to a mental imagery deficit. Therefore, an
260 impairment of high level processing of haptic signals leading to a mental representation of the
261 stimulus, *i.e.* a spatial cognition function known to occur in the right hemisphere, may also be
262 responsible for haptic shape discrimination deficits. Further investigations should explore
263 whether the haptic deficit is correlated with a mental imagery deficit and whether this imagery
264 is visual.

265 The parietal cortex is a multimodal area related to space representation (Huang & Serino,
266 2018) and orientation of spatial behaviour (Jeannerod, 1988) essential for haptic shape
267 processing. Recent fMRI studies revealed an activation of the right parietal lobe when healthy
268 subjects were asked to perform a haptic perception task (Van Boven *et al.*, 2005; Masson *et al.*,
269 2016). The overlapping lesion site in the parietal cortex in our three neglect patients seems
270 compatible with these results. However, as expected, our RDB+ patients tend to have larger
271 lesions than RDB- patients (Hier *et al.*, 1983; Leibovitch *et al.*, 1998; Mancini *et al.*, 2011), and

272 they also actually perform worse. Further studies with larger patient samples should specifically
273 address this issue and investigate the potential relationship between lesion site and/or size and
274 haptic deficits.

275 Finally, this haptic shape discrimination test appears to be reliable for assessing haptic
276 neglect with a left/right error rates asymmetry, as well as a haptic deficit in RBD patients
277 without neglect but with symmetrical error rates. This haptic test provides further support for
278 the argument suggesting that spatial neglect is a multisensory deficit (review in Jacobs *et al.*,
279 2012). Another new finding in the present study is that prism adaptation induced a clear
280 improvement in haptic neglect, with a substantial decrease of left error rates representing a
281 relative drop of about 80%. As discussed above regarding the two pre-test sessions, visual
282 control of exploratory movements failed to reveal any asymmetrical exploration movements or
283 over-exploration of the left side of the object, ensuring that the circumference and the surface
284 of the object was fully explored before the verbal response was made. In the RBD- group,
285 performance was already close to normal in the two pre-test sessions, making it difficult to
286 observe substantial improvement after PA. Our data show that initially impaired RBD+
287 performance reached control levels, *i.e.* RBD- performance, after PA. This further demonstrates
288 that prism adaptation can improve shape processing in a non-exposed modality. We cannot
289 exclude that a practise effect may potentially contribute to the pattern of results observed here
290 as the patients performed the task for the third time. The influence of practice was, however,
291 minimized by using a sequence of random pairs of object for each session and each patient.
292 Furthermore, performance varied by less than 3% between the two pre-test sessions while it
293 reached a magnitude of 15% between the second and third haptic tests in RBD+. To date, the
294 few studies investigating the effect of PA on tactile manifestations of neglect have shown an
295 improvement in the left hand of tactile extinction (*e.g.* Maravita *et al.*, 2003, Serino *et al.*, 2007),
296 pressure sensitivity and proprioception (Dijkerman *et al.*, 2004). Positive results of PA on a
297 haptic spatial judgement task have also been found both in a chronic neglect patient (McIntosh
298 *et al.*, 2002) and in healthy subjects (Girardi *et al.*, 2004), suggesting that PA affects higher
299 cognitive functions. Due to a uniform shift of the visual field, prism exposure is supposed to
300 manipulate the body-space interface in egocentric coordinates, as evidenced by the after effects
301 with a leftward shift in the straight ahead pointing tasks (Rossetti *et al.*, 1998, Sarri *et al.*, 2008).
302 In our haptic discrimination task one can postulate that objects must be compared one to another
303 using an object-centred frame of reference, which is affected in RBD+ (Ota *et al.*, 2001), and
304 which can also be influenced by PA treatment. It remains to be explained how such egocentric
305 manipulation may alter object-centred perception of shape in the haptic domain, knowing that

306 some visual object-centred tasks appear not be improved by PA (Sarri *et al.*, 2006). In our
307 experimental design, these two frames of reference may be confused, because objects are
308 aligned in the midsagittal plane. Therefore the impairment of high-level processing of haptic
309 signals can be linked either to a deficit of space representation (Bisiach & Luzzatti, 1978; Rode
310 *et al.*, 2001), or to a deficit of object representation (*e.g.* Ota *et al.*, 2001). Further studies should
311 address this issue, for example, by placing the object in different space locations. It is also worth
312 noting that we observed a milder improvement in right brain damaged patients without neglect,
313 suggesting that the cognitive effect of PA is not restricted to patients with unilateral neglect
314 (Tilikete *et al.*, 2001; Sumitani *et al.*, 2007; Jacquin-Courtois *et al.*, 2017), in accordance with
315 previously reported results in healthy subjects (Colent *et al.*, 2000; Berberovic & Mattingley,
316 2003; Girardi *et al.*, 2004). Finally, the slight improvement on the right error rates in all right
317 brain damaged patients suggests that PA enlarges the mapping of space not only on the left side,
318 but also on the right side, as has already been described for visual imagery (Rode *et al.*, 2001).

319 Numerous studies have shown that PA improves visuo-motor, non-motor, and also non-
320 visual tasks in unilateral neglect suggesting an expansion of PA to spatial cognition (review in
321 Jacquin *et al.*, 2013, Rode *et al.*, 2017). This “bottom-up” rehabilitation, which bypasses central
322 awareness of the deficit, might influence higher-level supramodal representations associated
323 with spatial attention rather than being limited to low-level sensori-motor re-mapping.
324 Moreover, this procedure seems to interact with higher other brain functions related to
325 multisensory integration and can have beneficial effects on sensory processing in different
326 modalities, supporting the hypothesis of cross-modal central effects. This intersensory
327 generalization of PA effects calls for further research in order to explore the mechanisms of
328 transfer and expansion to unexposed tasks.

329
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334

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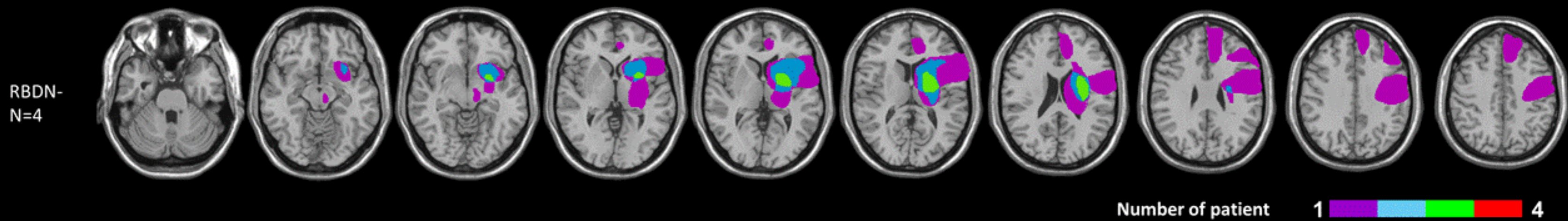
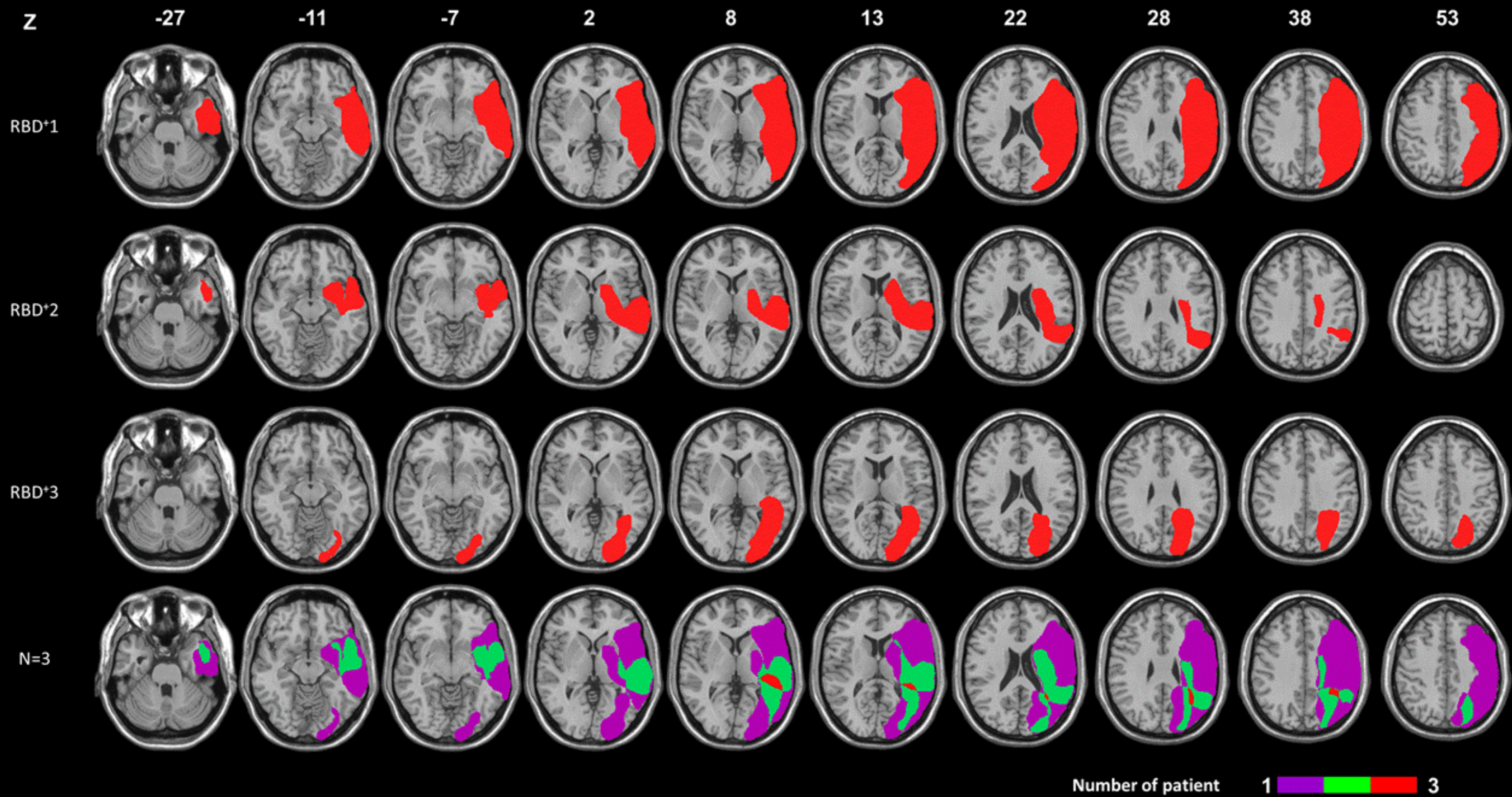
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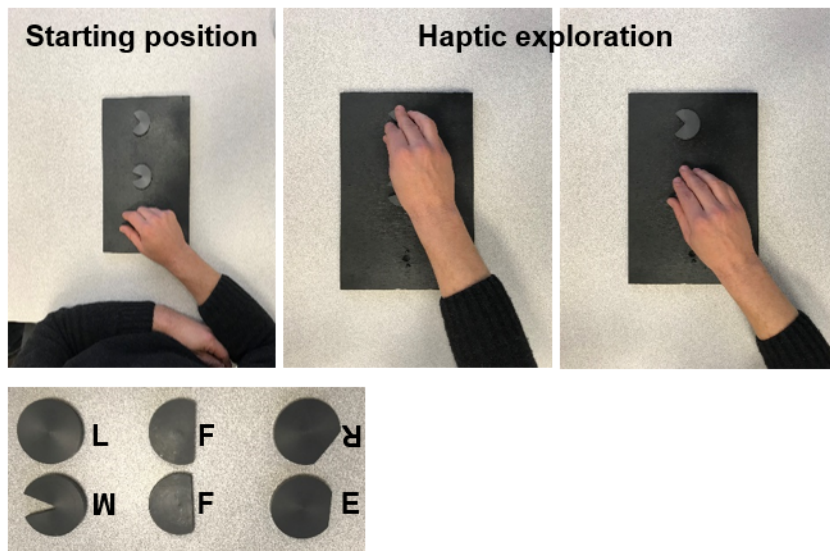
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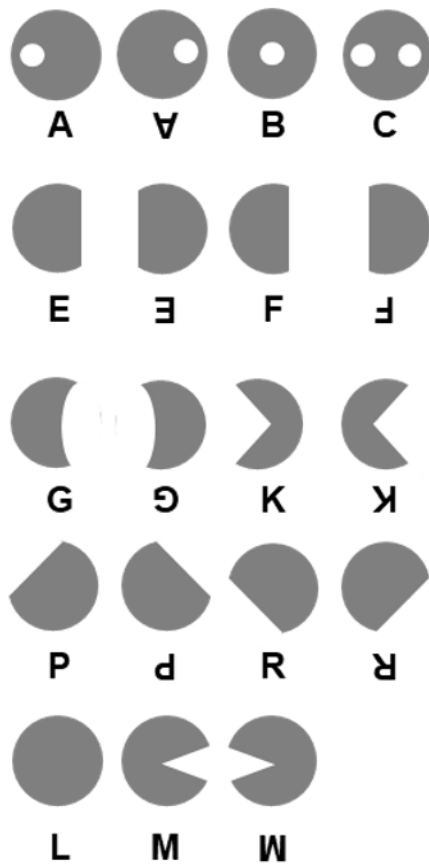


Figure 3

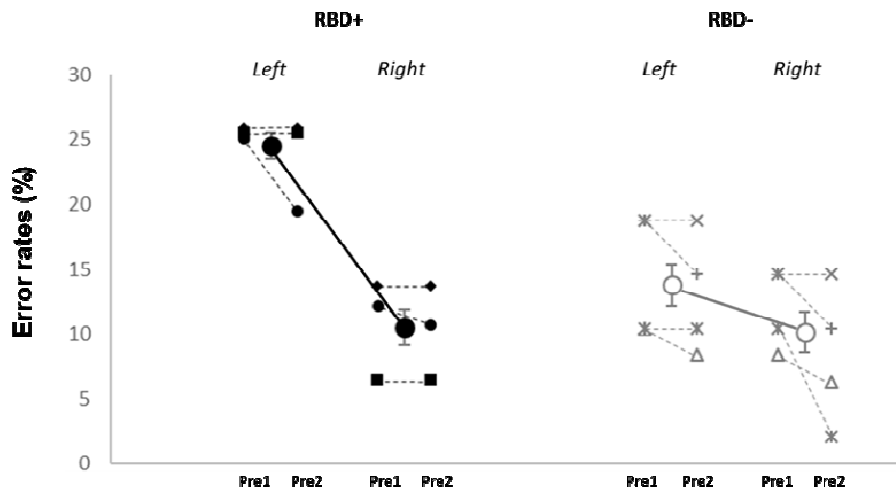
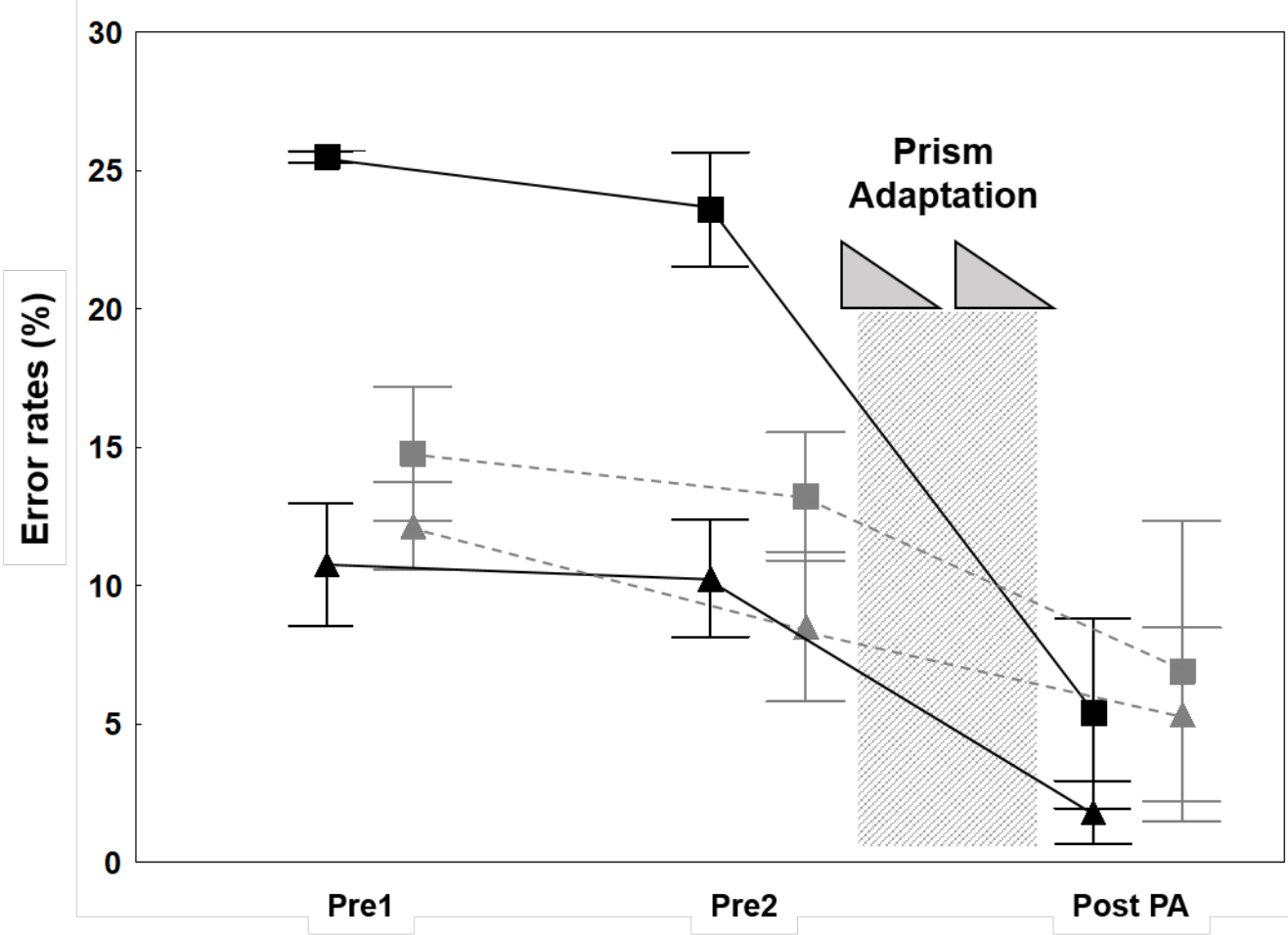


Figure 3: Raw error rates and mean (%) \pm SEM, in the haptic test performed by RBD+ (black) and RBD- (grey) in the two pre-test sessions (Pre1 and Pre2). **Left and Right refer to the sides of the object.** A huge increase of left side errors is visible in RBD+, who produced more than 120% more errors on the left as compared to the right, whereas in RBD- this ratio was only 30%.



Patients	Gender/Age	Lesion	Etiology	Days post stroke	LHH	Gainotti drawing	Star cancellation test omissions	Line bisection in mm
RBD+1	Female/38	Fronto-Parietal	Haemorrhagic	30	n	2	15**	19
RBD+2	male/66	Parietal-lenticular	Ischemia	31	n.a	3	11**, 2*	24
RBD+3	female/70	Parieto-Occipital	Haemorrhagic	30	y	2	7**, 2*	62
RBD-1	female/72	Capsulo-lenticular	Haemorrhagic	32	n	5	0	-10
RBD-2	female/72	Pontic infarct paramedian	Ischemia	35	n	5	0	12
RBD-3	female/58	Fronto-Parietal	Ischemia	28	n	4	1**, 1*	5
RBD-4	male/77	Capsulo-lenticular-cingular gyrus	Ischemia	31	n	5	2**, 2*	9