Cogn Process (2012) 13 (Suppl 1):S329–S332
DOI 10.1007/s10339-012-0505-5

SHORT REPORT

Spatial navigational impairments in hydrocephalus

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Published online: 18 July 2012

Abstract Whilst much is known about the neuropathological consequences of hydrocephalus, there have been comparatively few studies of the cognitive impairments associated with it. Studies using standardised tests of cognitive function have identified a general pattern of impairments, with patients exhibiting particular difficulty on tests of spatial memory and executive function. A strong prediction is that these deficits are likely to affect daily wayfinding behaviour, and we report a study of spatial and navigational abilities in a group of patients with hydrocephalus but without spina bifida. Participants completed a range of experimental tasks assessing spatial cueing behaviour, landmark memory and route-learning, and idiothetic path integration. This patient group was compared to a control sample matched on verbal, spatial, and intelligence measures, and hydrocephalus was found to be associated with relative impairments in each of the tasks. Patients exhibited reduced sensitivity to spatial cueing, less accurate route-learning, poorer memory for landmark objects, and less accurate spatial updating (with particular impairments in the calculation of heading). Overall, these data represent the first empirical demonstration of navigational impairments in hydrocephalus, and we suggest some of the cognitive, neural, and individual differences factors that may contribute to the pattern of performance reported.

Keywords Hydrocephalus · Navigation · Spatial cognition

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Introduction

Hydrocephalus is characterised by an increase in CSF volume, which leads to ventricular swelling that exerts widespread pressure across the brain. The condition causes damage to both cortical and subcortical structures, with posterior brain regions generally being more severely affected than anterior regions (Fletcher et al. 2000). Whilst much is known about the neuropathological consequences of the condition, there have been comparatively few insights into the cognitive impairments associated with it. Studies using standardised tests of cognitive function have identified a general pattern of deficits, with patients exhibiting particular difficulty on tests of spatial memory and executive function (Iddon et al. 2004). Although such findings are illustrative, it is unclear how these difficulties might impact upon more concrete everyday behaviours. A strong prediction is that these deficits are likely to affect daily wayfinding behaviour, and we here report a study of spatial and navigational abilities in a group of patients with hydrocephalus.

Only one previous study has explicitly addressed spatial navigation in patients with hydrocephalus: Wiedenbauer and Jansen-Osmann (2006) asked 18 children with spina bifida (of which 17 had concomitant hydrocephalus) to learn a route around a virtual maze containing landmarks and then required them to re-trace the route with landmarks removed. Compared to a healthy matched sample, the patient group demonstrated impaired route memory but intact landmark recall. It is, however, difficult to interpret these findings in terms of the deficits related to hydrocephalus as it has been reported that mobility from an early age is crucial for the development of spatial ability (Stanton et al. 2002). As a result, it is possible that reduced mobility in spina bifida affects the normal development of spatial abilities, which means that the deficits in route learning reported by Wiedenbauer and Jansen-Osmann (2006) could be a consequence of spina bifida, hydrocephalus, or a combination of both.

In the present study, we tested a group of hydrocephalus patients, without spina bifida and with full motility, on a series of experimental tasks that assessed different aspects of spatial and navigational behaviour. Taking them in turn, we first assessed spatial learning in a probability cueing search task, where the likely location of the target was statistically defined over the course of the experiment (see Pellicano et al. 2011; Smith et al. 2010a). Second, we measured route learning and landmark memory in a task similar to that of Janzen (2006): participants observed a route through a virtual environment and then completed a recognition memory task for landmarks encountered along it. Finally, path integration abilities (i.e. spatial updating by idiothetic means) were tested in a triangle completion task (Loomis et al. 1993; Smith et al. 2010b): participants were blindfolded, led two legs of an imaginary triangle, and were required to complete the hypotenuse without vision. This selection of tasks covers a range of abilities that are necessary for efficient navigation, with both visual and kinaesthetic components.

Method

$N = 15$ hydrocephalic volunteers (mean age: 28.9 years; range 20–34 years) participated in the study, and all individuals had received surgical intervention to relieve ventricular pressure. Eleven members of the patient group had been diagnosed with congenital hydrocephalus, whilst four had acquired hydrocephalus at the ages of 10, 15, 16, and 21 years. Patients were compared to a control group (mean age: 16.8 years; range 7–34 years) matched on measures of verbal memory (digit span), spatial memory (corsi span), and fluid intelligence (Raven's Progressive Matrices).

In the spatial learning task, participants were presented with a search array of concentrically arranged squares displayed on a monitor. Some of the squares were coloured green, and participants were required to click on each green square, using a computer mouse, until they had located the hidden target item (i.e. the green square that changed to red when activated). The target was always present on each trial, although the spatial distribution of targets was manipulated so that they appeared on one side of the array for 80 % of trials. In the route-learning task, participants observed an animated route through a virtual environment. Along the route were landmarks, half of which being placed at decision points (junctions) and the other half at non-decision points (corners or corridors). Following observation of the short route, participants were presented with a surprise object recognition task, containing all landmark items and an equal amount of matched distractor items, and were required to state whether they had encountered each landmark on the route. They were also asked to draw the route on a plan view of the environment. Finally, in the path integration task, participants were blindfolded and wore ear defenders, so that their perceived spatial location was not influenced by vision or ambient noise. The experimenter then led them along Leg 1 (1 or 2 m), turned them 90° (left or right), and led them along Leg 2 (1 or 2 m). Participants were then required to return unaided to the starting position along the hypotenuse of the triangle. The endpoint of their return vector was recorded to give a measure of both distance and heading estimation.

Results

Hydrocephalus patients performed less efficiently than controls on each of the experimental tasks, and there was no difference between congenital and acquired patients on any of the measures. In the spatial learning task, patients were less likely to modify their search behaviour according to the target statistics: hydrocephalic volunteers made similar numbers of visits regardless of whether it was a cued (mean = 10.684, SD = .437) or uncued (mean = 9.961, SD = .620) trial, whereas the control group made fewer visits on rich (mean = 10.765, SD = .445) compared to sparse (mean = 12.372, SD = .631) trials ($F(1,26) = 4.429$, $p < .05$). Interestingly, this seemed to be affected by the laterality of the cued side: this factor was counterbalanced across participants, and hydrocephalus patients only seemed to display a cueing benefit when the cued side was designated on the left: whereas control participants made similar percentage first visits to the rich side of the display regardless of whether the rich side was designated as left (mean = 59.722 %, SD = 5.855) or right (mean = 65.417 %, SD = 7.171), hydrocephalic participants made similar amounts of first visits to the rich side of space when it was on the left (mean = 62.188 %, SD = 6.210), but they made substantially fewer when it was designated to the right (mean = 20.357 %, SD = 6.639) ($F(1,26) = 13.417$, $p < .005$).

In the recognition memory component of the route-learning task, patients demonstrated poorer overall accuracy than controls (respectively, 62.67 % vs. 84.33: $t(28) = -5.15$, $p < .001$). We assessed whether the location of landmarks along the route affected recognition: a mixed design 2 (object location: decision point or non-decision point) × 2 (group: control, hydrocephalus) ANOVA revealed a main effect of group ($F(1,28) = 10.315$, $p < .005$), but no main effect of object location ($F(1,28) = .007$, $p = .935$), or a significant object location by group interaction ($F(1,28) = 1.511$, $p = .229$). Patients were also less accurate in the route-drawing component of the task, correctly negotiating fewer decision points than controls (respectively, 26.6 % vs. 63.8: $t(28) = -3.003$, $p < .01$).

Finally, analysis of path integration performance was based on absolute percentage error data for both angle (i.e. heading) and distance components of the return vector. The hydrocephalus group made significantly greater overall angular errors than the control group: $t(13.15) = 2.86$, $p < .05$. Analysis of distance error approached significance, with a trend towards greater error in the hydrocephalus group than controls: $t(14.84) = 1.95$, $p = .070$.

Discussion

Compared to a group of ability-matched controls, patients with hydrocephalus demonstrated relatively poorer performance on a number of tasks that measured abilities that support daily spatial and navigational behaviour. In a test of manual search, participants with hydrocephalus were less sensitive to spatial cueing by probability, often failing to modify their search behaviour according to the statistical likelihood of target location. This can be compared to a similar study by Pellicano et al. (2011) who studied probability cueing in a large-scale search task (i.e. requiring full body movements) of a similar design. They found that children with Autism were less sensitive to the spatial statistics of the array, taking longer to learn the distribution and demonstrating search behaviour that was less systematic or optimal than matched controls. These findings suggest that sensitivity to spatial cueing may be a useful measure of dysfunction within atypical populations, and our future work will address the nature of the paths taken by hydrocephalic participants, and also the effect that different search modalities may have on cueing.

In a test of route and landmark memory, patients displayed relatively poorer recognition memory for landmarks encountered along a novel virtual route and were also less accurate in their attempts to represent the route on a plan view of the environment. This contrasts with the previous finding that children with hydrocephalus and spina bifida demonstrated intact landmark recall but poor route memory (Wiedenbauer and Jansen-Osmann 2006). However, in their experiment, participants navigated themselves around the maze with a joystick in both encoding and test phases and were required to recall landmarks when at the appropriate point in the maze. In the present task, participants could not control the route around the environment and were required to recognise landmark objects outside of the environmental context in which they were encoded. These differences in paradigm, along with the concurrent presence of spina bifida in their sample, could be responsible for the putative inconsistencies in behaviour.

Lastly, analysis of path integration abilities revealed that patients were less accurate at spatially updating location through self-movement information: they produced greater error in both the distance and heading of their return vectors, with a greater apparent difference for heading information. These data tally with previous research demonstrating that the two components of path integration may be separately represented and differentially amenable to damage or improvement through experience (Smith et al. 2010b; Worsley et al. 2001).

Overall, these data represent the first empirical demonstration of navigational impairments in hydrocephalus and suggest that these behaviours must be studied in greater detail in order to gain a comprehensive picture of the condition. Future research also needs to address the impact of aetiology upon behaviour: although there were no differences observed in the present study, patients with congenital hydrocephalus will have experienced a different developmental trajectory to those that acquired the condition later in life. These differences in development may be responsible for some of the individual variations between patients that are often reported in clinics, and our next aim is to more closely assess the cognitive and neural consequences of these aetiological differences. At a clinical level, these data demonstrate that a relatively common neurological condition can impact upon a core component of everyday living. This is the first step towards identifying remedial strategies with which to assist individuals experience difficulties with wayfinding. Although patients are not routinely scanned after shunting, there is also a good argument for an analysis of performance in relation to neurological damage: some of the behaviours explored here have been shown to depend on hippocampal and parahippocampal cortices (Janzen and van Turennout 2004; Worsley et al. 2001), and so poorer performance in hydrocephalus may be related to anatomical differences in the medial temporal lobe.

Acknowledgments This work was supported by the Association for Spina Bifida and Hydrocephalus (ADS) and an Economic and Social Research Council research studentship (MGB).

Conflict of interest This supplement was not sponsored by outside commercial interests. It was funded entirely by ECONA, Via dei Marsi, 78, 00185 Roma, Italy.

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