Wayfinding behaviour in Down syndrome: a study with virtual environments

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WAYFINDING BEHAVIOUR IN DOWN SYNDROME:

A STUDY WITH VIRTUAL ENVIRONMENTS.

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ABSTRACT

The aim of this study was to assess wayfinding abilities in Down syndrome (DS). The ability to learn routes though a virtual environment (VE) and to make a novel shortcut between two locations was assessed in individuals with DS (N=10) and control participants individually matched on mental age (MA) or chronological age (CA). The results showed that most of the participants with DS was able to learn routes through VE, even though they needed more trials than the CA controls to reach the learning criterion. However, they did not have flexible wayfinding behaviour since they were not able to find a shortcut between two known locations (unlike the CA controls). The results suggested that most individuals with DS could acquire knowledge about specific routes without being able to integrate that knowledge into a configurational understanding.

Introduction

Down’s syndrome (DS), also referred to as Trisomy 21 (see Roubertoux & Kerdelhué, 2006), has an incidence of about 650-1000 live births and it is the most common genetic cause of intellectual disability (Bittles, Bower, Hussain, & Glasson, 2007). This genetic syndrome has been the subject of widespread cognitive research over the past two decades, highlighting a specific cognitive profile is in most individuals with DS. This profile involves relative weaknesses in expressive language and verbal short-term memory, contrasting with relative strengths in visuo-spatial tasks.

Deficits in the language domain have been extensively studied. However, researchers have devoted less attention to spatial processes, which have mainly been investigated through visuo-spatial short-term memory. Convergent evidence showed that individuals with DS had a relatively good level of performance at the Corsi Block Task, a measure of short-term memory for a series of spatial location. Indeed, they performed as well as typically developing children with the same mental age (MA)(Frenkel & Bourdin, 2009; Jarrold & Baddeley, 1997; Visu-Petra, Benga, & Miclea, 2007) or individuals with intellectual disability with the same MA (Numminen, Service, Ahonen, & Ruoppila, 2001). These results contrasted with their poor performances in verbal short-term memory, which were below their mental age level. Lanfranchi, Cornoldi and Vianello (2004) also found that the relative strength in visuo-spatial tasks disappeared when the control required by the task increased. They used a battery of five visuo-spatial tasks requiring different level of control and executive resources. DS participants performed lower than the MA control group only when the visuo-spatial tasks involved high level of executive resources (see also Lanfranchi, Baddeley, Gathercole, & Vianello, 2012).

A vast majority of experiments with individuals with Down syndrome have relied on small-scale spatial tasks. There have been very few attempts to assess visuo-spatial abilities in large-scale spatial task (Pennington, Moon, Edgin, Stedron, & Nadel, 2003; Uecker, Mangan, Obrzut, & Nadel, 1993). This is surprising since there is considerable evidence in cognitive psychology and in neuroscience showing that processing spatial information at different scale of space involves different processes and brain structures (Hegarty, Montello, Richardson, Ishikawa, & Lovelace, 2006). For example Previc (1998), identified different brain systems involved in spatial processing, including the peripersonal system and the action extrapersonal system. The former is mainly devoted to the near-body space and is involved in reaching and manipulative behaviours. It is predominantly located in the dorsolateral cortex. The later is used in spatial navigation and is located in the hippocampus and parahippocampal regions (see also Previc, Declerck, & de Brabander, 2005). Moreover, convergent evidences suggested that specific impairments in the hippocampal system are an important part of the cognitive phenotype in DS (Nadel, 2003). Clearly, research on spatial navigation in DS is required.

Mangan (1992) tested two groups of ambulatory children with DS (16 to 20 months and 26 to 30 months, *n* = 5 in both groups), and two groups of age-matched control children, on three spatial tasks. The response learning task, required the children to learn a specific motor response to locate a hidden toy (see also Uecker, et al., 1993). The cue learning task required them to learn an association between a single cue and the location of the goal (the participants found the toy when they approached a specific coloured cue). The place learning task required the utilisation of multiple cues to locate the goal. Successful performance on this task needed to rely on a representation of the spatial relationship between multiple cues and the toy location (a cognitive map), a spatial ability that depends on the hippocampal formation (Mangan, 1992; Nadel, 2003; Uecker, et al., 1993). Each task began with training trials and, upon reaching criterion, a memory test was given (children were removed from the apparatus for a delay interval). The results showed that children with DS needed more trials to reach the criterion in all three tasks, but they managed to learn the toy's locations. On the memory test, they performed at the same level as CA children on the response and cue tasks but they were severely impaired on the place task. This pattern of result was consistent with the hippocampal dysfunction hypothesis (Mangan, 1992; Nadel, 2003; Uecker, et al., 1993).

Pennington et al. (2003) conducted a neuropsychological assessment of prefrontal and hippocampal functions in participants with DS (mean CA =14.7) who were compared with typically developing children individually matched on MA (mean MA = 4.9). The tasks included a computer generated virtual Morris water maze, which was designed to study place learning and memory in humans (this task was an adaptation from the water maze task used in animals to study cognitive maps). In this task, the participants were required to find an invisible platform located in a virtual circular arena, which was surrounded by four walls with distinctive features. The platform remained in the same place across trials and the participants had to learn its spatial location relative to the distal cues provided by the features on the walls. The participants with Down syndrome performed lower than children with the same MA in this task, which was supposed to assess the generation and use of a cognitive map, a function of the hippocampus.

Thus, the existing research suggests individual with DS have difficulties in coding the spatial location of an object in term of distance and direction with respect to landmarks located in the local surround. These place learning difficulties may impact spatial navigation in more complex and ecologically valid tasks where the destination to reach is located in the neighbourhoods and is not visible from the current location. In these large-scale spatial tasks, space can be viewed only in segments, and information from multiple views must be integrated (McDonald & Pellegrino, 1993). Such tasks require wayfinding, which can be defined as a goal-directed and planned movement of one's body around an environment which is coordinated to distal as well to local surrounds (Montello, 2005, p. 259). An efficient wayfinding behaviour can take different forms. At a basic level, individuals simply have to know what action to take when they reach decisions points (or *nodes)*. The sequence of the decision points, together with the sequences travelled from one decision point to another constitutes a route (Hunt & Waller, 1999). At a higher level, individuals know the configuration of the environment and locations are defined in terms of distance and direction to landmarks or important places. Their wayfinding behaviour is flexible, they can navigate on novel paths and create shortcuts. A deficit in place learning may impair ability in individuals with DS to create a configurational representation of their environment. However, it would not impair their ability to learn routes, provided that proximal landmarks are placed along the path.

In the present experiment, we used virtual environments to study wayfinding abilities in individuals with DS. The methodology, adapted from Mengue-Topio, Courbois, Farran, and Sockeel (2011), allowed us to assess memory for landmarks, route learning abilities, and shortcut performance. Participants explored two routes (A ⇔ B) and (A ⇔ C) until they reached a learning criterion. Then they were placed at B and were asked to find the shortest way to C. We expected individuals with DS to be able to learn the two routes and to have a good memory for landmarks (There are evidences for a relative sparing in visual memory in Down syndrome (Laws, 2002). Moreover, we expected individuals with DS to have a low level of performance in the shortcut task.

Method

Participants

Three groups of participants were assessed: Individuals with Down's syndrome (DS), individuals without Down's syndrome matched on chronological age (CA), and typically developing children matched on mental age (MA). All the participants, except one child in the MA group, used computer several times per week. The Down syndrome group comprised 6 females and 4 males, ranging in age from 14.2 to 29.9 years (mean age: 22.22). Their mental age, assessed with the French scale NEMI-2 (Cognet, 2006), ranged from 7 to 9 years (mean mental age: 7.68). The CA group comprised 10 participants who were individually matched on sex and age (+/- 6 months; mean age: 22.11). The MA group was composed of 10 children individually matched on the basis of sex and mental age (+/- 6 months; mean age: 7.73). We did not obtain authorizations for testing children in the MA group with an intelligence scale. We assumed the chronological age was a good indicator of mental age in these children. Consent for taking part in the study was obtained from the parents of the participants in DS and MA groups (and for under age children in the CA group). All the participants were informed regarding the nature of the study and gave their consent to take part in it. They were also informed that they were free to withdraw from the study at any time.

Materials

The study was conducted in a virtual environment using the 3D VIDIA VIRTOOLS software (Dassault Systèmes). It comprised a 4×4 regular grid of streets lined with high brick walls (see Figure 1 for a map of the VE). This space was surrounded by distant landscapes providing no distinctive cues. Three buildings and 17 landmarks were located in different places of the space. The buildings were a "railway station" (A), a "store" (B), and an "apartment building" (C)[1]. The three buildings were not visible from each other. The landmarks were a railing, a bus shelter, a streetlight, an old car, a fountain, a bench, a slide, a bin, a white car, a tree, a dog, a billboard, a statue, a road sign, a bicycle, a pedestrian, a traffic light.

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[1] These buildings were extracted from a virtual environment designed by (Gyselinck, Picucci, Nicolas, & Piolino, 2006)

During familiarization and the first two phases (memory for landmarks and route learning), the VE was presented such that the participants could not explore the whole space. Barriers were used to signal the roads that were not available on a particular route. In one familiarization VE the shortest route between the station and the store (route A⇔B) was demonstrated by using visible barriers that blocked all but the correct path. In the other familiarization VE, the barriers signified the shortest route between the station and the apartment building (route A⇔C). During learning, the VE was presented in the same manner as at familiarization, except that the barriers were not visible. That is, when a participant attempted to walk down an incorrect path, the barrier appeared, blocking their way (the barriers were located two meters away from the intersection). During the test phase, the participant can walk along any street in the environment. The barriers no longer exist.

The VE was projected onto a 1.20 × 1.50 m screen. The distance between the screen and the participant was 2 meters. Participants navigated from a first person viewpoint, at a constant velocity. They controlled their movement using the keyboard and the mouse. Pressing the backspace key effected forward movement and moving the mouse to the right or left controlled rotational movements.

Procedure

In a preliminary phase, participants were asked to practice moving along the VE using the backspace key and the mouse (route A⇔B or route B⇔C), counterbalanced across the participants). When they were proficient at controlling their movement, the experiment started. The test session was composed of three phases, each of them assessing a major component of spatial navigation: memory for landmarks, route learning and finding a shortcut.

Memory for landmarks. Participants faced the station and were told to follow the route from the station to the store (or from the station to the apartment) and then to return to the station. The order of the routes was counterbalanced, with half the participants in each group walking from the station to the store first (route A⇔B), and the other half walking from the station to the apartment building first (route A⇔C). The experimenter asked the participants to look carefully at the surroundings. Each route was constrained by visible barriers that prevented participants from taking an incorrect path. The participants walked the route forwards and back twice. Then, they were presented with a sequence of eight slides showing landmarks. Across the eight slides, four showed landmarks located along the route the participants had just walked, and four showed landmarks located elsewhere in the town. For each of the slides, the participants were simply asked to say if they saw this object along the route they had just walked.

Route learning. Participants faced the station and were asked to find the route between the station and the store (or the apartment) without choosing a wrong path. The order of the routes was counterbalanced across participants. When participants entered an incorrect path, a barrier appeared, preventing the participant from going further. The trial was repeated until participants reached a criterion of walking the route forwards and back twice without any errors. The maximum number of learning trials was ten round trips. Participants who passed the criterion in routes (A⇔B) and (A⇔C) were given the test phase.

Finding a shortcut. This test phase began with the participants facing the store. They were told they could walk along any street, and no barriers would appear. They were also asked to find the shortest route between the store and the apartment. The trial was repeated until participants walked the shortest the route between the store and the apartment twice. No feedback was provided. The test was stopped after the tenth trials for participants who were not able to find the shortcut. The route explored by the participant was automatically recorded. The walked distance was also computed.

Results

All the participants were able to control their displacement within the maze after a short period of practice. As the data did not consistently meet the assumptions of normality (Shapiro-Wilk's test), it was analysed using non-parametric tests. We used the Kruskal-Wallis test to evaluate differences in medians among the three groups. When the test was significant ($p<.05$), we conducted pairwise comparisons using the Mann-Whitney *U* test.

Memory for landmarks

The numbers of correctly recognized landmarks in routes (A⇔B) and (A⇔C) were summed (max = 16). The Kruskal-Wallis test indicated there was a significant difference in the medians among the groups, χ^2 (2, *N*=30) = 10.99, $p<.004$. Pairwise comparisons indicated that the DS group recognised significantly less landmarks than the CA and the MA groups (see Table 1, Mann–Whitney *U* test, respectively: $p<.003$ and $p<.01$).

Route learning

All participants in the CA group reached the criterion of two consecutive trials without error in both routes. They were 9 in the MA group and 7 in the DS group. The numbers of trials to reach the criterion in routes (A⇔B) and (A⇔C) were summed in these participants. The group effect was significant, χ^2 (2, *N*=26) = 14, $p<.001$. The number of trials was significantly higher in the DS group or the MA groups when they were compared with the CA group (see Table 1, respectively: $p<.001$ and $p<.007$).

Insert Table I about here

Test phase

The median walked distances were not significantly different among the groups during the first trial, χ^2 (2, *N*=26) = 3,57, $p<.16$. They became significantly different during the last trial χ^2 (2, N=26) = 13,02, $p<.001$. In this trial, the CA group walked significantly lower distances than the DS or the MA groups (see Table 1, respectively: $p<.001$ and $p<.01$). Walked distances significantly decreased between the first and the last trial for the CA group and the MA group (Wilcoxon one-tailed test, respectively: $p<.002$ and $p<.03$). In the DS group, there was a trend for the walked distance to decrease between the first and the last trial ($p<.07$). All participants in the CA group found the shortcut when walking from the store to the apartment building (route B => C). They were 5 out of 9 in the MA group, and 2 out of 7 in the DS group. When the data of these participants was excluded from the statistical analyses, the trial effect on the walked distance was no more significant in both MA and DS groups ($p>.50$)

Discussion

The aim of this research was to study memory for landmarks, route learning and shortcut performance in individuals with DS. We expected these participants to have a good memory for landmarks since there is evidence for a relative sparing in visual memory in individuals with DS. Indeed, they performed at the same level as typically developing children of the same mental age in a colour memory task (Laws, 2002). However, our DS group recognized significantly less landmarks than the CA and MA groups. This result is surprising since their performances in the learning phase suggested they could use the landmarks to learn new routes. Yet, the memory test took place before the learning phase. A plausible explanation may be that individuals with DS paid less attention to landmarks than the TD children at the beginning of the experiment since they simply had to follow the route. Moreover, it may be possible they were more concentrated in using the input device than the control participants during the first two trials of the experiment, even though they had experience with computers and were familiarized with the display prior the experimental session.

Seven out of ten participants with DS were able to learn the two routes, even though they needed more trials than the CA controls to reach the criterion. They might have achieved this performance by using different strategies. A first strategy may have involved the memorization of the ordered sequence of landmarks and actions to be taken. This strategy could not be based on a simple association of each landmark with a unique response (ie response learning), since the routes were walked forwards and back. However, there were only four changes of heading in each route. Individuals with DS may have memorized this very simple sequence. Indeed, there is evidence that the spatial sequential working memory is relatively preserved in DS. Lanfranchi, Carretti, Spano and Cornoldi (2009) found they performed at the same level as TD children of the same mental age in a 2-D task where they had to recall pathways. A second strategy may have involved a beacon-following procedure (Montello, 2005). Individuals using this strategy may have looked for a known landmark in the local surround, moved toward it, and then looked for another known landmark. This undemanding strategy may be efficient in the very simple environment we used. Further research is needed to better understand route learning strategies in individual with DS.

Did individuals with DS encode the spatial layout of the environment during the learning phase? Results from the shortcut test suggested most of them did not elaborate a configurational representation of their environment. Only two participants with DS were able to find the shortest route between the store and the apartment whereas all the participants in the CA group found the shortcut. Moreover, distance did not decrease significantly during the ten trials of the test phase for the other participants. Qualitative data analysis in participants who did not find the shortcut revealed that most of them found a relatively long path to reach the destination and tended to follow it over trials. Indeed participants with DS used the same path in 48% of trials (35% for the MA group). Moreover, in 35% of trials, they combined the two known routes to reach the destination[2] (15% in MA group). They did (B => A => C) instead of (B => C). These participants did not err. They were engaged in a goal directed and planned activity, however they lacked the configurational knowledge allowing them to find short paths.

The hippocampal dysfunction hypothesis would have predicted that individuals with DS would perform lower than TD children with similar mental age in the shortcut test (Pennington, et al., 2003). Our results did not confirm this hypothesis. This null result is difficult to interpret and might be due to a lack of statistical power. Children in the MA group had slightly better performances than participants with DS, but the task seemed difficult for them too. Interestingly, in a research on spatial knowledge acquisition in a real and a virtual large-scale environment, Schmelter, Jansen, & Heil, (2009) found that 7-8 year old children showed less configurational knowledge than older children (11-12 year-olds) and adults. Moreover, their results suggested that the developmental process in spatial knowledge was comparable in real and virtual environments.

The results suggested that most individuals with DS could acquire knowledge about specific routes without being able to integrate that knowledge into a configurational understanding. However, we also found individual differences in this group. Some participants were unable to learn the routes; others could learn the routes but their wayfinding behaviour was not flexible; and very few of them were able to find the shortcut. It may be interesting to check if the observed variations reflect individuals differences in wayfinding behaviour in real environments. If so, VEs would become promising tools for assessing wayfinding abilities in individual with DS.

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[2] They walked toward the station and, when they arrived at the junction of the second known route, they continued their way to reach the store.

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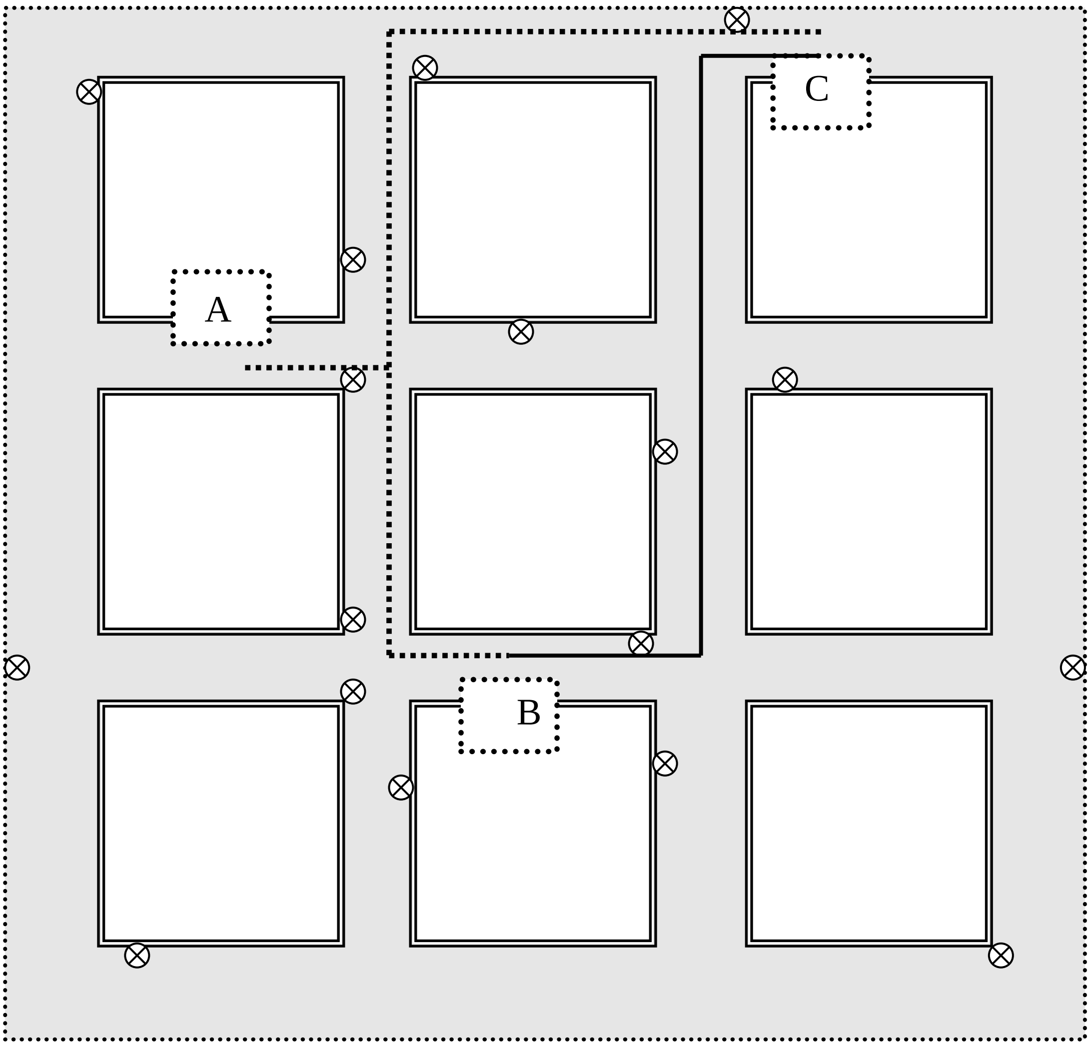

Fig. 1. Map of the virtual environment (A = the railway station; B = the store; C = the apartment building; circles = landmarks; dashed line = routes A,B and B,C; solid line = the shortcut).

Table 1. Results from the three experimental phases (DS = Down Syndrome, MA = mental age, CA = chronological age; interquartile ranges are in brackets).

		DS	MA	CA
Phase 1 Memory for landmarks	Median number of correctly recognized landmarks (max = 16)	10,5 (4,25)	13 (2,25)	13,5 (1,75)
Phase 2 Route learning	Number of participants who reached the learning criterion (max = 10)	7	9	10
	Median number of trials to reach criterion (max = 20)	9 (3)	6 (4)	4 (1)
Phase 3 Shortcut	First trial: Median walked distance	760 (1564)	523 (454)	425 (591)
	Last trial: Median walked distance	405 (446)	337 (222)	277 (11)
	Number of participants who found the shortcut	2	5	10