ROUTE LEARNING AND SHORTCUT PERFORMANCE IN ADULTS WITH INTELLECTUAL DISABILITY: A STUDY WITH VIRTUAL ENVIRONMENTS

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ABSTRACT

The ability to learn routes though a virtual environment (VE) and to make novel shortcut between two locations were assessed in eighteen adults with intellecual disability and eighteen adults without intellectual disability matched on chronological age. Participants explored two routes (A⇔B and A⇔C) until they reached the learning criterion. Then, they were placed in B and were asked to find the shortest way to C (B⇔C, five trials). Participants in both groups could learn the routes, but most of the participants with intellectual disability could not find the shortest route between B and C. However, the results also revealed important differences in the individuals with intellectual disability, with some participants having more efficient wayfinding behaviour than others. Individuals with intellectual disability may differ in the kind of spatial knowledge they extract from the environment and/or in the strategy they used to learn the routes.

Introduction

Intellectual disability is characterized by significant limitations both in intellectual functioning (IQ below 70) and in adaptive behaviour (AAIDD, 2010). Approximately 80 % of the intellectual disability population has mild limitations in intellectual functioning (IQ range of 55 to 70). Most of these individuals can acquire basic academic skills. They often work in a sheltered workshop or supported employment setting. They are relatively autonomous and, in some cases, can live independently with support. Travel skills are essential for independent living and community participation. They allow the individuals to access a wide range of vocational, educational and recreational opportunities (Neef, Iwata, & Page, 1978). However, few individuals with intellectual disability practice independent travel. According to Slevin, Lavery, Sines, & Knox (1998), the most significant obstacles to independent travel are the individual's cognitive limitations and the reservations of their parents or caregivers due to perceived risks. Indeed, individuals with intellectual disability sometimes get lost, even when walking routes that they are familiar with. Importantly, this suggests that their spatial navigation abilities are limited.

Spatial navigation is a goal directed movement of one's self through the environment (Montello, 2005). When the goal is not located in the proximal surround, navigation requires wayfinding, which involves both planning and decision making. Moreover, wayfinding relies heavily on the spatial knowledge acquired from navigating through the environment (Golledge, Smith, Pellegrino, Doherty, & Marshal, 1985). This includes knowledge of landmarks, knowledge of routes and an understanding of the spatial configuration of places within the environment. Landmark knowledge involves storing objects or scenes in memory with little knowledge about the spatial relations between them. Route knowledge is a one-dimensional representation of the sequence of landmarks and associated turns along a path, with ordinal route knowledge being a precursor of metric knowledge (e.g. distance and direction). Survey knowledge (*aka* a cognitive map) is a two-dimensional representation of the layout of the environment. It contains information about spatial relationships among landmarks, including metric properties such as distance and direction. Moreover, it is thought to include relational information about landmarks between which direct travel has never occurred. The ability to make novel shortcuts between two locations is a hallmark of survey knowledge (Golledge, et al., 1985; Montello, Hegarty, Richardson, & Waller, 2004; Siegel & White, 1975).

According to Siegel and Whites's influential approach (1975), the microgenesis of spatial knowledge consists of a progression through three stages, with landmark knowledge being a prerequisite for route knowledge, and route knowledge being a prerequisite for survey knowledge. Only non-metric information (landmarks and ordinal routes) are memorized during the early period of learning. With practice, route knowledge includes information about distance and direction, a prerequisite for the development and elaboration of survey knowledge. Finally, survey knowledge emerges through the integration of different routes into a global allocentric reference system. However, recent empirical evidence does not support this three stages model. Ishikawa and Montello (2006) found that some individuals could acquire metric route or survey knowledge from the first session of exposure to a new environment. Moreover, they found that some of their participants never acquired good survey knowledge of the environment. They concluded that ordinal route knowledge is not necessarily a precursor of survey knowledge (see also Blades, 1991).

Few studies have studied wayfinding in individuals with intellectual disabilities. Golledge, Richardson, Rayner and Parnicky (1983) assessed the spatial knowledge of individuals with mild and moderate intellectual disability of the environment in which they lived. Among different tasks, participants were asked to name all the places that they knew in their town, to put pictures of different scenes located along a familiar route in the correct sequential order, and to place the main city landmarks on a neighborhood map. Their results were compared to those of a control group living in the same town. Individuals with intellectual disabilities were found to have developed a one-dimensional understanding of places: Landmarks along routes of their familiar environment were known. However, their representation of the two-dimensional configuration of landmarks was random which indicates that they could not integrate the different routes into a coordinated reference system. Recently, Farran, Blades, Boucher and Tranter (2010) investigated route learning in individuals with Williams syndrome and individuals with moderate intellectual disability. Participants were guided along an unfamiliar route and then were asked to retrace the route themselves (two trials). Route knowledge was measured by the number of correct turns. "Relational knowledge" was assessed by accuracy in a pointing task (pointing to non-visible landmarks located along the route). Results showed that participants with Williams syndrome and with moderate intellectual disability could learn a route, even though they performed less well than a typically developing group matched on chronological age. Despite good performance on the route learning task, these two groups performed poorly at the relational knowledge task. Their average pointing error was much higher than the typically developing group. The two experiments described above were different in the familiarity of the environment and the measures of spatial knowledge. Nevertheless, they led to similar conclusions: Individuals with intellectual disabilities can acquire route knowledge, but they have difficulties in developing survey knowledge of their environment.

The assessment of spatial knowledge in natural settings has ecological validity, but also has limitations. Golledge et al. (1983) indicated that their participants had resided in the neighborhoods for a period between six months and two years. However, this does not necessarily mean they regularly practiced independent travel. Golledge himself (1993), observed that incidences of spatial navigation in individuals with intellectual disability are limited and few in number (see also Slevin, et al., 1998). He also noticed that their travelled routes are not a matter of free choice, but are often controlled by supervisors. Individuals with intellectual disability, therefore, may have a lower of experience of their neighborhood than control individuals living in the same area. Furthermore, active exploration of an environment is thought to be important for the development of spatial knowledge (see for example Lehnung, et al., 2003). Therefore, a limitation in autonomous self-generated displacements may prevent individuals with a disability from acquiring good spatial knowledge of their environment (Foreman, 2007). Wayfinding tasks in novel environments may be more appropriate to use in comparative research because they make it possible to equate the level of active experience across groups. However, they also have a drawback. Due to the constraints of time and fatigue, participants can only experience routes several times (two trials in Farran, et al., 2010). Virtual environments (VE) may provide a suitable solution to resolve this problem.

Virtual environments are a means of providing participants with repeated, active exploration. They activate similar cognitive mechanisms as real-world environments (Maguire, Burgess, & O'Keefe, 1999), but do not entail the time and physical demands that limit real-world investigations. Experimental evidence has shown that the spatial knowledge acquired in VEs transfers successfully to the equivalent real word space (Foreman, Stanton, Wilson, & Duffy, 2003; Foreman, Stanton-Fraser, Wilcox, Duffy, & Parnell, 2005). VEs are increasingly used in experimental research to address questions about spatial processes in typical or atypical populations (Foreman, et al., 2003; Jansen-Osmann & Wiedenbauer, 2004). Moreover, active exploration in VEs is thought to enable the acquisition of survey knowledge, especially when the environments depicted have a simple layout or are relatively small (Montello, et al., 2004; Richardson, Montello, & Hegarty, 1999). Importantly, Rose, Brooks and Attree (2002) found that people with intellectual disabilities were able to use VEs and were motivated to learn with this method. Indeed, several researchers have used virtual technology for training skills necessary for independent living, and these learnt skills were found to transfer to real-world environments (Standen & Brown, 2005).

The aim of this experiment was to study two important components of wayfinding in adults with intellectual disability: route learning and shortcut performance. We used a VE to provide a safe arena for active self-governed exploration of an environment. We also chose a simple layout (a grid-formation) to make the acquisition of spatial knowledge relatively easy. In the learning phase, participants explored two different routes in the environment (A⇔ B and A⇔C) until they reached a learning criterion. In the test phase, participants were placed at B and asked to find the shortest way to C (B⇔C). There were five consecutive test trials. Our hypothesis was that individuals with intellectual disability would be able to learn the routes, but would have difficulties in finding a shortcut between two visited places. We were also interested to see whether their shortcut performance would improve across trials with active self-governed exploration of the VE.

Method

Participants

Eighteen adults with intellectual disability and eighteen adults without intellectual disability matched on chronological age participated in the study. The mean age of the group with intellectual disability (ID group) was 29.39 years (SD = 4.6 years) and the mean IQ was 55.45 (WAIS III; SD = 3.48). The mean age of the control group was 27.11 years (SD = 4.14 years). There were 12 males and 6 females in each group.

Materials

The experimental VE was constructed 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). The three buildings were not visible from each other. The landmarks were a yellow car, a bus shelter, a streetlight, a statue, a fountain, a bench, a billboard, a guardrail, a grey van, a bicycle, a bin, a dog, a tree, a pedestrian, a playground, a traffic light and a road sign.

During familiarization and 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 B⇔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).

The VE was projected onto a 1.20 × 1.50 m screen. The distance between the screen and the participant was 2 meters. The participants explored the virtual town using a keyboard and a mouse. A preliminary study suggested that our participants found it difficult to use a joystick to combine movements of translations and rotations. Therefore, we used two separated devices: Pressing the backspace key effected forward movement and moving the mouse to the right or left controlled rotational movements. Participants navigated from a first person viewpoint, at a constant velocity.

Procedure

Individual test sessions lasted 30 to 60 minutes. In a preliminary phase, participants were asked to practice moving along a familiarization VE using the backspace key and the mouse. When they were proficient at controlling their movement, the experiment started. The test session was composed of three phases: learning a route from the station to the store, learning a route from the station to the apartment, finding a new route from the apartment to the store (or from the store to the apartment). In the two learning phases, the order of the routes was counterbalanced, with half the participants in each group learning the route from the station to the store first, and the other half learning the route from the station to the apartment building first.

Each learning phase began with two familiarization trials. 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. For each trial, the route was constrained by visible barriers which prevented participants from taking an incorrect path. Then, the learning trials were administered. 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. When they 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.

The test phase began with the participants facing either the store (half of the participants) or the apartment (the other half). Participants 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 (or the reverse) and back again. Five round trip trials were administered. No feedback was provided. The route explored by the participant was automatically recorded. The walked distance was also computed.

Results

Participants in both groups were able to control their displacement within the maze after a short period of practice. One participant in the ID group did not meet the learning criterion. Their data was excluded from the analyses. As the data did not consistently meet the assumptions of normality and homogeneity of variance (Shapiro-Wilk's test and Levene's test), it was analysed using non-parametric tests.

Learning phase

The mean number of trials to reach the learning criterion was significantly higher in the ID group than in the control group for routes (A⇔B) and (A⇔C) ($p<.05$ for both, see table 1). The mean number of errors per trial was also higher in the ID group (Mann–Whitney U test, $p<.05$).

Insert table 1 about here

Test phase

Figure 2 shows the mean walked distance as a function of trial (each trial represents a walk between B and C and back). There was a decrease in walked distance with increased number of trials in both groups. However the traveled distance was higher for the ID group across all trials. The Wilcoxon tests for paired samples confirmed that the distance was significantly lower for the fifth trial compared to the first trial in both groups ($p<.05$). The Mann-Whitney U tests performed on each trial also established that the ID group systematically walked longer distances ($p<.01$ for each trial).

Insert figure 2 about here.

At the first test trial, half of the participants in the control group found the shortcut when walking in either the forward and/or the reverse direction. Only one participant of the ID group found the shortcut when walking in the reverse direction, and none of the ID group found the shortcut when walking in the forward direction. There were more participants who found the shortcut at the fifth trial, but very few from the ID group (see table 2). The number of participants who found the shortcut was significantly higher in the control group (Fisher's exact test computed on trial 1-forward direction; trial 1-reverse direction; trial 5-forward; trial 5-reverse direction; one-tailed test, $p<.05$ for all).

Insert table 2 about here

Qualitative data analysis also revealed that some participants used a slightly longer path to reach the destination (370 meters, compared to the shortest route of 290 metres, see figure 3). When this route was considered as correct, the number of participants who found a "short path" (this route or the shortcut) increased in both groups (see table 3). Eight participants in the ID group found a "short path" in the forward and/or the reverse travel during the last trial. However, the number of participants who found a short path in trial 1 or trial 5 was still significantly higher in the control group (Fisher's exact tests, one-tailed test, $p<.05$ for both). We also split the participants with intellectual disability into two sub-groups: a sub-group of those who took a "short path" during the last trial (ID+ group, n=10; 2 in the forward direction, 2 in the reverse direction, 6 in both directions) and a sub-group of participants who did not take a "short path" (ID- group). Then we compared the mean travelled distances in trial 1 and trial 5 in both groups (Wilcoxon one-tailed test, $p<.05$). Mean travelled distances decreased significantly for the ID+ group, but not for the ID- group (see table 4).

Insert Figure 3, table 3 and 4 about here

Discussion

The aim of this research was to study route learning and shortcut performance in individuals with intellectual disability. The hypothesis was that participants would be able to learn routes in VEs, but would have difficulty in finding a shortcut between two visited places. The VE we used had a simple layout to make the acquisition of spatial knowledge relatively easy. In order to provide the optimum opportunity for survey knowledge to develop, the VE enabled a self-generated exploration of the environment. Moreover, because routes were learnt to a fixed criterion, wayfinding performance on the learnt routes was equal between the two groups before the shortcut test.

Half the participants without disability were able to find the shortcut on the first test trial, and by the last trial, this proportion increased to 77%. This demonstrates that these participants were able to find the shortest path between B and C using their knowledge of two separate routes (A⇔B) and (A⇔C). The ability to take a novel shortcut between visited places is considered as behavioural evidence for the construction of survey knowledge (Poucet, 1993; Stanton, Wilson, & Foreman, 2003), and thus we conclude that the majority of the control group had developed survey knowledge of the layout of the VE. Our results are congruent with other studies showing that exploration of VEs enabled acquisition of survey knowledge when the depicted space was small and had a simple layout (Montello, et al., 2004; Richardson, et al., 1999). It is possible, even likely, that the survey knowledge of the layout of the VE in these individuals was not very accurate. Much of the literature on spatial knowledge has shown it is inaccurate and distorted (see Ishikawa et al., 2006). However, participants' survey knowledge contained enough directional and distance information to enable flexible navigation through the VE.

The participants with intellectual disability could learn the two routes, even though they needed more trials than adult controls to reach the criterion. Importantly, they were able to memorise the temporal order of the correct turns of each route in the VE. However, they had difficulties in finding the shortcut. Only one participant with ID took the shortest path during the first trial, and two of participants took the shortest path during the last trial. This result appears to be congruent with the hypothesis of a deficit in survey knowledge in individuals with ID (Golledge, et al., 1985). However, individual differences should be considered.

Some of the participants with intellectual disability could not find any short path. Moreover, the travelled distances of these individuals did not decrease significantly during the test phase. These individuals were able to learn the routes, but their wayfinding behaviour was not flexible. During the learning phase, they may have memorized associations between landmarks and actions, without encoding information about distance and direction. This kind of procedural knowledge may be sufficient to perform some navigation tasks well, such as retracing a fixed route. However, it may not be sufficient to find a novel route or to make a detour. Interestingly, spatial navigation in real environments in individuals with intellectual disability is often described as non-flexible, with minor changes in the environment causing errors or loss (Neef et al., 1978). In contrast, other individuals with intellectual disability were able to find a “short path” even though it was not the shortest one. Their spatial knowledge was probably less detailed than control individuals, but it enabled efficient navigation. Moreover, for this subgroup, the travelled distances of these individuals decreased significantly during the test phase which indicates that wayfinding performance improved during the test phase without any feedback. This suggests that this subgroup had developed spatial knowledge of the VE which included distance information, a prerequisite for the elaboration of survey knowledge. It is possible that further experience of the environment would have enabled them to develop more detailed survey knowledge, and find the shortest route.

What are the origins of these individual differences? According to Golledge et al. (1985), the progression from one-dimensional to two-dimensional knowledge implies a qualitative difference in the nature of spatial information represented in memory. A first hypothesis would be that some – but not all – individuals with intellectual disability find it difficult to make this qualitative change due to deficits in spatial representations. The elaboration of survey knowledge would not be possible in these individuals, forcing them to rely on a procedural knowledge based on ordered sequences of landmarks associated this motor responses. According to this deficit hypothesis, these individuals would not be able to acquire more flexible wayfinding behaviour, even after specific training. A second hypothesis would be that individuals with intellectual disability differed in the strategy they used during the learning phase. Learning new routes is often described as a strategic behaviour involving controlled processes (Allen & Willenborg, 1998; Cornell, Hadley, Sterling, Chan, & Boechler, 2001; Montello, 2005). Some of the individuals with intellectual disability may have learnt simple associations between landmarks and motor responses, while the others used explicit strategies to maintain their orientation over the travelled distances (for example: trying to update their position with respect to a non-visible landmark). The simple associative learning strategy cannot lead to the elaboration of survey knowledge. However, when trained to change the associative strategy for spatial orientation strategies, individuals with intellectual disability would improve their spatial knowledge of the environment.

The conclusions drawn from this experiment using a VE were similar to those from experiments in natural environments (Farran, et al., 2010; Golledge, et al., 1983). As a group, individuals with intellectual disability can learn routes but they have difficulties in developing survey knowledge. Nevertheless, the methodology we used also revealed individual differences. Some participants with ID had more flexible wayfinding behaviour than others. Further experiments using VEs will offer means to understand the causes of these individual differences. VEs provide interesting settings for experimental research in which the layout, the landmark locations, and complexity of learned routes can be manipulated. Moreover, in future research we will check if the variations we observed reflect differences in wayfinding behaviour in real environments. If so, VEs will provide interesting and safe tools for the assessment of navigation abilities in individuals with intellectual disability, and for training wayfinding strategies.

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Table 1. Learning phase. Mean number of trials (including the criteria trials) and mean number or errors per trial as a function of route and of group (ID = adults with intellectual disability; control = adults without intellectual disability), standard deviations are in brackets.

	Number of trials		Number of errors / trial	
	Route (A⇔B)	Route (B⇔C)	Route (A⇔B)	Route (B⇔C)
ID	3.24 (1.56)	3.41 (1.54)	2 (2.74)	1.59 (2.37)
Control	2.22 (0.43)	2.33 (0.77)	0.28 (0.57)	0.33 (0.84)

Table 2. Test phase: Number of participants who found the shortcut as a function of trial for forward and reverse routes (ID = adults with intellectual disability; control = adults without intellectual disability).

		First trial		Fifth trial	
		Forward	Reverse	Forward	Reverse
ID	Shortcut	0	1	2	1
	Other paths	17	16	15	16
Control	Shortcut	5	9	14	12
	Other paths	13	9	4	6

Table 3. Test phase: Number of participants who found a "short path".

		First trial		Fifth trial	
		Forward	Reverse	Forward	Reverse
ID	Short paths	5	5	8	8
	Long paths	12	12	9	9
Control	Short paths	13	13	18	15
	Long paths	5	5	0	3

Table 4. Test phase. Mean travelled distances in the two ID groups (ID+, participant who found a short path, ID- other participants), standard deviations are in brackets.

	First trial		Fifth trial	
	Forward	Reverse	Forward	Reverse
ID+	811 (*190)*	887 *(185)*	455 (*75)*	492 (*85)*
ID-	888 *(245)*	877*(288)*	591 *(205)*	839 *(187)*

FIGURE CAPTIONS

Figure 1. Map of the virtual environment (A = the station; B = the shop; C = the apartment building; circles = landmarks; dashed line = routes A⇔B and B⇔C; solid line = the shortcut).

Figure 2. Test phase: Mean travelled distances in forward route (upper panel) and reverse route (lower panel) as a function of group (ID = adults with intellectual disability; control = adults without intellectual disability).

Figure 3. Test phase : the shortcut (solid line) and another short path used by some participants (dashed line).

Figure 1

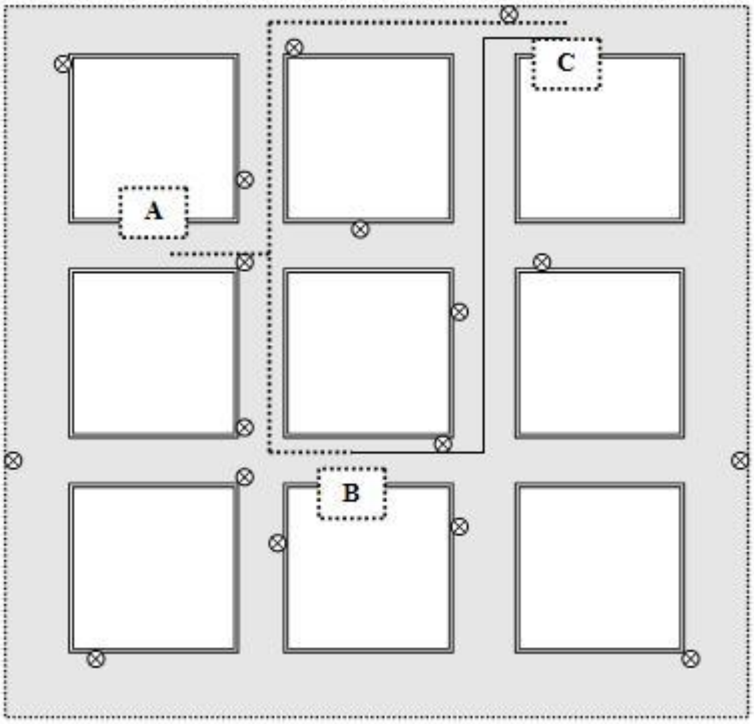
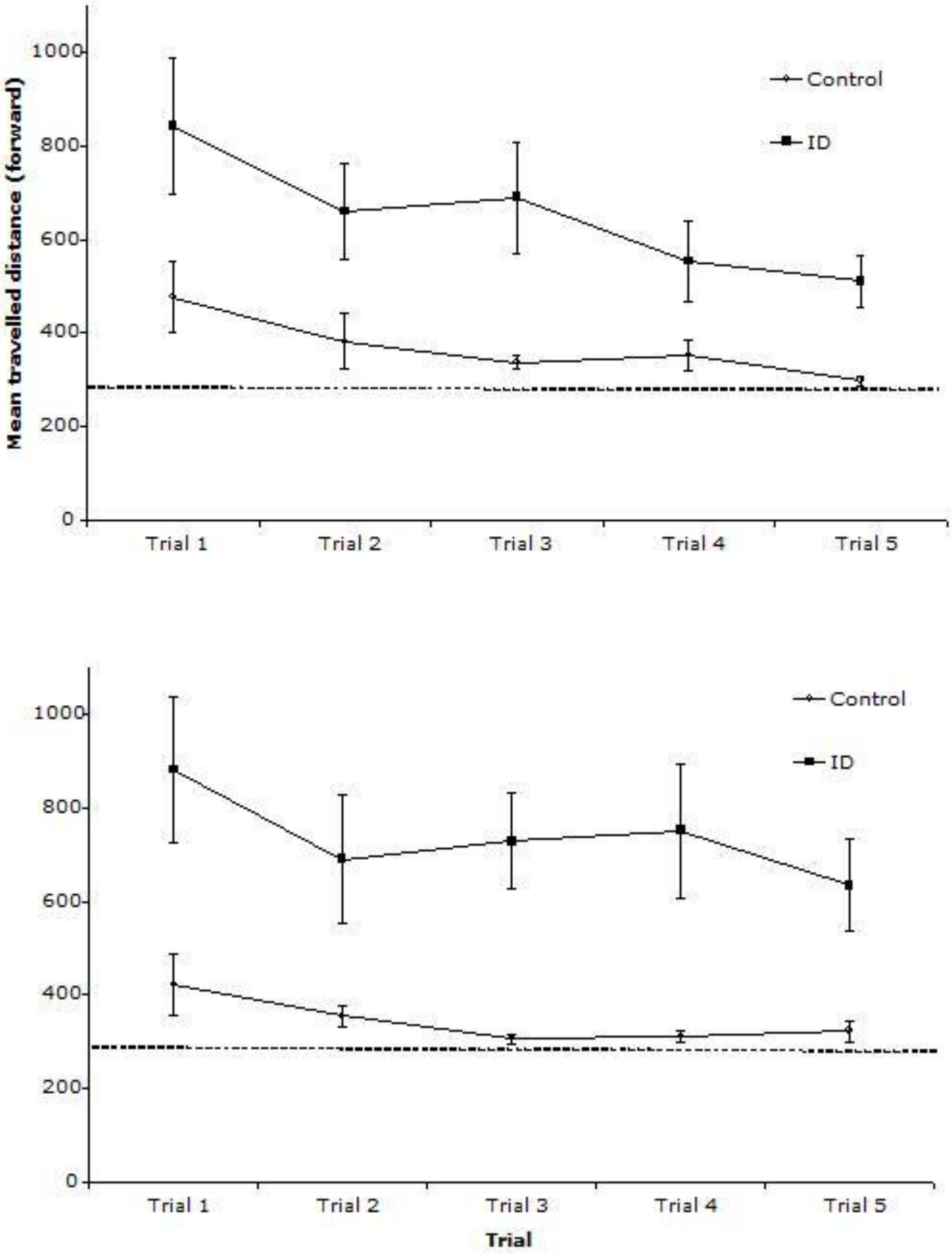


Figure 2



Mean travelled distance (forward)
1000
800
600
400
200
0
Control
ID
Trial 1
Trial 2
Trial 3
Trial 4
Trial 5
1000
800
600
400
200
0
Control
ID
Trial 1
Trial 2
Trial 3
Trial 4
Trial 5
Trial

Figure 3