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Do high functioning persons with autism present superior spatial abilities?

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Abstract

This series of experiments was aimed at assessing spatial abilities in high functioning individuals with autism (HFA), using a human-size labyrinth. In the context of recent findings that the performance of individuals with HFA was superior to typically developing individuals in several non-social cognitive operations, it was expected that the HFA group would outperform a typically developing comparison group matched on full-scale IQ. Results showed that individuals with autism performed all spatial tasks at a level at least equivalent to the typically developing comparison group. No differences between groups were found in route and survey tasks. Superior performance for individuals with HFA was found in tasks involving maps, in the form of superior accuracy in graphic cued recall of a path, and shorter learning times in a map learning task. We propose that a superior ability to detect [Human Perception and Performance 27 (3) (2001) 719], match [Journal of Child Psychology and Psychiatry 34 (1993) 1351] and reproduce [Journal of Child Psychology and Psychiatry 40 (5) (1999) 743] simple visual elements yields superior performance in tasks relying on the detection and graphic reproduction of the visual elements composing a map. Enhanced discrimination, detection, and memory for visually simple patterns in autism may account for the superior performance of persons with autism on visuo-spatial tasks that heavily involve pattern recognition, either in the form of recognizing and memorizing landmarks or in detecting the similarity between map and landscape features. At a neuro-anatomical level, these findings suggest an intact dorso-lateral pathway, and enhanced performance in non social tasks relying on the infero-temporal pathway.

Keywords: Autism; Cognitive map; Spatial orientation; visual-spatial; “What” pathway; “Where” pathway; Primary visual cortex

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1. Introduction

Autism is a neurodevelopmental disability characterized by deficits in several domains, while, in other domains, affected individuals exhibit performance that exceeds that of typically developing individuals. This enhanced performance characterizes individuals with autism as a group, and should therefore be distinguished from the outstanding performances exhibited by “savant” individuals with autism, which are found only in a restricted subgroup of individuals with autism (Miller, 1999).

Superior performance has been demonstrated by individuals with autism in pitch processing and memory (Bonnel et al., 2003; Heaton, Hermelin, & Pring, 1998; Mottron, Peretz, & Ménard, 2000; Mottron & Burack, 2001), pattern discrimination (Plaisted, O’Riordan, & Baron-Cohen, 1998), the block design subtest of the WAIS (Shah & Frith, 1993; Tymchuk, Simmons, & Neafsey, 1977), the graphic reproduction of impossible figures (Mottron, Belleville, & Ménard, 1999) and detecting embedded figures (Jolliffe & Baron-Cohen, 1997; Shah & Frith, 1983). An enlarged surface of activation in the occipital primary visual areas and an enhanced activation in the ventral occipito-temporal regions during the embedded figure task was found in individuals with autism in a study using fMRI (Ring et al., 1999). In addition, an atypical activation of the primary visual cortex during face perception (Pierce, Muller, Ambrose, Allen, Courchesne, 2001) and significantly more dorsal electrophysiological response during visual selective attention task (Hoeksma, Kemner, Verbaten, & van Engeland, 2002) have

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also been observed. These findings suggest that autistic individuals use different neural structures in the early processing of visuo-spatial stimuli.

The current study represents the first systematic assessment of spatial abilities in individuals with autism. More precisely, it aims to establish if individuals with autism possess a superior ability to learn the spatial layout of the environment built from an explored environment or from a map. Superior spatial ability in high functioning individuals with autism (HFA) may be expected on the basis of empirical evidence for preserved or superior visual spatial abilities (Minshew, Goldstein, & Siegel, 1997; Ozonoff, Pennington, & Rogers, 1991; Rumsey & Hamburger, 1988; Lord, Rutter, & Le Couteur, 1994) and from superior recognition memory of topographical landmarks such as buildings, landscapes, and outdoor scenes (Blair, Frith, Smith, Abell, & Cipolotti, 2002; Cipolotti, Robinson, Blair, & Frith, 1999). In addition, anecdotal reports of restricted interest in maps and bus routes, as well as the ability to detect minimal positional changes in the environment (Wing, 1976) suggest that visuo-spatial abilities are enhanced among persons with autism. The visuo-spatial tasks in which persons with autism present enhanced abilities (e.g., block design) consist typically of reproducing a 2D or 3D model by manipulation of its components and require a high degree of spatio-constructive ability. However, this superiority should not be manifested in those spatial tasks drawing heavily on executive functions, because operations that require conscious manipulation of information, such as planning or switching from one mental set to another, are impaired in autism (Bennetto, Pennington, & Rogers, 1996).

Spatial ability can be decomposed into multiple interrelated functions that will be presented from the more complex to the more elementary. Only the spatio-cognitive aspect of spatial navigation tasks, *cognitive mapping,* will be investigated in the current study. Cognitive mapping is the process by which an individual acquires, codes, stores, recalls, and decodes information about the relative locations and attributes of the spatial environment (Downs & Stea, 1973). A cognitive map may be grouped under two subheadings: *survey map* and *route map* (e.g., Evans & Pezdek, 1980; Hirtle & Hudson, 1991; Thorndyke & Hayes-Roth, 1982). These two types of maps differ in the sources from which they are primarily acquired, the aspects of the environment that they represent, and the tasks in which they are most useful. A survey map is characterized by the knowledge of the global spatial layout from an external perspective, such as a standard road map. This knowledge reflects the individual's ability to generalize beyond learned routes and to locate the position of objects within a general and fixed frame of reference (Gale, Golledge, Pellegrino, & Doherty, 1990; Hirtle & Hudson, 1991). One easy way to obtain survey knowledge is to look at a plan that provides an overview of a space otherwise too large to be seen in a glance. Frequent travels on a particular route can also lead to survey knowledge (Siegel & White, 1975; Thorndyke & Goldin, 1983). A *route map* refers to the knowledge of the spatial layout from the ground level observer's perspective. It refers to the knowledge of sequential locations, or sequence of actions, required to follow a particular route. It includes an explicit representation of decision points (DPs) along the route where turns occur, as well as a representation of the decisions to be taken at each of these points. This knowledge is acquired by navigating through the environment.

FMRI studies during spatial navigation tasks performed in virtual reality environments are informative about the neural networks involved in survey and route map tasks (Shelton & Gabrieli, 2002; Mellet et al., 2000; Ino et al., 2002; Pine et al., 2002). Route tasks are associated with activation of the bilateral medial temporal lobes, including parahippocampal cortex and posterior hippocampus, as well as the bilateral postcentral gyrus (BA 5, 7), the right superior (BA 7) and inferior (BA 40) parietal cortices. Survey tasks are associated with activation of the bilateral fusiform, inferior temporal Gyri (BA 37, 19), bilateral superior parietal cortex (BA 7) and left insula/claustrum (BA 13). Thus, in both route and survey processing, a common network of brain areas is recruited; the survey mapping is associated with a subset of areas also involved by route encoding, though the former operation results in a greater activation in the inferior temporal cortex, postcentral gyrus and posterior superior parietal cortex. These results do not support the hypothesis that route and survey information rely on different neural systems, but suggest a hierarchical relationship between these two spatial functions.

At a lower integration level, spatio-cognitive processes are under the dependence of visuo-perceptual activity. Neuroimaging studies demonstrate two distinct neural pathways that subserve topographical learning. The ventral, occipito-temporal (or "what") pathways, and more specifically, the inferior temporal cortex in the region of the fusiform gyrus (Moscovitch, Kapur, Kohler, & Houle, 1995) is involved in the recognition of objects. The temporal activation observed in survey knowledge may reflect greater object processing because of the map-like nature of the survey encoding (Tanaka, Saito, Fukada, & Moriya, 1991). Accordingly, maps can be treated as physical objects per se, in addition to providing spatial information. The dorso-lateral, occipito-parietal (or "where") pathway, and more specifically, the right inferior parietal lobule in the region of the supramarginal gyrus (Moscovitch et al., 1995), is involved in the processing of spatial relations between objects and of spatial locations (Haxby et al., 1991). In addition, the medial temporal lobe is involved in space integration. Specifically, the parahippocampal gyrus is implicated in the encoding of object features and their locations within space (Aggleton & Mishkin, 1983; Maguire, Burke, Phillips, & Staunton, 1996; Maguire, Frith, Burgess, Donnett, & O'Keefe, 1998; McCarthy, Evans, & Hodges, 1996).

The current research consisted of five spatial tasks. The first set of tasks was performed in a human-size labyrinth and investigated route map learning (Experiment 1; route learning), route map manipulation (Experiment 2; reversing a route) and survey map (Experiment 3; pointing toward unseen location). The level of information manipulation required by these three tasks ranged from minimal (route learning) to intermediate (reversing a route) and high (reorganizing spatial information to produce a survey map). In addition, each of these tasks was performed at several levels of difficulty in order to assess how the level of difficulty interacts with the spatial cognitive functions involved. The level of difficulty—and therefore, the performance level—of the task is dependent on the storage and manipulation components of working memory (Owen, Downes, Sahakian, Polkey, & Robbins, 1990).

The scale of represented space was manipulated in the second set of tasks in order to assess the ability to transfer spatial knowledge across different scales of space. When spatial layouts are not perceived all at once (e.g., a human-size labyrinth), the subject is confronted with a *macro-scale* space. Spatial information has to be experienced by integration of perceptual experiences over space and time through the use of memory and reasoning (Montello, 1993; Passini, Rainville, & Habib, 2000; Siegel, 1981). By contrast, spatial cognition at a *micro-scale* refers to situations where a person can perceive a spatial configuration (e.g., a map) from a single point of view (see McDonald & Pellegrino, 1993 for an overview). It allows direct access to survey knowledge. Experiment 4 involved transforming knowledge acquired through macro-scale learning into a micro-scale representation, through memorizing a human-size path and then drawing it on a sheet of paper. Experiment 5, a route execution task, required the transfer of spatial knowledge acquired from a micro-scale space where global relationships were simultaneously perceived and learned (a map) toward a macro-scale space (human-size labyrinth).

2. General methodology

2.1. Participants

Two groups of adolescent and adult individuals participated in the study. The clinical group was comprised of 16 participants with autism (HFA; $N = 11$ males) or Asperger syndrome ($N = 5$, four males, one female) with IQ scores in the average range, randomly chosen from the database of the Specialized Clinic for diagnosis and evaluation of Pervasive Developmental Disorders of Rivières-des-Prairies Hospital (Montreal, Canada). The diagnosis of autism was made on the basis of the Autism Diagnosis Interview-Revised (ADI-R; Lord et al., 1994), a diagnostic instrument operationalizing the DSM-IV (American Psychiatric Association, 1994) criteria for autism. The ADI-R was administered by one of the authors (LM) who obtained a reliability score of 0.9 with the creators of the instrument. This diagnosis was confirmed by an explicit assessment of DSM-IV criteria through clinical observation, using the Autism Diagnosis Observation Schedule-Generic (ADOS-G, module 3 or 4) (Lord et al., 2000). All participants scored above the cut-offs of the algorithms of the two instruments, except one participant who scored under the communication cut-off of the ADI. This participant was nevertheless included, considering his high score at the other sub-scales of the ADI and at the ADOS-G algorithm.

A pilot study using typical individuals of increasing age was conducted to establish the lowest age at which children could read the map used in the experiment. This resulted in including only participants older than 9 years of age. It should be emphasized that at the time of recruitment of the clinical participants, the experimenters were blind to individuals' ADI-R scores that assess visuo-spatial abilities (item 106) or to their block design scores, which assess spatio-constructive abilities. Although the clinical group under study presented the classical superiority in block design (see Table 1) as compared to the typically developing group (Shah & Frith, 1993), this group is representative of the general population of high functioning persons with autism and does not represent a subgroup with "special abilities" in this domain. All participants attended school, were verbal, and were able to read and write. At the time of testing, none of the participants were taking medication. They all had normal or corrected-to-normal vision, tested by a Snoellen Eye Chart prior to the experiment.

The comparison group was comprised of 16 typically developing participants, matched with the clinical group on gender, chronological age, education, performance IQ (WAIS or WISC) and laterality (Oldfield, 1971). No statistically significant differences were found between the two

Table 1
Characteristics of high functioning participants with autism (HFA) and typically developing (TD) participants

Group	Age Mean (S.D.)	PIQ Mean (S.D.)	VIQ Mean (S.D.)	FSIQ Mean (S.D.)	Education Mean (S.D.)	Block design Mean (S.D.)
HFA	17.6 (6.3)	112.3 (12.9)	102.2 (21.2)	107.7 (13.1)	10.0 (3.2)	15.3 (3.3)*
Range	11–36	93–139	63–141	77–144	6–18	10–19
TD	18.9 (5.7)	107.3 (12.1)	111.1 (10.4)	110.1 (10.5)	10.9 (2.4)	12.6 (2.9)
Range	13–37	87–130	91–128	88–128	8–16	8–18

* Significant difference on this variable ($P = 0.019$).

groups on these variables. In addition, a posteriori analyses comparing verbal IQ and full-scale IQ among these groups did not reveal differences among groups. The typically developing individuals and their first-degree relatives were screened for current or past neurological, developmental, or psychiatric disorder. The experiment was formally approved by a local ethics committee. All participants were given financial compensation for their participation. Table 1 shows the individual values, means and standard deviations for chronological age, PIQ, VIQ, FSIQ, level of education and block design.

2.2. Apparatus

An indoor, life-sized (39 ft. × 26 ft.) labyrinth was used for the entire set of experiments. The alleys were 3.3 ft. wide and bounded by white configuration panels 6.6 ft. high. It was relatively soundproof and diffusely lit. The white, removable panels of the labyrinth enabled the experimenters to (1) control for the dimensions involved in the spatial tasks, (2) control task difficulty, (3) limit extraneous perceptual factors, which might interfere with the measure of spatial-cognitive abilities, and (4) minimize the visual cues used for the build-up of spatial knowledge in natural settings. Close to the experimental labyrinth, a reduced labyrinth (16 ft. × 13 ft.) was used for practice trials. The experimental layout has been used in previous research testing spatial orientation and wayfinding abilities of persons with visual impairments (Passini, Proulx, & Rainville, 1990) and patients with Alzheimer's disease (Passini, Rainville, Marchand, Joanette, & Lepage, 1997).

2.3. General procedure

The nature of the experiment was explained to all participants (or to their representing parent) at the occasion of signing the research consent. After informed consent was obtained, all participants were individually administered the five tasks in the same order. The instructions relevant to each particular task were presented and practiced in a small labyrinth before the experiment. The entire testing session lasted approximately 1 h 30 min.

3. Experiment 1: route learning

This task was used to assess route mapping skills. The encoding of spatial information in a route learning task is based on the sequential memorization of the starting point, the decision points, and the destination of the route. This cognitive process is considered to be simple (Tolman, 1948) because it does not require a reorganization of spatial information. However, it varies in difficulty according to the number of decision points of the route to be learned (Hillier, Hanson, & Peponis, 1984; O'Neill, 1991; Passini, Rainville, & Habib, 2000; Peponis, Zimring, & Choi, 1990; Weisman, 1981). Accordingly, the memory load (Owen et al., 1990), and the magnitude of spatial interference (Book & Garling, 1978a,b; Lindberg & Gärling, 1978) are negatively affected by the number of DPs; performance increases when the number of DPs is decreased. Enhanced spatial ability in participants with autism could manifest itself in one of two ways. Participants with autism could exhibit superior performance at each level of difficulty. Alternately, the performance of the participants with autism could exhibit less influence than typically developing participants from increasing the levels of difficulty.

3.1. Stimuli

Three experimental routes of increasing level of difficulty were tested (see example Fig. 1). Path difficulty was manipulated by varying the total length of the path (121, 135 and 148 ft.), and number of turns (23, 24 and 26). Regarding the number of decision points, the intersections where the participant has to choose among two or three possible directions, a pilot experiment revealed that paths with less than 6 decision points were memorized without errors. As a result, DP = 8, 10 and 12 were used. The total number of DP with two and three choices was held constant across paths in order to control for the number of choices, which might have interfered with assessing the impact of the previous variables. Paths were constructed in a manner to avoid salient sequences that could be used as mnemonic cues during the encoding phase. Thus, the paths did not contain repetitions of a sequence of directions (e.g., right-front-left-right-front-left), identifiable gestalts (round, square), or more than two consecutive turns in the same direction. Possible interference between the target path and recently memorized spatial information was minimized by experimental routes beginning and ending at the outer border of the labyrinth.

3.2. Procedure

For each path, the testing was comprised of a learning phase, five successive recalls, and a pause during which the configuration panels of the labyrinth were moved. In the leaning phase, participants were told that their ability to learn a route in the labyrinth would be assessed. Then, the experimenter guided individual participants along the path from the point of departure to the point of arrival at a fixed walking speed. After completion of the learning phase, participants were accompanied to the point of departure, where they had to execute the path by themselves. The experimenter followed the participants approximately 5–7 ft behind. The participants were informed of their errors, within a few steps in a wrong direction, by asking them to backtrack 5 ft. When they approached the decision point, the examiner pointed in the appropriate direction while saying " the route goes this

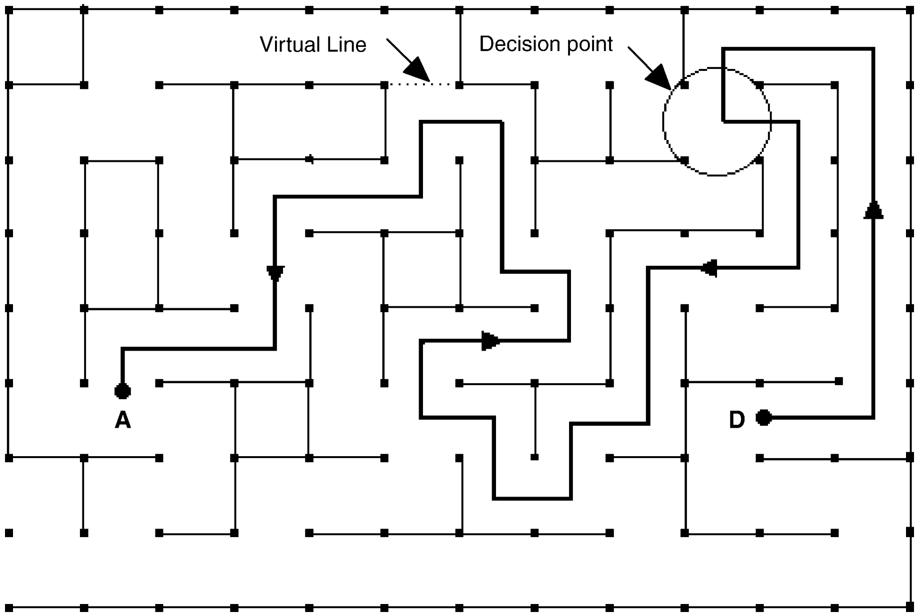


Fig. 1. Example of stimuli used in the route learning task (eight decision points or DP).

way”. Errors and speed of the participants to reach the end of the path were recorded on-line by the observer.

3.3. Results

Route learning performance was analyzed using a Group (HFA, TD) × condition (8, 10, 12 DP) analysis of variance (ANOVA), performed on errors and execution time. The ANOVA revealed a main effect of condition for both variables (errors: F (2, 60) $= 6.61$, $P < 0.005$; execution time: F (2, 60) $= 33.39$, $P < 0.00001$), but no main effect of group. No group × condition interaction was found, indicating that increases in difficulty had a similar effects on both the clinical and comparison groups. Both groups displayed similar increases in the number of errors and took more time to complete the task as the difficulty of the path increased ($DP_8 = DP_{10} < DP_{12}$). The mean number of errors ranged from 1.0 errors (S.D.: 0.7) to 1.5 errors (S.D.: 1.0) in the HFA group and from 1.1 errors (S.D.: 0.8) to 1.6 errors (S.D.:1.31) in the TD group. Similarly, the mean execution time ranged from 39.3 s (S.D.: 11.7) to 48.6 s (S.D.: 15.4) in the HFA group and from 42.7 (S.D.: 8.7) to 52.8 s (S.D.: 12.2) in the TD group.

Additional analyses compared the performance of the two groups on each trial (1–5) within one level of difficulty (8, 10, 12 DP), and the learning effect across trials. This last variable was examined through a group × trial ANOVA performed on decreases in errors (e.g., errors trial 2 − errors trial 1) and relative decreases in execution time [(T trial 2 − T trial 1)/trial 1] between two consecutive trials. The two groups did not differ on these variables. Finally, distributions of errors along the decision points of the path did not differ between groups (*t*-test) and did not show primacy or recency effects.

3.4. Discussion

Individuals with HFA performed the route learning task with the same accuracy and at the same speed as the comparison group, indicating that route mapping skills are preserved, but not superior, in individuals with HFA. The variability of performance was large in both groups of participants, ranging from poor to outstanding levels of performance (HFA = 6–41 errors, TD = 4–41 errors). This variability, along with the absence of a group × level of difficulty interaction, suggests an identical vulnerability of spatial working memory to memory load and to interference in the two groups, while the lack of a group × trial interaction suggests an identical learning curve.

4. Experiment 2: reversing a route

Reversing a route requires the manipulation of spatial information by updating this spatial information according to a new sequence of decisions and associated directions. As demonstrated by studies with adults (Kosslyn, Thompson, Kim, & Alpert, 1995) and children (Piaget, Inhelder, & Szeminska, 1948), reversed recall of a route is at a higher level of complexity than direct route learning. Superior spatial abilities, if revealed only at a high level of complexity, should result in the clinical group performing better than the comparison group in this task. However, inasmuch as manipulation of information is impaired in autism (Bennetto et al., 1996), increased manipulation of spatial information may result also result in an inferior performance in this task.

4.1. *Task, stimuli and procedure*

This one-trial task consisted in returning backwards from the arrival point of a path to its departure point and was accomplished at the end of the fifth trial of each route performed in Experiment 1 (see Fig. 1). Recording procedures were the same as in Experiment 1.

4.2. *Results*

A two-way analysis of variance (ANOVA) group (HFA, TD) × condition (8, 10, 12 DP) performed on errors and execution time revealed a main effect of condition [errors: $F\ (2,\ 60) = 5.84$, $P < 0.005$; execution time: $F\ (2,\ 60) = 12.69$, $P < 0.0001$], but no main effect of group. Both groups committed similar or more errors and took more time to complete the task as the difficulty of the reverse path increased. The mean number of errors ranged from 1.6 errors (S.D.: 1.4) to 2.2 errors (S.D.: 1.3) in the HFA group and from 2.3 errors (S.D.: 1.6) to 2.7 errors (S.D.: 1.2) in the TD group. Similarly, the mean execution time ranged from 45.7 s (S.D.: 13.9) to 52.5 s (S.D.: 11.6) in the HFA group and from 51.4 s (S.D.: 10.6) to 60.4 s (S.D.: 9.9) in the TD group. No group × condition interactions were found.

4.3. *Discussion*

This task is a difficult one for the TD group. Accordingly, their error rate increased from 0.5 errors (fifth trial of direct learning) to 2.0 errors (reverse recall), which was almost identical to the first trial of the direct learning route (2.4 errors).

This decline in performance may be attributable to the impossibility of solving this task by merely memorizing the spatial context of each of the DPs, as reversing the route modifies the visual perspective of the DPs. In addition, manipulating memorized spatial information in order to map current (reversed) and previous (forward) routes creates a higher demand on the executive system. Whatever mechanism is involved, this spatial task does not appear to be easier for participants with autism, at least at the various levels of difficulty assessed here. Finally, in accordance with Experiment 1, performance decreases as the difficulty level of the path increases, thus suggesting that the spatial working memory of the participants with HFA is at a comparable level to the comparison group, a finding consistent with recent literature on intact spatial working memory in autism.

5. Experiment 3: pointing toward an imperceptible direction

The pointing task assesses the survey mapping skill of individuals with HFA. In order to perform this task, individuals must combine and reorganize spatial information learned along the route, and elaborate an integrated representation of the labyrinth. Survey knowledge is typically acquired after repeated navigation in an environment. According to animal studies (Etienne et al., 1998; McNaughton et al., 1996; Wehner & Menzel, 1990; Worsley et al., 2001), this task may also rely on path integration (or “dead reckoning”). Path integration is a form of navigation in which perceived self-motion is integrated over time without the elaboration of a cognitive map. This knowledge derives from the cues generated by a point of reference (e.g., starting point), and subsequent self-movement. This ability depends on the integrity of the right temporal regions (Worsley et al., 2001) and the hippocampal formation (Whishaw & Maaswinkel, 1998). As it does not make use of external cues, this path integration process leads to rapid accumulation of errors involving both the direction and distance of the goal (Etienne, Maurer, & Séguinot, 1996). Consequentially, it should be highly sensitive to an increase in the number of turns and of the segment lengths of the paths.

5.1. *Task, stimuli and procedure*

The task consisted of pointing toward the departure point of a path from the arrival point of this path. This task was performed after Experiments 1 and 2. The same configuration panels (except one) used in the 12 DP path of Experiments 1 and 2 were used in Experiment 3 in order to benefit from the knowledge of the spatial layout acquired in the previous experiment. However, different paths were used in order to maximize the acquisition of information on this configuration. Participants were first asked to memorize the departure point of a new path. Then the participants were asked to follow the experimenter to the arrival point. The participants were told that, in contrast to Experiments 1 and 2, the purpose of this experiment was not to memorize the route traveled in the labyrinth. The participants were also told they could not keep track of the target by pointing to the departure point as they walked through the path. Once at the arrival point, the participants had to point as accurately as possible toward the departure point, which was not visible from this position. Four pointing trials of increasing difficulty level (P1, P2, P3, P4) were performed. Trial difficulty was manipulated by increasing the number of turns (8, 14, 11 and 33), and length (49, 75, 56 and 180 ft.) of the path taken. The point of arrival on each trial was the point of departure of the subsequent pointing task, except for the last pointing task, where the participant had to point toward the first point of departure (Fig. 2). The examiner stood behind the participant and recorded pointing accuracy.

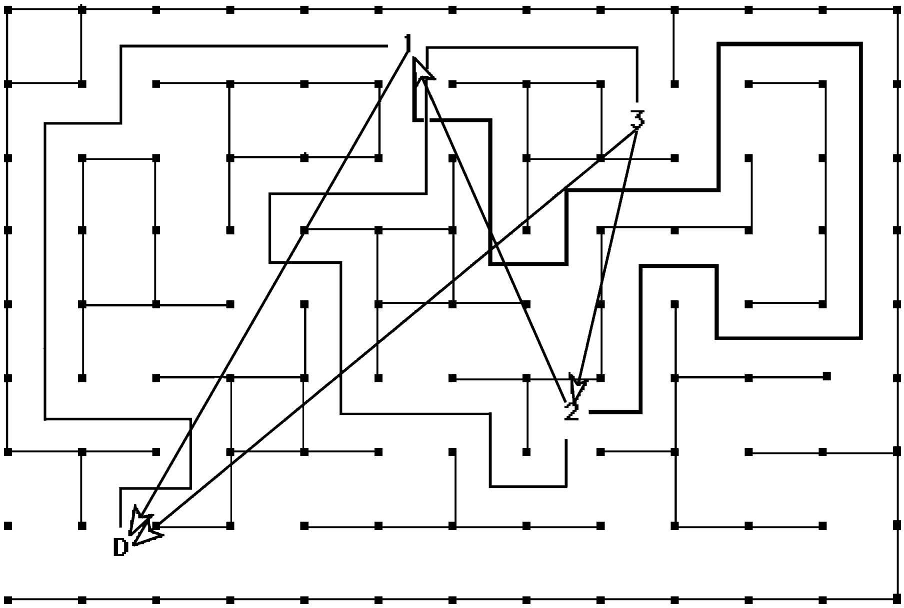


Fig. 2. Pointing task. The participant has to point from 1 to D, from 2 to 1, from 3 to 2, and from 3 to D.

5.2. Results and discussion

The mean absolute error (degrees) was compared across groups using a Mann–Whitney test. Although the participants with autism performed more poorly (mean: 26.3°, S.D.: 31.6) than the comparison group (mean: 15.3°, S.D.: 19.6), the difference did not reach significance. Considering that the error averaging gives an excessive weight to the participant's performance whose pointing was at random, in comparison to those whose pointing is approximate, a binary scoring (passed/failed) was used. We considered a correct answer to lie within a ±15° error margin from the target. A chi-square comparing the proportion of passing participants among groups did not show significant difference between the groups. This indicates that survey knowledge is acquired at an identical level in the two groups.

In order to assess the possible use of the path integration strategy, pointing performance was analyzed by a group (HFA, TD) × condition (P1, P2, P3, P4) ANOVA. No main effect of condition was found between P2, P3, P4, indicating that increase in segment lengths and number of turns did not significantly decrease the performance of the two groups. Similarly, no group × condition interaction was found, indicating that this effect was similar for the clinical and the comparison group, a result which does not support the use of path integration strategy in the participants.

6. Experiments 4a and 4b: map drawing in cued recall and free recall

Map-drawing tasks involved the graphic recall of spatial knowledge. This task investigated the content and structure of cognitive maps, and required a scale translation from macro to micro-scale. As a recall task, map-drawing tasks may be realized in a free recall or a cued recall condition. In the free recall condition (Experiment 4a) the participant had to draw a path from memory on a blank sheet. This condition assessed the processing of spatial mental imagery when the visual input is no longer present. Performance on such a task is modulated by graphic and planning skills. In the cued recall condition (Experiment 4b), the participant was asked to draw the learned path on a reduced map of the labyrinth. Due to the support of recall cues (see Fig. 3c), this task is less dependent on graphic or planning skills. Participants with autism generally exhibit impaired performance on free recall tasks (Bennetto et al., 1996), but preserved performance on cued recall tasks (Mottron, Morasse, & Belleville, 2001). Therefore, the clinical group should exhibit impaired performance relative to the typically developing participants in the free recall condition unless these findings do not extend to spatial information. For the same reason, they should perform at a normal or superior level in the cued recall condition.

6.1. Procedure

6.1.1. Learning phase

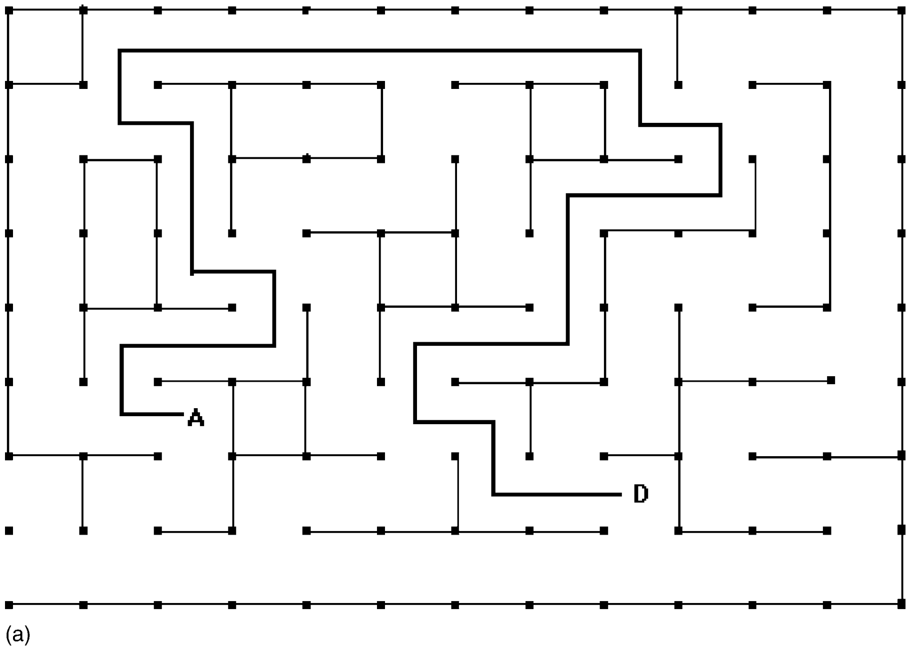
Participants were required to learn a path in the labyrinth (see Fig. 3a) and perform five successive recalls of this path, using the same procedure as in Experiment 1. The path to be learned in this experiment included a long straight segment in the middle, in order to simplify the coding of the free recall drawings. A pilot experiment determined that most of the participants should be able to memorize this path errorlessly within four or five trials.

6.1.2. Recall phase

After the learning phase, the participants where asked to reproduce as accurately as possible the learned path on two 8.5 in. × 11 in. sheets of paper containing a 13 × 9 dot matrix (Experiment 4a; free recall; Fig. 3b) or a reduced-scale reproduction of the labyrinth (Experiment 4b; cued recall; Fig. 3c). In both tasks, the departure point was indicated on the sheet. No time limit was imposed on participants for completion of the drawing tasks. The participants were allowed to erase in case of errors until completion of the task. The time required to complete each drawing task was recorded on-line by the experimenter.

6.1.3. Control task

After the recall phase, a timed copying task was performed to control for the motor drawing abilities of the participants. Participants were asked to copy a model of the target path on a blank matrix.



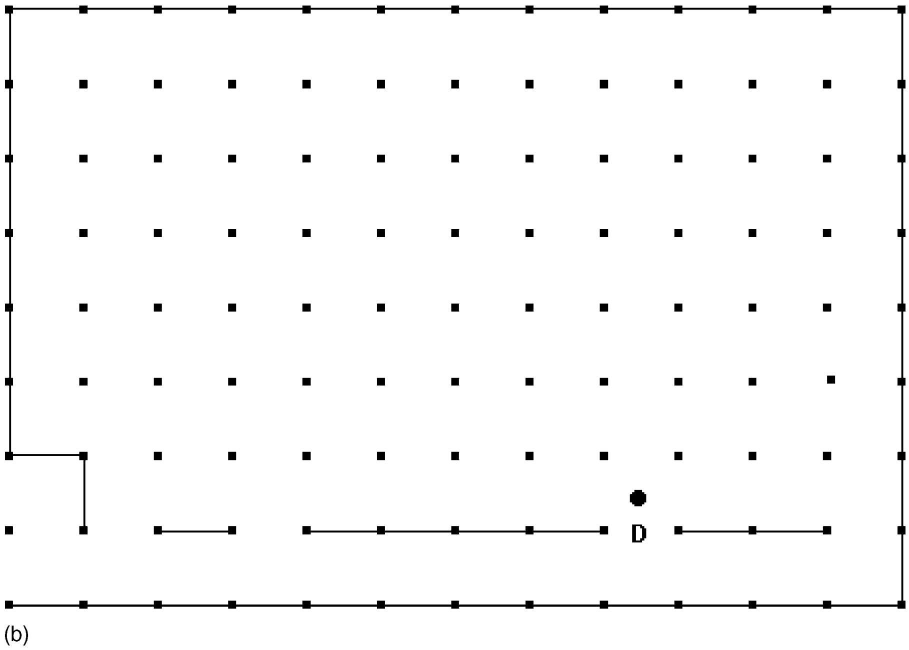


Fig. 3. Map-drawing task: (a) stimulus; (b) free recall response sheet; and (c) cued recall response sheet.

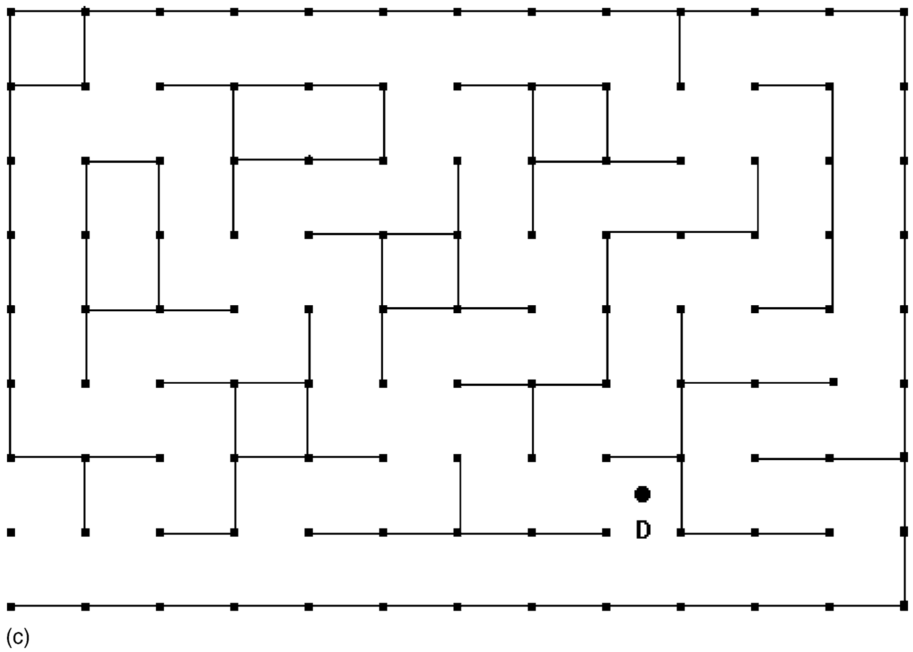


Fig. 3. (*Continued*).

6.2. Results

6.2.1. Learning task

As the purpose of this experiment was to test the graphic production of a well known route, only participants accumulating less than 1 error for the fourth and the fifth trial of this task (15 HFA, 13 TD) were included in the analyses.

6.2.1.1. Experiment 4a: free recall. In a first analysis, five judges rated the drawings from 1 to 5 on a qualitative basis, according to their global similarity with the target path. For this purpose, the participants' drawings were reproduced on blank paper without the grid. Judges were asked to score the overall gestalt similarity without paying attention to metric properties. The reliability of the mean score was very high, with an intraclass correlation coefficient of 0.94. A *t*-test performed on average similarity scores did not reveal differences among groups on this measure In a second quantitative analysis, participant's drawings were converted into a sequence of letters, coding for the direction of turns and length of segments. These sequences were read by software (Fimbel, 2002) inspired by genome sequencing techniques (Gusfield, 1997; Smith & Waterman, 1981). This software computes a similarity coefficient between the drawing of the participant and the target path from the minimal number of transformations (e.g., deletions) required to transform one into the other. Complete drawings (14 HFA, 12 TD) only were submitted for analysis. Two *t*-tests were performed, one based on direction similarity alone and the other on direction and metric similarity. Both analyses revealed an equivalent level of performance between groups.

Comparison of execution time (HFA = 65.1 s; TD = 97.6 s) for graphic production of the path revealed that the clinical group was faster in this aspect of the task than the comparison group (Mann–Whitney = 39, $P < 0.05$). Qualitative examination of RT distribution shows that a speed accuracy trade-off is evident in a small number of the "fast" subgroup of individuals with autism. In order to assess possible differences in speed independently of these trade-off, a secondary analysis was performed only on typical participants actually performing well in this task. High level of performance was defined as graphic production accuracy higher than one standard deviation over average of qualitative (judge) and quantitative scores (software) (HFA = 10, TD = 9). This resulted in HFA individuals not being significantly faster than typically developing participants (HFA = 64.7 s; TD = 91.2 s; Mann–Whitney: $z = 1.80$; $P = 0.072$), therefore indicating absence of particular spatial aptitude in a non-cued condition.

6.2.1.2. Experiment 4b: cued recall. In this task, a wrong direction at one decision point results in multiple inaccurate positions on the grid. Therefore, binary scoring (passed/failed) was used, with drawings scored as failing as soon as there was an error at an intersection point. A chi-squared analysis comparing the proportion of participants passing the task between groups (HFA: 73.3%; TD: 30.8%) showed that the clinical group exhibited superior performance to the comparison group on this task (Pearson: 5.073; $P < 0.024$). However, the two groups did not differ in the graphic production time.

6.2.1.3. Control task. Both groups achieved ceiling performance in this task, with identical copy times.

6.3. Discussion

The free recall task was aimed at assessing the representation of spatial knowledge when the visual input is no longer present. Individuals with HFA performed this task with the same accuracy and speed than the comparison group. Although the participants in this task were recruited among individuals who performed the learning phase without errors, 50% of the individuals of both groups scored under 2.6 out of a possible 5.0. This may be explained by a spatial knowledge being sufficient to adequately perform a route learning task, but not sufficient to perform the graphic recall, which also requires mental imagery and graphic planning.

The recall of a path in the cued condition assessed the representation of spatial knowledge in presence of spatial cue. Individuals with autism performed this task at the same speed as the comparison group, but with superior accuracy. In the cued-recall condition, the participants have to recognize the similarity between a graphic representation of the decision points on the one hand, and the environmental features of the corresponding decision points in the labyrinth on the other hand. Therefore, superior performance in this task can first be explained by superior recognition of decision points, and their integration through mental imaging i.e., by a superior cueing effect of the elements composing the plan on retrieved information. A second interpretation of this finding can be that participants with autism are more able than the comparison group to manually put together local parts of a path into a coherent whole according to a mental model. In this sense, the superiority of the clinical group in assembling, disposing and ordering segments of a path would be related to a superior spatio-constructive ability. Accordingly, the clinical group presented a significant superiority over the comparison group on a spatial-constructive task, the block design subtest of the WAIS (see Table 1).

The pattern of results found in tasks 4a and 4b is consistent with the literature for participants with autism exhibiting atypical gain in cued recall condition relatively to free recall condition (Bennetto et al., 1996; Mottron et al., 2001).

7. Experiment 5: execution of a route learned on a map

This task was aimed at assessing the transfer of spatial knowledge acquired from a map of the labyrinth (micro-scale space) to a human-size labyrinth (macro-scale space). In this task, the source of survey knowledge is a map, where the integration of spatial features can be directly perceived. This transfer of knowledge requires a capacity to adapt the orientation of the memorized map to the orientation of the labyrinth. Accordingly, after the first turn, map and labyrinth orientation are misaligned. It was expected that participants with autism would perform this spatial task at a superior level than the typically developing group.

7.1. Procedure

Participants were told that they would have to learn a path on a reduced-scale reproduction of the labyrinth. The participants were then lead to the departure point of the real-size labyrinth corresponding to the departure point indicated on the map. The map (Fig. 4) was presented to the

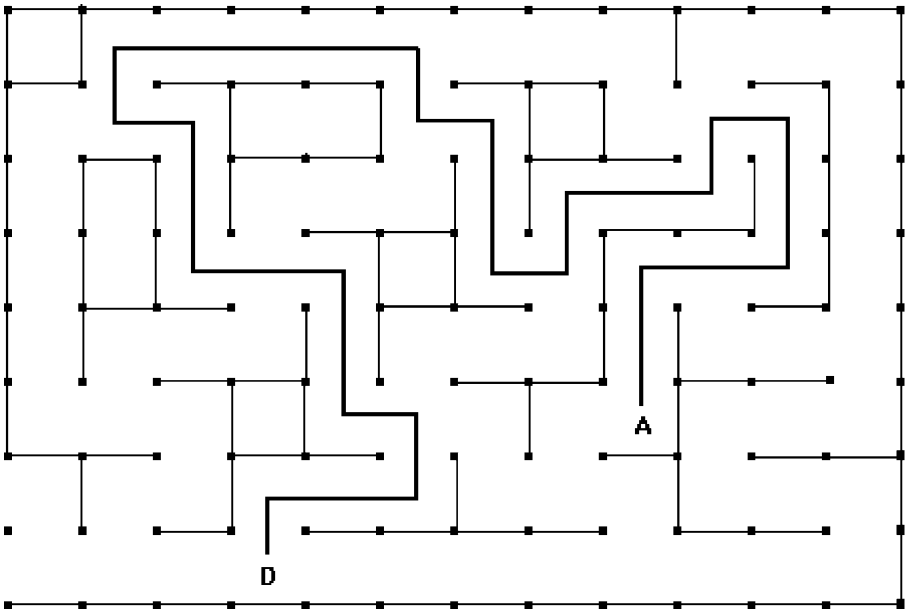


Fig. 4. Map learning task: stimulus.

participant with an orientation coinciding with that of the real-size labyrinth. No limitations were applied on subsequent manipulations of the map. Participants were given a maximum of 2 min to study the map, but could move on to the recall phase as soon as they were ready. The same procedure and measures as in Experiment 1 were applied for the recall phase of the path, with the exception that only one trial was performed. The time required to memorize the route during the learning phase, the number of errors and the time required to execute the path were recorded on-line by the observer.

7.2. Results and discussion

Comparisons of the number of errors and route execution time revealed identical performance in the two groups (Mann–Whitney). The mean number of errors was 1.4 errors (S.D.: 1.4) in the HFA group and of 0.8 errors (S.D.:1.2) in the TD group. However, the clinical group was significantly faster to the comparison group in learning the map [HFA = 57.7 s (S.D.: 40.1); TD = 79.1 s (S.D.: 21.9); Mann–Whitney; $z = 2.04$; $P = 0.042$]. Qualitative examination of RT distribution showed that a subgroup of individuals with autism (9 out of the 16) learned the map faster than the fastest participant in the comparison group (Fig. 4). A speed accuracy trade-off was evident in a small number of the “fast” subgroup of individuals with autism. Four of the nine fastest participants with autism presented 3 or 4 errors. In order to assess possible differences in speed independently of this speed accuracy trade-off, a secondary analysis was performed only on participants with 1 or 0 errors (7 HFA, 10 TD). This resulted in HFA individuals demonstrating faster reaction times than typically developing participants (Mann–Whitney: $z = 2.34$; $P = 0.019$). These findings indicate that individuals with autism do not present any difficulty in translating spatial knowledge from micro to macro-scale and using abstract mental representation of the environment to navigate efficiently through the maze. In addition, they are more efficient than the comparison group when it comes to the encoding of micro-spatial information.

8. Additional analysis

The number of individuals exhibiting a consistent success across tasks 4b, 5 and block design was compared in the two groups and was found to be identical. Moreover, the use of non-parametric tests, based on rank rather than raw scores, diminishes the relative weight of subjects displaying extreme scores. In addition, scatter-plots do not show the presence of heterogeneous sub-groups within the experimental group after excluding subjects that display a trade-off. This shows that individuals with HFA are superior to comparison participants as a group on these tasks.

In order to assess the contribution of the block design performance on graphic cued recall (task 4b) and map learning time (task 5), logistic and regression analyses were respectively conducted. When block design performance is entered as the first variable in the model predicting the performance at the graphic cued recall (task 4), the effect is significant [Likelihood ratio test: chi-square(1) = 9.08; $P = 0.003$]. When the group (clinical versus typical) variable is added to the model, the improvement is not significant [Likelihood ratio test: chi-square (1) = 2.25; $P = 0.134$]. The consistency among block design task and graphic cued recall task is an expected finding, both tasks being spatio-constructive in nature.

When block design performance is entered as the first variable in the map learning task (task 5), it explains 17% of the variance [$F(1, 15) = 3.13$; $P = 0.097$]. When the group variable is added to the model, the explained percentage of the variance is increased to 41% and this increase is significant [$F(1, 14) = 5.78$; $P = 0.031$]. In sum, the difference in performance on map learning time between groups remains significant after controlling for differences in performance on block design task.

9. General discussion

9.1. Data summary

This series of experiments was aimed at assessing spatial abilities in high functioning participants with autism. In the context of recent findings that this group of individuals is superior to typically developing individuals on several non-social cognitive operations, it was expected that the clinical group would outperform a comparison group matched on full-scale IQ in spatial tasks. Results show that individuals with autism perform all the tasks at a level at least equivalent to a comparison group. No differences were found in route learning, reversing a route or on a pointing task. However, superior performance by participants with autism was found on tasks involving transfer of knowledge between micro and macro-scale, in the form of a superior accuracy in graphic cued recall of a path, and a shorter learning time in a map learning task.

9.2. Preserved versus superior spatial skills

The first finding of this series of experiments is that high functioning participants with autism possess intact spatial abilities. Experiments 1–3 demonstrated that route mapping, route map reversal, and survey mapping are preserved in individuals with HFA. Preserved spatial abilities were expected considering the intact abilities evident in this group in numerous non-social cognitive operations. However, the absence of superior performance in route and survey tasks comes as a surprise, in relation to the often-quoted clinical remark that individuals with autism present remarkable performance in spatial abilities. A similar prediction of superior spatial abilities is predicted by Baron-Cohen "extreme-male brain" hypothesis for cognitive profile in autism (Baron-Cohen, 2002), considering the general superiority of male over female individuals (for a review, see Jones, Braithwaite, & Healy, 2003).

One explanation would be that the clinical reports of persons with autism performing at a superior level in these tasks results from an implicit comparison of their performance in this domain with their substantially impaired performance in other domains such as language and social cognition. Another possibility would be that this superiority vanishes when individuals with autism reach an adult age. Accordingly, the mean age of the group under study (17 years) and their high level of intelligence, prevents the extension of these findings to younger or lower functioning individuals with autism.

The second finding is that an increase in difficulty within task, as well as in complexity level between tasks, has the same detrimental effect on the two groups under investigation. On the one hand, the increase in memory load (e.g., number of decision points) within route mapping, route map reversal, and survey mapping abilities, is associated with a similar decrease in performance in the two groups. On the other hand, the level of manipulation of spatial information required by these three tasks ranges from minimal (route learning), intermediate (reversing a route), to high (reorganizing spatial information to produce a survey map). This increase in executive loading is plausibly responsible for the increase in error rates between tasks 1, 2 and 3 evident in the two groups, although the three tasks are not directly comparable. Together, these findings indicate that the storage and the manipulation components of spatial working memory are unremarkable in individuals with autism, a result consistent with the notion of intact working memory in autism for different types of material (Bennetto et al., 1996).

In addition to preserved spatial skills, the current pattern of findings indicates that a certain number of tasks are realized at a superior level in high functioning persons with autism. First, individuals with autism show superior accuracy levels in a cued graphic recall task that assesses spatial representation when spatial cues are available. Second, in a route execution task requiring the transfer of spatial knowledge acquired from a micro-scale space, individuals with autism exhibit a faster learning time of a map. This superior performance cannot be explained by improved route knowledge, which would have resulted in a superior performance in Experiments 1 and 2, or in survey knowledge, which would have also yield superior performance in Experiment 3.

The superior performance of participants with autism in Experiments 4 and 5 may be related to other findings of superior memory for objects, such as superior visual recognition memory in comparison with verbal IQ-matched individuals, evident for topographical material (Blair et al., 2002). More precisely, one explanation for the dissociation between typical performance in Experiments 1–3 and superior performance in Experiments 4 and 5 may be the presence or absence of visual perceptual cues. Accordingly, although Experiments 1 through 3 approximate spatial abilities in ecological settings, they differ from real world conditions by a quasi absence of perceptual cues. In contrast, a map is a visually presented (Experiment 5)—or graphically constructed (Experiment 4)—object, composed of elementary visual patterns, which would explain that the clinical group shows superior performance only in the components of Experiments 4 and 5 involving the encoding and retrieval of visual (graphic) components. The superior ability evident in individuals with autism to detect (O'Riordan, Plaisted, Driver, & Baron-Cohen, 2001), match (Shah & Frith, 1993) and reproduce (Mottron et al., 1999) simple visual elements, may represent an advantage in tasks 4 and 5. This advantage would be manifested in easier on-line comparisons of the spatial configuration of decision points with segments of the internal representation of the path.

Consistent with this interpretation, it has been proposed that faster graphic reproduction of impossible geometric figures by individuals with autism, together with unremarkable reproduction of possible figures, may be explained by an ability to ignore irrelevant visual material when accomplishing a visual detection task (Mottron et al., 1999). The same explanation has recently been proposed for similar speed of detection for a letter embedded within other similar letters (Mottron, Burack, Iarocci, Belleville, & Enns, 2003), whereas a comparison group exhibited a longer detection time for embedded than for isolated letters. This explanation is consistent with the clinical group under investigation showing a clear superiority over the comparison group in the block design subtest of the WISC/WAIS (see Table 1), a task relying on disembedding a segment of the figure to be reproduced from its global appearance, and on matching this segment with the faces of the blocks used in the construction of the figure. Although it has been suggested (Benton & Fogel, 1962; Benton, 1967) that drawing tasks may be testing a different ability than assembly tasks, other investigators have found high correlations between performance on these two types of constructional tasks (Arrigoni & De Renzi, 1964; Dee, 1970). The positive correlation found between the individuals' performances on the block design and the cued graphic recall of a path clearly support this second alternative.

9.3. Neuro-anatomical implications

The integrity of route and survey knowledge in participants with autism is consistent with the findings of no structural abnormalities reported in the regions typically involved by these processes among persons with autism (up to now, no fMRI studies of route and survey knowledge in autism have been presented). These findings suggest the preservation of the spatial functions served by bilateral medial temporal lobes (including hippocampus and parahippocampal gyrus, postcentral gyrus, and right posterior cingulate) and by the inferior temporal cortex (including bilateral fusiform gyri, posterior-superior parietal cortex and left medial frontal gyrus). However, this does not preclude that typical performance may be obtained by persons with autism through different brain regions, as it cannot be discarded that non-spatial functions served by the above mentioned regions may be impaired in autism.

The current pattern of preserved versus enhanced performance may be examined in light of the “where” versus “what” distinction among processing systems. The spatial functions requiring the integrity of the parietal dorso-lateral regions, or “where” pathway, seem to be preserved according to the current findings. Remarkably, motion perception, a function under the dependence of the magnocellular pathway, a major component of this region, has been reliably found to be abnormal in autism (Bertone, Mottron, Jelenic, & Faubert, 2003; Gepner & Mestre, 2002; Milne et al., 2002; Spencer et al., 2000), although movement integrated at the level of the primary visual cortex is preserved (Bertone et al., 2003). Therefore, although the “where” system is not impaired according to the set of experiments presented here, it is premature to make conclusions regarding the integrity of this system in autism.

Regarding the occipito-temporal pathway, or “what” system, the superiority that individuals with HFA exhibit in tasks involving maps is consistent with findings that individuals with autism show more activation in the occipital primary visual cortex and ventral occipito-temporal regions than typically developing individuals during a task of detecting an embedded figure (Ring et al., 1999). In addition of being involved in the recognition of objects such as maps, these regions have been reported to be activated by typically-developing individuals performing a topographical representation of a mental image (Kosslyn et al., 1995). Accordingly, Tasks 4 and 5 require manipulating the representation of a previously perceived environment and moving mentally from one point to another, an ability that is related to a type of spatial mental imagery.

Superior visual and auditory perceptual performances of persons with autism in laboratory tasks are now evident, using multiple paradigms. An atypical involvement of perception in ecological tasks typically performed by higher order processes is therefore a prospective direction for future cognitive research in this group of individuals, that could be addressed through brain imaging and ERP research.

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