Journal of the International Neuropsychological Society (2013), **19**, 54–62.

doi:10.1017/S1355617712000963

Egocentric and Allocentric Spatial Representations in Williams Syndrome

Inês Bernardino,[1] Susana Mouga,[1,2] Miguel Castelo-Branco,[1] and Marieke van Asselen[1]

[1]Visual Neuroscience Laboratory, IBILI, Faculty of Medicine, University of Coimbra, Portugal
[2]Child Center, Neurodevelopment and Autism Department, Pediatric Hospital of Coimbra, CHUC, Coimbra, Portugal

(Received January 10, 2012; Final Revision June 13, 2012; Accepted June 14, 2012)

Abstract

Williams syndrome (WS) is a neurodevelopmental disorder characterized by severe visuospatial deficits, particularly affecting spatial navigation and wayfinding. Creating egocentric (viewer-dependent) and allocentric (viewer-independent) representations of space is essential for the development of these abilities. However, it remains unclear whether egocentric and allocentric representations are impaired in WS. In this study, we investigate egocentric and allocentric frames of reference in this disorder. A WS group ($n = 18$), as well as a chronological age-matched control group ($n = 20$), a non-verbal mental age-matched control group ($n = 20$) and a control group with intellectual disability ($n = 17$), was tested with a computerized and a 3D spatial judgment task. The results showed that WS participants are impaired when performing both egocentric and allocentric spatial judgments even when compared with mental age-matched control participants. This indicates that a substantial deficit affecting both spatial representations is present in WS. The egocentric impairment is in line with the dorsal visual pathway deficit previously reported in WS. Interestingly, the difficulties found in performing allocentric spatial judgments give important cues to better understand the ventral visual functioning in WS. (*JINS*, 2013, *19*, 54–62)

Keywords: Spatial cognition, Reference frames, Dorsal visual stream, Viewer-dependent coordinates, Viewer-independent coordinates, Visuospatial

INTRODUCTION

Williams syndrome (WS) is a genetic neurodevelopmental disorder resulting from a hemideletion on chromosome 7q11.23 (Bayes, Magano, Rivera, Flores, & Perez-Jurado, 2003; Korenberg et al., 2000). This rare syndrome is characterized by a specific cognitive profile defined by a predominant visuospatial impairment while language processing is relatively spared (Bellugi, Lichtenberger, Jones, Lai, & St George, 2000).

Visuospatial deficits have been widely reported in WS, particularly concerning the perception of two-dimensional (2D) form-from-motion stimuli (Reiss, Hoffman, & Landau, 2005), the discrimination of coherent motion and action planning (Atkinson et al., 2003). Furthermore, a decreased efficiency in visual search was reported and is characterized by a less structured scan-pattern. This involves an increase in fixation duration and number of fixations which results in more time required to process the visual scene (Montfoort, Frens, Hooge, Haselen, & van der Geest, 2007). WS participants were also found to be impaired on visual working memory tasks requiring the recognition of the location of a previously presented object appearing in one of four quadrants (Vicari, Bellucci, & Carlesimo, 2005). These deficits regarding the processing of spatial information have been demonstrated in small-scale as well as in large-sale environments (Farran, Courbois, & Cruickshank, 2009). WS participants were found to be slightly impaired in learning a route in the real world (Farran, Blades, Boucher, & Tranter, 2010) and in correctly performing wayfinding tasks (Atkinson et al., 2001). The aforementioned weaknesses have important outcomes for the daily life of these patients which are evidenced by their parents' reports revealing difficulties in following directions and establishing their perceptual organization of space (Semel & Rosner, 2003). The development of the spatial representation of the surrounded space under different frames of reference is pivotal for the acquisition of spatial navigation and wayfinding abilities. Nardini, Atkinson, Braddick, and Burgess (2008), defined developmental trajectories of different spatial frames of reference in WS by using a spatial memory paradigm

---

Correspondence and reprint requests to: Inês Bernardino, IBILI - Visual Neuroscience Laboratory, Faculty of Medicine, University of Coimbra, Azinhaga de Santa Comba, 3000-354 Coimbra, Portugal. E-mail: ibernardino@fmed.uc.pt

including either array-, body-, or environment-based frames of reference judgments. Results demonstrated that spatial memory coding in WS was slow and incomplete compared to controls, although it did not follow an anomalous developmental pattern. WS of all ages were severely impaired on this task, particularly when a local landmark was used as reference frame.

Two main classes of reference frames to represent spatial information can be distinguished, namely egocentric and allocentric representations. Egocentric coordinates represent positions of locations that are related to the position of the viewer (viewer-dependent). In contrast, allocentric information computes the positions of objects in relation to other objects in the environment, independent of the position of the viewer (viewer-independent). There is the evidence that the dorsal visual stream is responsible for processing egocentric information while the ventral visual stream processes spatial information from an allocentric perspective (Goodale & Haffenden, 1998). Accordingly, neuroimaging studies, which have explored the neural basis of egocentric and allocentric reference frames, have confirmed different neural structures and pathways underlying these systems (Galati et al., 2000; Holdstock, Mayes, Cezayirli, Aggleton, & Roberts, 1999; Vallar et al., 1999).

Egocentric encoding of space has been shown to recruit a fronto-parietal network along the dorsal stream (Galati et al., 2000; Vallar et al., 1999), which plays an important role for spatial processing and mediates visual control of skilled actions directed at objects (Milner & Goodale, 2008). Patients with lesions along the dorsal visual pathway (parietal-lobe regions) were described to be less accurate in navigating through computer-simulated tunnels shown from a first person perspective than frontal lobe patients and age-matched control participants, supporting the role of the parietal lobe in processing egocentric information (Seubert, Humphreys, Muller, & Gramann, 2008). These findings are in line with neurophysiological approaches in the monkey in which neurons coding viewer-dependent spatial positions have been found in the posterior parietal and premotor cortices (Cohen & Andersen, 2002).

On the other hand, allocentric spatial processing is thought to recruit ventromedial temporal structures along the ventral visual stream (Holdstock et al., 1999) which is mainly responsible for the perception of object properties (Milner & Goodale, 2008). However, the cortical representation of the allocentric information seems to be more diffuse than that of the egocentric reference frame (Grimsen, Hildebrandt, & Fahle, 2008). Patients who underwent unilateral temporal lobectomy showed impairments in performing allocentric but not egocentric spatial memory tasks suggesting that the anterior temporal lobe, as well as the hippocampus play an important role in allocentric coordinates (Feigenbaum & Morris, 2004). Involvement of the hippocampal and parahippocampal regions was found exclusively in allocentric spatial memory processing (van Asselen et al., 2006). These findings are in line with the theory of O'Keefe and Nadel (1978), who stated that the hippocampus is pivotal in the processing of allocentric spatial information. In fact, the hippocampal formation has been described as crucial for the processing of spatial navigational information and was found to have an abnormal functioning in WS. Meyer-Lindenberg, Mervis, and Berman (2005) reported abnormal function and metabolism of the anterior hippocampal formation despite preserved volume and subtle altered shape evidencing the neural basis for spatial navigation dysfunction in this disorder. Additionally, the dorsal visual stream, associated with the processing of information from an egocentric perspective, has been described as impaired in WS. Indeed, the noticeable deficits in the visuospatial domain reported in WS have been explained by developmental impairments within the dorsal visual pathway (Jackowski et al., 2009; Meyer-Lindenberg et al., 2004). The ventral visual stream has been described to be relatively less affected in WS (Paul, Stiles, Passarotti, Bavar, & Bellugi, 2002), resulting in fairly normal object recognition, color processing and recognition of faces (Bellugi et al., 2000).

The goal of the present study was to explore how WS participants use both egocentric and allocentric reference frames. Although several studies addressed spatial processing in WS, until now, no study has explicitly differentiated between the use of egocentric and allocentric reference frames. To achieve this goal, we used a computerized spatial judgment task as well as a 3D spatial judgment task. The 3D spatial judgment task was introduced to control for weaknesses in performing the task due to the difficulty in interacting with the computer. Thus, this 3D spatial task involves high ecological validity, in which the materials and setting approximate a real-life situation. This ecological approach is important keeping in mind that this clinical group is characterized by mild to moderate mental retardation and these patients are not familiar with computerized environments.

Considering the importance of the posterior parietal cortex for processing spatial information from an egocentric perspective, we hypothesized that WS participants will be impaired on tasks involving viewer-dependent judgments. Furthermore, since processing information from an allocentric perspective is associated with areas along the ventral visual pathway and hippocampal formation, we expected that performance on viewer-independent tasks may also be affected in this disorder.

METHODS

Participants

Eighteen WS participants (11 males and 7 females) participated in this study. The WS participants were recruited from a database used in previous studies (Castelo-Branco et al., 2007; Mendes et al., 2005). All patients were diagnosed based on clinical and genetic examinations. Fluorescence in situ hybridization (FISH) analysis was used, which demonstrated the hemizygous Elastin deletion. Additional

Table 1. Characteristics of patient and control groups

	WS (n = 18)			TD_CA (n = 20)			TD_NVMA (n = 20)			ID (n = 17)		
	Mean	Range	SE	Mean	Range	SE	Mean	Range	SE	Mean	Range	SE
CA (years)	18.00	8–34	1.9	17.25	9–34	1.7	6.00	4–9	0.2	19.53	9–35	1.59
Education (years)	5.06	0–12	1.0	7.95	4–14	0.7	0.90	0–4	0.2	7.00	0–9	0.80
Standard FSIQ	53.94	42–75	2.0	110.71	95–120	1.9	106.14	89–119	3.9	53.59	40–77	2.47
RCPM score	18.56	9–30	1.3	33.56	30–36	0.4	21.10	13–30	1.2	19.71	12–28	1.20
Gender (m:f)	11:7			11:9			9:11			8:9		
Handedness (right:left)	15:3			19:1			19:1			12:5		

genetic analysis revealed the same deletion size ($\sim$1.55 Mb) in all WS participants. None of the WS participants was diagnosed with attention-deficit/hyperactivity disorder (ADHD) or was taking medication to control for attentional and behavioral problems.

Three control groups were created. A chronological age-matched control group (TD_CA), in which 20 typically developing participants were matched for chronological age ($t(36) = 0.346$; $p = .732$) and handedness (Fisher's exact test, $p = .328$) with the WS group. A non-verbal mental age matched control group (TD_NVMA), in which 20 typically developing participants were matched for non-verbal mental age ($t(36) = -1.442$; $p = .158$) and handedness (Fisher's exact test, $p = .328$) with the WS group. Non-verbal mental age was defined on the basis of the score on the Ravens Colored Progressive Matrices (RCPM; Raven, 1947). The RCPM are recognized as a non-verbal measure of fluid intelligence and were previously described as being a useful tool to make an adequate match between WS and respective control groups (Van Herwegen, Farran, & Annaz, 2011). None of the control participants had a history of psychiatric, neurologic and ophthalmologic illness and all were naïve concerning the testing procedures. They were recruited from local schools and were individually tested at their own schools. Finally, a control group with intellectual disability (ID) was included, in which 17 participants were matched for chronological age (Mann-Whitney test, $p = .630$), Full-Scale Intelligence Quotient (FSIQ) ($t(33) = 0.113$; $p = .911$), education level ($t(33) = -1.494$; $p = .145$), Raven score ($t(33) = -0.641$; $p = .526$), and handedness (Fisher's exact test; $p = .443$) with the WS group. The FSIQ score was obtained by using the Portuguese adapted version of the Wechsler Intelligence Scales, namely the Wechsler Intelligence Scale for Children – 3rd edition (WISC-III) or the Wechsler Adult Intelligence Scale – 3rd edition (WAIS-III), according to the participant's age (Wechsler, 2003, 2008). These participants were recruited from local special education institutes. None of these participants were taking selective serotonin reuptake inhibitor or neuroleptic medications. Participants with co-morbid conditions were excluded (epilepsy, brain injury, sensory deficits, associated genetic syndromes, and motor deficits that could interfere with task response). The characteristics of the patient and control groups are summarized in Table 1.

Informed consent was obtained from parents of participants or, when appropriate, the participants themselves. The study was approved by our local ethics committee and was conducted in accordance with the declaration of Helsinki.

Procedure

Participants were asked to perform two experimental tasks: a computerized and a 3D spatial judgment task. Two different tasks were used to explore both egocentric and allocentric spatial frames of reference.

Computerized spatial judgment task

In the computerized spatial judgment task, participants were individually tested in a quiet and darkened room, seated in a comfortable chair. The room was totally darkened for the computerized spatial judgment task to prevent that participants use the borders of the monitor or other landmarks as reference frame when performing the task. Stimuli were shown on a 33.8×27.1 cm computer screen using the software package Presentation (Neurobehavioral systems). After instructions were given, participants were asked to place their chin in a chin rest that was positioned at a distance of $\approx$50 cm from the computer screen. Two different experimental tasks were included: an egocentric task and an allocentric task.

In the egocentric task, an image of a tiger was shown during 300 ms on a dark screen after which participants had to indicate whether the tiger appeared on their left or on their right, using their own body as a frame of reference (Figure 1a). No time limit was used to respond. All participants were able to differentiate between left and right directions. The distance between the tiger and the center of the screen was manipulated by defining eight different positions across the horizontal axis. The defined locations were 0.57°, 1.72°, 3.02°, and 4.23° from the center of the screen on both left and right side, representing different levels of task difficulty. On each trial, the tiger was randomly presented on one of the eight locations. A total of 64 trials was included for the egocentric task. Eight practice trials were given and the practice phase was repeated whenever the subjects did not understand the instructions or had difficulties in coordinating the motor response.

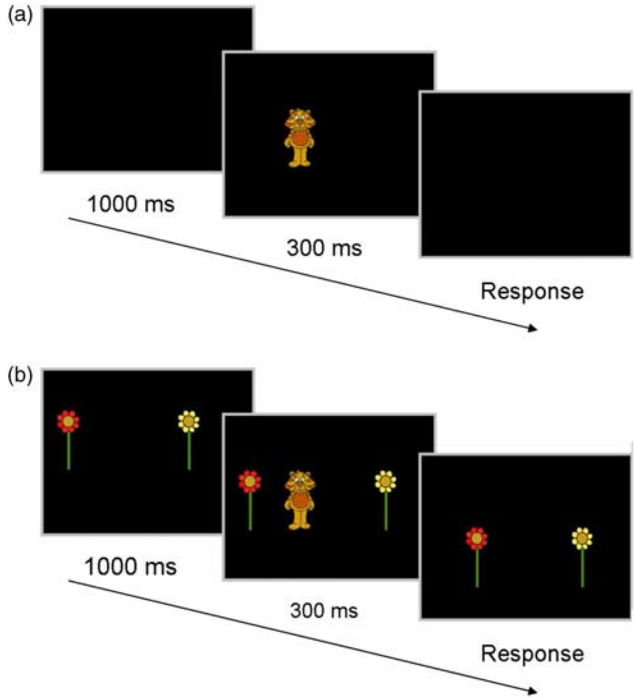

Fig. 1. Example of the display used on (a) egocentric and (b) allocentric computer tasks.

In the allocentric task, participants were also required to judge the position of a tiger that appeared during 300 ms. However, in this task, the judgments were performed in relation to two flowers that appeared on the screen (Figure 1b). Participants had to indicate whether the tiger was closer to the left or to the right flower. The distance between the two flowers was 22.90°. On each trial, the position of the flowers changed across the horizontal axis, although the distance between them remained constant to avoid body-centered spatial judgments. The position of the tiger was never in the center of the screen, but could be positioned in one of four locations on either left or right side of the center (0.57°, 1.72°, 3.02°, and 4.23°). A total of 64 trials was included as well as the eight practice trials.

3D spatial judgment task

In the 3D spatial judgment task participants were individually tested in a quiet and illuminated room, seated in a comfortable chair in front of a table where a white board was positioned. This task also included an egocentric and an allocentric task, as occurred in the previous task. For both tasks, three small toys were arranged on a white board of 42 × 29 cm.Ten trials were conducted and the position of the toys was manipulated on each trial. In the egocentric task, participants had to indicate which of the three toys was closer to their own body (Figure 2a). In the allocentric task, the procedure was the same as used in the egocentric task but including one additional toy (a white plane) (Figure 2b). No time limit was used for stimulus presentation or response. Subjects were instructed to indicate which of the three toys was closer to the white plane. This task also included ten trials.

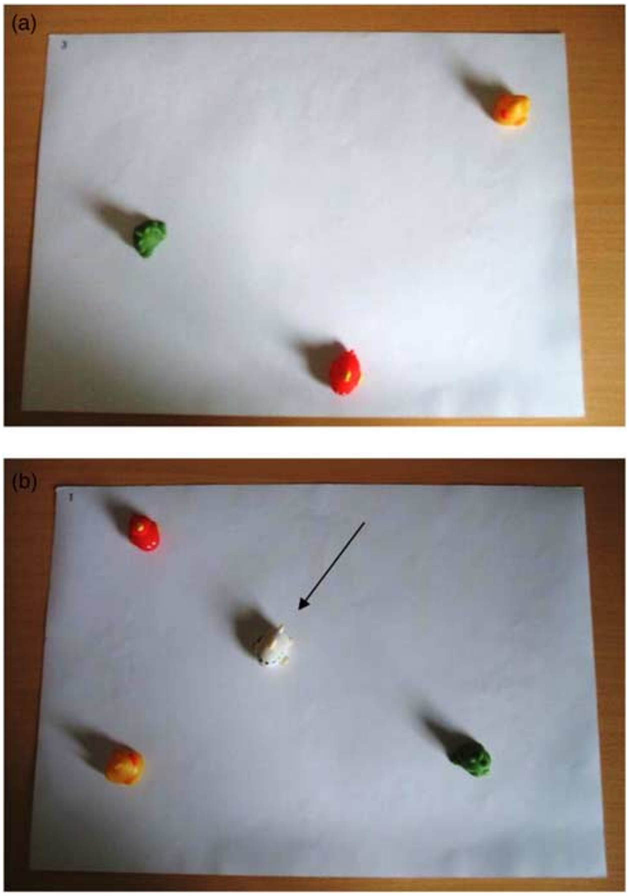

Fig. 2. Example of the display used on (a) egocentric and (b) allocentric three-dimensional tasks.

RESULTS

Separate analyses were performed for the computerized and 3D spatial judgment tasks, using percentage of incorrect responses and reaction times in ms as dependent variables.

For the *computerized spatial judgment task*, a repeated-measures analysis of variance (ANOVA) with Group (WS, TD_CA, TD_NVMA, ID) as between-subject factor and Task (egocentric, allocentric) and Condition (0.57°, 1.72°, 3.02°, 4.23°) as within-subject factor was conducted on the percentage of incorrect responses (Figure 3a,b), including age as covariate. No significant effect was found for Task ($F(1,71) = 1.30$; $p > .05$, $\eta^2 = 0.018$) nor an interaction effect for Task × Group ($F(3,71) = 0.190$; $p > .05$; $\eta^2 = 0.008$). These data suggest that, for the three groups, performance on both egocentric and allocentric tasks did not differ. Importantly, an overall effect of Group was found ($F(3,71) = 31.19$; $p < .001$; $\eta^2 = 0.569$). Tukey's *post hoc* testing showed that the WS group performed significantly worse than all control groups (TD_CA: $p < .001$; $d = 2.69$; TD_NVMA: $p < .001$; $d = 1.13$; ID: $p < .001$, $d = 1.43$). A main effect for Condition was found ($F(3,71) = 232.732$; $p < .001$; $\eta^2 = 0.766$), indicating that the different conditions that were used really represent different levels of task difficulty. Furthermore, the interaction effect for Condition × Group ($F(9,71) = 4.398$;

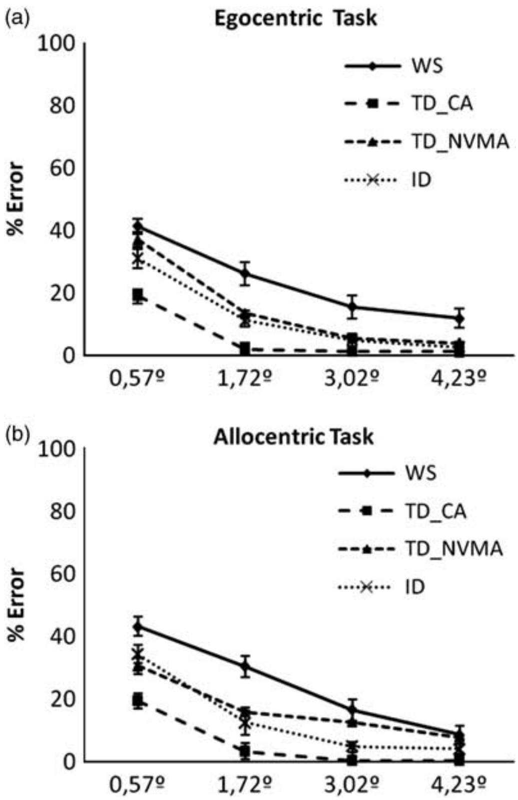

Fig. 3. Computerized task: percentage of error and standard errors of the mean for Williams syndrome (WS), chronological age-matched control group (TD_CA), non-verbal mental age matched control group (TD_NVMA), and control group with intellectual disability (ID) groups as a function of task difficulty (0.57°, 1.72°, 3.02°, and 4.23°) on (a) egocentric and (b) allocentric tasks.

$p < .001$; $\eta^2 = 0.157$) suggest that the WS group made relatively more errors in the more difficult trials. Additionally, age did not show a significant contribution to explain the present findings ($p > .05$). Together, these results indicate that the WS group made significantly more errors than all control groups when asked to perform both egocentric and allocentric spatial judgments in this computer task.

In a complementary analysis, we fit a psychometric function to each subject's response to understand the effect of the different levels of difficulty introduced in the task on the subject's performance. As can be seen in Figure 4, the function that best fitted the pattern of performance in response to this task was the Gaussian function. Thus, the conditions that evoked more errors are those in which the tiger appeared near to the center of the screen and the easiest conditions are those in which the tiger appeared in both extremes, on left and right sides. The Gaussian fitting was performed by using the Curve Fitting Toolbox of the Matlab software (7.10.0 version). The function used to obtain the fitting was a1*exp (−((x−b1)/c1)^2), in which "a" corresponds to the peak intensity, "b" gives the peak position and "c" represents the "width" of the Gaussian curve. Additionally, we obtained the r-square (the correlation between the response values and the predicted response values) for each fitting, which measures how successful the fit is in explaining the variation of the data. The values of the r-square were between 0.85 and 1 for the egocentric task and between 0.88 and 1 for the allocentric task.

All these parameters were obtained for each subject in both egocentric and allocentric tasks. For the analyses including the parameters from the Egocentric task, a one-way ANOVA revealed a group effect for the "width" of the curve measure ($F(3,70) = 7.23$; $p < .05$; $\eta^2 = 0.237$), while no group effect was found for the peak intensity ($F(3,70) = 2.63$; $p > .05$; $\eta^2 = 0.101$) and the peak position ($F(3,70) = 1.30$; $p > .05$; $\eta^2 = 0.053$). *Post hoc* analyses (Tukey's test) revealed that significant differences concerning the "width" of the curve occurred between the WS group and all control groups (TD_CA: $p < .001$; $d = 1.08$; TD_NVMA: $p < .05$; d = 0.93; ID: $p < .05$; $d = 0.85$) (see Figure 4a).

Regarding the analyses including the parameters from the Allocentric task, a one-way ANOVA did not show a group effect for the peak intensity ($F(3,70) = 1.69$; $p > .05$; $\eta^2 = 0.069$), but revealed a group effect for the position of the peak ($F(3,70) = 31.05$; $p < .001$; $\eta^2 = 0.578$) and for the "width" of the curve ($F(3,70) = 14.21$; $p < .05$; $\eta^2 = 0.385$). *Post hoc* testing indicated that concerning the peak position, the WS group differed from the TD_NVMA ($p < .001$; $d = -1.93$) and the ID ($p < .001$; $d = -2.95$) control group, but not from the TD_CA ($p > .05$; $d = -1.13$) group. Concerning the "width" of the curve, the WS group differed from the TD_CA ($p < .001$; $d = 2.57$) and the ID ($p < .001$; $d = 1.46$) group, but not from the TD_NVMA group ($p > .05$; $d = 0.63$) (see Figure 4b).

Since we found a significant main effect for Group for the peak position in the allocentric task, we performed a One-Sample *t*-test, for each group, comparing the value of the peak position with 0 (corresponding to the center of the screen) to identify a possible bias for one of the sides of the screen (left or right sides). Interestingly, significant differences were found for all control groups (TD_CA ($t(19) = 3.60$; $p < .05$), TD_NVMA ($t(19) = 5.764$; $p < .001$) and ID ($t(16) = 8.38$; $p < .001$)), but not for the WS group ($t(17) = -1.93$; $p > .05$). These results revealed that control participants showed a left visual hemifield advantage, whereas WS participants did not. The differences found concerning the "width" of the curve revealed that WS participants made more errors in the intermediate and in the easiest conditions when compared with the controls, although in the allocentric task the performance was similar to the TD_NVMA controls. Additionally, the peak intensity results indicated that the difficulty of the task has the same impact on the performance of both WS and control groups with all groups showing more errors on the more difficult conditions (0.57° left and right).

To analyze the reaction times of the computerized spatial judgment task, a repeated measures ANOVA with Group (WS, TD_CA, TD_NVMA, ID) as between-subject factor and Task (egocentric, allocentric) and Condition (0.57°, 1.72°, 3.02°, 4.23°) as within-subject factor was conducted (see Figure 5a,b), including chronological age as covariate. Results revealed no significant main effect for Task ($F(1,71) = 0.06$; $p > .05$; $\eta^2 = 0.001$), nor a significant

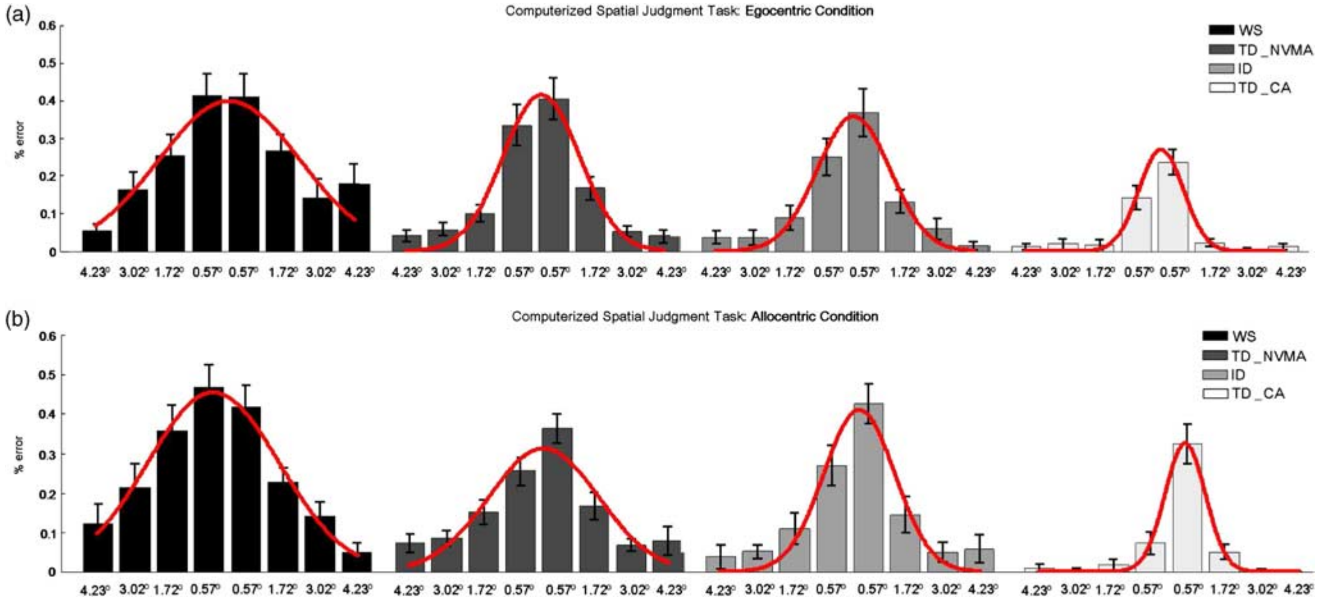

Fig. 4. Gaussian fitting [a1*exp (−((x−b1)/c1)^2)] to the error responses of the Williams syndrome (WS), chronological age-matched control group (TD_CA), non-verbal mental age matched control group (TD_NVMA), and control group with intellectual disability (ID) groups for the (a) egocentric and (b) allocentric tasks.

interaction effect for Task × Groups ($F(3,71) = 0.264$; $p > .05$; $\eta^2 = 0.011$). On the other hand, a significant main effect for Condition ($F(3,71) = 27.594$; $p < .001$; $\eta^2 = 0.280$) was found as well as a significant interaction effect for Condition × Group ($F(3,71) = 2.486$; $p < .05$; $\eta^2 = 0.095$). Additionally, a significant effect of Group was also found ($F(3,71) = 5.094$; $p < .05$; $\eta^2 = 0.177$). Tukey's *post hoc* testing revealed that the WS group is significantly slower than the TD_CA group ($p < .05$; $d = 1.04$), but need the same time to respond as both the TD_NVMA ($p > .05$; $d = 0.32$) and the ID ($p > .05$; $d = 0.46$) control group. Again, age did not contribute to explain the results ($p > .05$).

For the 3D spatial judgment task, the pattern of results was similar to those obtained in the computerized spatial judgment task (Figure 6). A repeated measures ANOVA with Group (WS, TD_CA, TD_NVMA, ID) as between-subject factor and Task (egocentric *vs.* allocentric) as within-subject variable showed a significant effect for Task, ($F(1,71) = 15.457$; $p < .001$; $\eta^2 = 0.179$). However, no significant interaction occurred for Task × Group ($F(3,71) = 0.15$; $p > .05$; $\eta^2 = 0.006$). Moreover, a significant effect of Group was found ($F(3,71) = 6.53$; $p < .05$; $\eta^2 = 0.216$). Tukey's post-hoc tests indicated that WS participants made significantly more errors than TD_CA ($p < .001$; $d = 1.43$) but performed similarly as both TD_NVMA ($p > .05$; $d = 0.53$) and ID ($p > .05$; $d = 0.61$) control groups. Age did not contribute to explain the results ($p > .05$). The WS group exhibited deficits in perceiving egocentric as well as allocentric information when compared with chronological age-matched controls but achieved the level of performance exhibited by participants with intellectual disability and with matched non-verbal skills when tested in more ecological environments and without time-limits.

DISCUSSION

The current study was aimed at investigating visual processing of egocentric and allocentric spatial relations between objects in WS. We conducted two experimental tasks requiring subjects to perform visual spatial judgments of the location of objects using their own-body or external objects as frames of reference.

In the first task, subjects needed to discriminate locations of objects that appeared on a computer screen using allocentric as well as egocentric frames of reference. The results of this task indicate that the ability to make egocentric and allocentric spatial judgments is impaired in WS participants. Interestingly, no interaction effect emerged for Group and Task, indicating that the impairment exhibited by WS participants is equally serious for both egocentric and allocentric spatial judgments. WS participants performed significantly worse than all control participants on all levels of task difficulty for both reference frames. These results were found even when the groups were matched for non-verbal mental age and also for intellectual disability. Thus, WS participants were consistently impaired in all conditions. Importantly, the larger number of errors exhibited by WS group is not related to faster responses due to attentional problems and impulsive responses, as was demonstrated by reaction time analysis. Indeed, WS participants were slower than control participants matched for chronological age and needed the same time as both control participants matched on non-verbal mental age and intellectual disability. It remains, however, important to analyze the qualitative pattern of results especially taking into account the different levels of complexity introduced in the task. The fitting analysis demonstrated that the WS group show similar results as both control groups in the more

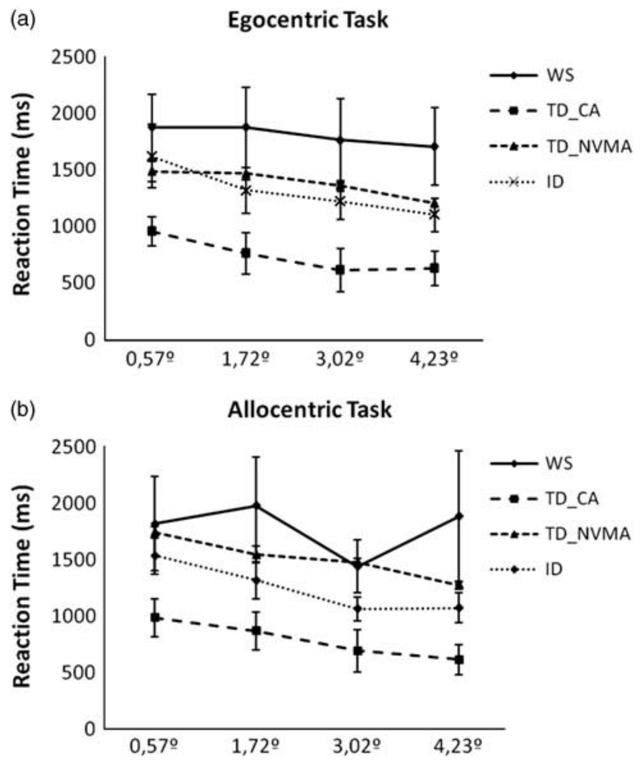

Fig. 5. Computerized task: reaction times (ms) and standard errors of the mean for Williams syndrome (WS), chronological age-matched control group (TD_CA), non-verbal mental age matched control group (TD_NVMA), and control group with intellectual disability (ID) groups as a function of task difficulty (0.57°, 1.72°, 3.02°, and 4.23°) on (a) egocentric and (b) allocentric tasks.

difficult conditions (peak intensity measure), but committed more errors in the intermediate and in the easiest conditions ("width" of the curve measure). Additionally, for the allocentric task, the peak position analysis revealed a left visual hemifield advantage for all the control groups, but not for the WS participants. The left hemifield advantage found in control participants is in line with some studies suggesting that neurologically normal participants exhibit a phenomenon similar to that found in neglect patients called "pseudoneglect" (Bowers & Heilman, 1980). In fact, this left visual hemifield advantage has been demonstrated in several tasks that involve visual attention (McCourt & Garlinghouse, 2000) and is thought to be the result of the dominant role of the right posterior parietal cortex in visuospatial attention.

It should be noted that the computerized spatial judgment task, particularly the egocentric task, required a well established knowledge of left and right directions which might introduce additional confounds for WS participants, even though they all were able to correctly discriminate between left and right.

In the second task, a more ecological approach was used by using 3D small toys that were displayed on a board. Subjects were again asked to make either an egocentric or allocentric spatial judgment. The results of this task were similar to those found in the computer task confirming the egocentric and allocentric impairments in WS participants. Indeed, no interaction effect was found between the tasks and the groups, suggesting equal impairment for both egocentric and allocentric tasks. In this 3D spatial judgment task, WS participants achieved similar results to those found in participants with the same level of intellectual disability and non-verbal mental age. This suggests performance improves when using more ecological approaches and by giving them unlimited viewing time.

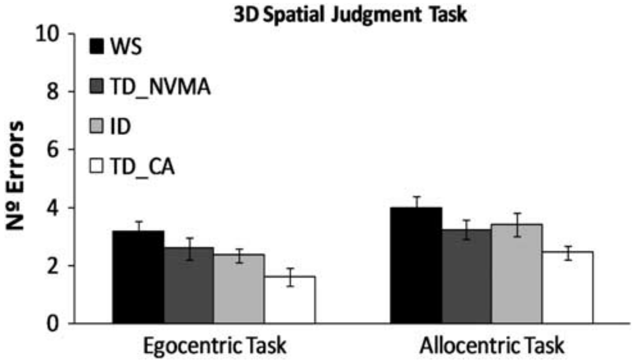

Fig. 6. The 3D Task. Number of errors and standard errors of the mean for Williams syndrome (WS), non-verbal mental age matched control group (TD_NVMA), control group with intellectual disability (ID), and chronological age-matched control group (TD_CA) groups for the egocentric and allocentric tasks.

These findings indicate that egocentric as well as allocentric perception is impaired in WS. These results are in line with the study of Nardini et al. (2008), who showed that both body- and landmark- spatial memory representations are impaired in this disorder. Our results indicate that the deficit found in WS participants regarding the spatial memory coding of egocentric and allocentric information might not only be a result of memory component requirements but it is present even when only perceptual judgments are involved.

The impairment in representing egocentric information is in agreement with existing literature suggesting a dorsal stream dysfunction in WS (Atkinson et al., 2003; Castelo-Branco et al., 2007; Meyer-Lindenberg et al., 2004). Moreover, the evidence of impaired processing concerning allocentric information suggests impaired ventral stream and hippocampal and parahippocampal functioning. That is, neural correlates of allocentric spatial representations are thought to include the ventral stream and hippocampal and parahippocampal regions (Holdstock et al., 2000). The latter regions have been found to be affected in WS participants (Meyer-Lindenberg et al., 2005), although a ventral stream weakness is less documented. Although psychophysical and neuroimaging studies have provided important insights into the ventral functioning in WS (Paul et al., 2002), thus far most studies have focused on face perception and recognition skills of WS participants, who demonstrate an overall good performance on these tasks which seems to be comparable to typically developing individuals, albeit conducted by differing mechanisms (Deruelle, Mancini, Livet, Casse-Perrot & de Schonen, 1999; Karmiloff-Smith et al., 2004). Moreover, the involvement of both egocentric and allocentric spatial representations was found to be determinant for face processing (Chang, Harris, & Troje, 2010). More research is still needed to understand the role of egocentric and allocentric frames of reference in face processing, thereby adding to our understanding of visual pathway functioning in WS.

It is interesting to note, however, that studies exploring the developmental trajectories for egocentric and allocentric representations as well as classical developmental literature (Piaget & Inhelder, 1948) suggest that the spontaneous use of allocentric representations develops during the school years, while the egocentric spatial coding emerges in early infancy. Bullens, Igói, Berthoz, Postma, and Rondi-Reig (2010) demonstrated that the correct use of allocentric representations arises between 7 and 10 years of age, reaching the ability to elaborate complex representations of the environment from 10 years onward. On the other hand, the spontaneous use of egocentric spatial representations is established at 5 years of age (Bullens et al., 2010), although Nardini, Burgess, Breckenridge, and Atkinson (2006) have proposed that the viewer-dependent spatial judgments are present as early as 3 years. This suggests a progressive shift from body-centered perspectives to world-centered representations between 5 and 10 years of age. Accordingly, it was recently suggested by Zaehle et al. (2007) that the allocentric representations develop late in phylogenesis as well as in ontogenesis. The authors proposed that allocentric coding develops based on egocentric coding and partly shares the same neural sources (precuneus), although it recruits additional brain areas, namely right parietal areas, the bilateral ventral visual stream and the hippocampal formation. Therefore, although there are some studies claiming the parallel development of egocentric and allocentric spatial representations (Iglói, Zaoui, Berthoz, & Rondi-Reig, 2009), other studies argued that some dependencies occur between the two frames of reference and they interact to process complex representations of the environment (Burgess, 2006). Based on these findings, we could hypothesise that the egocentric deficits found in WS, as a result of dorsal visual stream impairment, might also be contributing to the difficulties evidenced in the allocentric spatial judgment tasks. Thus, the lack of body-centered spatial representations in WS participants could be an important factor for determining the incomplete development of external reference frames. In fact, the use of landmarks as a complement of the body-centered reference frame in wayfinding tasks has been consistently found to be impaired in this disorder (Atkinson et al., 2001).

Concluding, the current study demonstrated that perception of both egocentric and allocentric spatial relations is impaired in WS participants. The impairment concerning the processing of egocentric information confirms the dorsal visual pathway deficit extensively reported in WS. On the other hand, the difficulties found in performing allocentric spatial judgments are in line with the hippocampal dysfunction and may suggest impaired ventral visual stream function. However, further research is still needed to contribute for a better understanding of the ventral visual stream functioning in WS and its possible implications for the development of spatial representations in this disorder.

ACKNOWLEDGMENTS

We thank the WS participants, their families and “Associação Portuguesa de Pais e Amigos do Cidadão com Deficiência Mental” (APPACDM) of Coimbra and “Associação Paralisia Cerebral Coimbra (APCC)/ Quinta da Conraria” for their participation and support. The authors disclose the absence of commercial or financial relationships that could constitute a potential conflict of interest. The information in this manuscript and the manuscript itself has never been published either electronically or in print. This research was supported by the Foundation for Science and Technology Portugal (I.B., grant number SRFH/BD/41401/2007), (S.M., grant number PIC/IC/82986/2007), (M.C.B. grant numbers PTDC/SAU-NEU/68483/2006 and PIC/IC/82986/2007), (M.V.A., grant number PTDC/SAU-NSC/113471/2009).

REFERENCES

Atkinson, J., Braddick, O., Anker, S., Curran, W., Andrew, R., & Wattam-Bell, J. (2003). Neurobiological models of visuospatial cognition in children with Williams syndrome: Measures of dorsal-stream and frontal function. *Developmental Neuropsychology*, *23*(1–2), 139–172.

Atkinson, J., Shirley, A., Braddick, O., Nokes, L., Mason, A., & Braddick, F. (2001). Visual and visuospatial development in young children with Williams syndrome. *Developmental Medicine & Child Neurology*, *43*(5), 330–337.

Bayes, M., Magano, L.F., Rivera, N., Flores, R., & Perez-Jurado, L.A. (2003). Mutational mechanisms of Williams-Beuren syndrome deletions. *The American Journal of Human Genetics*, *73*(1), 131–151.

Bellugi, U., Lichtenberger, L., Jones, W., Lai, Z., & St George, M. (2000). I. The neurocognitive profile of Williams Syndrome: A complex pattern of strengths and weaknesses. *Journal of Cognitive Neuroscience*, *12*(Suppl 1), 7–29.

Bowers, D., & Heilman, K.M. (1980). Pseudoneglect: Effects of hemispace on a tactile line bisection task. *Neuropsycologia*, *18*(4–5), 491–498.

Bullens, J., Igóli, K., Berthoz, A., Postma, A., & Rondi-Reig, L. (2010). Developmental time course of the acquisition of sequential egocentric and allocentric navigation strategies. *Journal of Experimental Child Psychology*, *107*, 337–350.

Burgess, N. (2006). Saptial memory: How egocentric and allocentric combine. *Trends in Cognitive Sciences*, *10*, 551–557.

Castelo-Branco, M., Mendes, M., Sebastião, A.R., Reis, A., Soares, M., Saraiva, J., … Silva, E. (2007). Visual phenotype in Williams-Beuren syndrome challenges magnocellular theories explaining human neurodevelopmental visual cortical disorders. *The Journal of Clinical Investigation*, *117*(12), 3720–3729.

Chang, D.H., Harris, L.R., & Troje, N.F. (2010). Frames of reference for biological motion and face perception. *Journal of Vision*, *10*(6), 1–11.

Cohen, Y.E., & Andersen, R.A. (2002). A common reference frame for movement plans in the posterior parietal cortex. *Nature Review Neuroscience*, *3*(7), 553–562.

Deruelle, C., Mancini, J., Livet, M.O., Casse-Perrot, C., & de Schonen, S. (1999). Configural and local processing of faces in children with Williams syndrome. *Brain Cognition*, *41*(3), 276–298.

Farran, E., Courbois, Y., & Cruickshank, A. (2009). Learning a route in a virtual environment: The effects of differing cues on the performance of typical children and individuals with Williams syndrome. *Cognitive Processing*, *10*, S152–S153.

Farran, E.K., Blades, M., Boucher, J., & Tranter, L.J. (2010). How do individuals with Williams syndrome learn a route in a real world environment? *Developmental Science*, *13*, 454–468.

Feigenbaum, J.D., & Morris, R.G. (2004). Allocentric versus egocentric spatial memory after unilateral temporal lobectomy in humans. *Neuropsychology*, *18*(3), 462–472.

Galati, G., Lobel, E., Vallar, G., Berthoz, A., Pizzamiglio, L., & Le Bihan, D. (2000). The neural basis of egocentric and allocentric coding of space in humans: A functional magnetic resonance study. *Experimental Brain Research*, *133*(2), 156–164.

Goodale, M.A., & Haffenden, A. (1998). Frames of reference for perception and action in the human visual system. *Neuroscience & Biobehavioral Review*, *22*(2), 161–172.

Grimsen, C., Hildebrandt, H., & Fahle, M. (2008). Dissociation of egocentric and allocentric coding of space in visual search after right middle cerebral artery stroke. *Neuropsychologia*, *46*(3), 902–914.

Holdstock, J.S., Mayes, A.R., Cezayirli, E., Aggleton, J.P., & Roberts, N. (1999). A comparison of egocentric and allocentric spatial memory in medial temporal lobe and Korsakoff amnesics. *Cortex*, *35*(4), 479–501.

Holdstock, J.S., Mayes, A.R., Cezayirli, E., Isaac, C.L., Aggleton, J.P., & Roberts, N. (2000). A comparison of egocentric and allocentric spatial memory in a patient with selective hippocampal damage. *Neuropsychologia*, *38*, 410–425.

Iglói, K., Zaoui, M., Berthoz, A., & Rondi-Reig, L. (2009). Sequential egocentric strategy is acquired as early as allocentric strategy: Parallel acquisition of these two navigation strategies. *Hippocampus*, *19*, 1199–1211.

Jackowski, A.P., Rando, K., Maria de Araujo, C., Del Cole, C.G., Silva, I., & Tavares de Lacerda, A.L. (2009). Brain abnormalities in Williams syndrome: A review of structural and functional magnetic resonance imaging findings. *European Journal of Paediatric Neurology*, *13*(4), 305–316.

Karmiloff-Smith, A., Thomas, M., Annaz, D., Humphreys, K., Ewing, S., Brace, N., … Campbell, R. (2004). Exploring the Williams syndrome face-processing debate: The importance of building developmental trajectories. *Journal of Child Psychology and Psychiatry*, *45*(7), 1258–1274.

Korenberg, J.R., Chen, X.N., Hirota, H., Lai, Z., Bellugi, U., Burian, D., … Matsuoka, R. (2000). VI. Genome structure and cognitive map of Williams syndrome. *Journal of Cognitive Neuroscience*, *12*(Suppl 1), 89–107.

McCourt, M.E., & Garlinghouse, M. (2000). Asymmetries of visuospatial attention are modulated by viewing distance and visual field elevation: Pseudoneglect in peripersonal and extrapersonal space. *Cortex*, *36*, 715–731.

Mendes, M., Silva, F., Simoes, L., Jorge, M., Saraiva, J., & Castelo-Branco, M. (2005). Visual magnocellular and structure from motion perceptual deficits in a neurodevelopmental model of dorsal stream function. *Cognitive Brain Research*, *25*(3), 788–798.

Meyer-Lindenberg, A., Kohn, P., Mervis, C.B., Kippenhan, J.S., Olsen, R.K., Morris, C.A., & Berman, F. (2004). Neural basis of genetically determined visuospatial construction deficit in Williams syndrome. *Neuron*, *43*(5), 623–631.

Meyer-Lindenberg, A., Mervis, C., & Berman, F. (2005). Neural mechanisms in Williams syndrome: A unique window to genetic influences on cognition and behaviour. *Nature Reviews*, *7*, 380–393.

Milner, A.D., & Goodale, M.A. (2008). Two visual systems re-viewed. *Neuropsychologia*, *46*(3), 774–785.

Montfoort, I., Frens, M.A., Hooge, I.T., Haselen, G.C., & van der Geest, J.N. (2007). Visual search in Williams-Beuren syndrome. *Neuropsychologia*, *45*, 931–938.

Nardini, M., Atkinson, J., Braddick, O., & Burgess, N. (2008). Developmental trajectories for spatial frames of reference in Williams syndrome. *Developmental Science*, *11*(4), 583–595.

Nardini, M., Burgess, N., Breckenridge, K., & Atkinson, J. (2006). Differential developmental trajectories for egocentric, environmental and intrinsic frames of reference in spatial memory. *Cognition*, *101*, 153–172.

O'Keefe, J., & Nadel, L. (1978). *The hippocampus as a cognitive map*. Oxford: Clarendon.

Paul, B.M., Stiles, J., Passarotti, A., Bavar, N., & Bellugi, U. (2002). Face and place processing in Williams syndrome: Evidence for a dorsal-ventral dissociation. *Neuroreport*, *13*(9), 1115–1119.

Piaget, J., & Inhelder, B. (1948). *The child's conception of space*. New York: Norton.

Raven, J.C. (1947). *Coloured progressive matrices sets A, Ab, B*. Oxford: Oxford Psychologists Press Ltd.

Reiss, J.E., Hoffman, J.E., & Landau, B. (2005). Motion processing specialization in Williams syndrome. *Vision Research*, *45*(27), 3379–3390.

Semel, E., & Rosner, S.R. (2003). *Understanding Williams syndrome. Behavioural patterns and interventions*. New Jersey. Lawrence Erlbaum Associates.

Seubert, J., Humphreys, G.W., Muller, H.J., & Gramann, K. (2008). Straight after the turn: The role of the parietal lobes in egocentric space processing. *Neurocase*, *14*(2), 204–219.

Vallar, G., Lobel, E., Galati, G., Berthoz, A., Pizzamiglio, L., & Le Bihan, D. (1999). A fronto-parietal system for computing the egocentric spatial frame of reference in humans. *Experimental Brain Research*, *124*(3), 281–286.

van Asselen, M., Kessels, R.P., Kappelle, L.J., Neggers, S.F., Frijns, C.J., & Postma, A. (2006). Neural correlates of human wayfinding in stroke participants. *Brain Research*, *1067*(1), 229–238.

van Herwegen, J., Farran, E.K., & Annaz, D. (2011). Item and error analysis on Raven's coloured progressive matrices in Williams syndrome. *Research in Developmental Disabilities*, *32*, 93–99.

Vicari, S., Bellucci, S., & Carlesimo, G. (2005). Visual and spatial long-term memory: Differential pattern of impairments in Williams and Down syndromes. *Developmental Medicine & Child Neurology*, *47*, 305–311.

Wechsler, D. (2003). *Manual for intelligence scale for children* (3rd ed.). Lisbon: Cegoc-Tea.

Wechsler, D. (2008). *Manual for intelligence scale for adults* (3rd ed.). Lisbon: Cegoc-Tea.

Zaehle, T., Jordan, K., Wüstenberg, T., Baudewig, J., Dechent, P., & Mast, F.W. (2007). The neural basis of the egocentric and allocentric spatial frame of reference. *Brain Research*, *1137*, 92–103.