Egocentric and allocentric spatial references in children with Cerebral Palsy

Laura Barca (laura.barca@istc.cnr.it)
Neuroscience and Neurorehabilitation Department
Children's Hospital Bambino Gesù - IRCCS
Lungomare G. Marconi 36, 00058 - Santa Marinella (Rome), Italy

Giovanni Pezzulo (giovanni.pezzulo@cnr.it)
Istituto di Linguistica Computazionale 'Antonio Zampolli', CNR, Pisa, Italy
Istituto di Scienze e Tecnologie della Cognizione, CNR – Roma, Italy

Enrico Castelli (enrico.castelli@opbg.net)
Neuroscience and Neurorehabilitation Department
Children's Hospital Bambino Gesù - IRCCS
Lungomare G. Marconi 36, 00058 - Santa Marinella (Rome), Italy

Abstract

Spatial memory is supported by multiple parallel representations of the environment. Egocentric perspective (body-centered) and allocentric representations (object-centered) are integrated to allow correct interaction with the world. According to Milner and Goodale (1995, 2008), the action-related dorsal system is specialized for location of objects in space and visuo-motor integration, and uses an egocentric frame of reference. The perception-related ventral system is specialized for categorical recognition of objects and forms, and supports an allocentric frame of reference. Here we use a Distance Judgment Task to explore the use of different spatial frames in children with Cerebral Palsy (CP). Following the dorsal stream vulnerability hypothesis (Atkinson et al., 2007) children with CP might have more difficulties in egocentric judgments and in the processing of peri-personal space than controls. No significant difference emerged between CP children and controls in allocentric judgments, whereas performance was worse in egocentric judgment, indicating inefficient use of the body-centered representations. **Keywords:** Egocentric-allocentric spatial references; Distance Judgment task; Cerebral Palsy (CP).

Introduction

Humans are provided with different reference systems to code the environment and its physical attributes. For example, if we have to specify the location of an object we can make use of different frames of reference: we can define its position with respect to our body (egocentric frame) or we can refer to other objects in the environment or the environment itself (allocentric frame). Egocentric coordinates are based on the organism's position, and then linked to the specific perspective under which spatial information has been processed. Hence, these representations are particularly relevant in action planning and motor control in near space, when there is a direct interaction between body and objects. Egocentric frames have been described in relation to the different body part they are based on, such as head-centered, eye-centered, and arm-centered (Colby, 1998). Allocentric, or object-centered frames, are external to the organism and usually centered on objects in the environment. Such coding of space has an important role in the processing of far space when objects are out of reach. Among allocentric representation, distinctions can be made when the point of reference is centered on an object of interest (object-centered) or on the environment (e.g., room-centered) (Colby, 1998). The information derived by egocentric and allocentric maps is usually integrated to allow proficient spatial processing (Burgess, 2006). However, some tasks rely more on one frame than the other. For example, pointing to a location in space within arm reach or grasping an object are likely accomplished within an egocentric framework, whereas defining the fastest route between two destinations is likely to involve an allocentric frame. Overall, selection of what spatial frame(s) of reference to use is highly action-specific.

A number of studies showed that several regions of the cerebral cortex subserved functions involved in spatial processing, having a reach network of reciprocal connections and link with subcortical structures. In the fMRI study by Zaehle et al., (2007) participants performed a spatial judgment task based on verbal instructions. They have to define the spatial relations between different objects (allocentric condition), or the position of objects with respect to the participants (egocentric condition). A fronto-parietal network was involved in both egocentric and allocentric judgments (e.g., superior occipital gyrus, medial portion of superior parietal cortex, superior frontal gyri bilaterally), but partly separated networks mediate different spatial coding strategies. While egocentric spatial coding revealed activation mainly within the medial parts of the posterior superior parietal lobe, the use of the allocentric reference frame revealed activation in right parietal lobe, bilateral ventrolateral occipito-temporal cortex and bilateral hippocampal formation. There is also increasing evidence of the critical role of connecting circuits, and the vestibular system (Paillard, 1991). Dysfunction of egocentric frames appeared to be associated with damage in premotor cortex involving frontal eye field, whereas allocentric impairments are linked to lesions in more ventral regions near the parahippocampal gyrus (for a recent review see Grimsen, Hildebrandt, and Fahle, 2008). Patients with visual form agnosia, which is associated with ventral stream damage, have been reported to have selective impairments in allocentric judgments of spatial coding, with spared egocentric processing (Carey, Dijkerman, and Milner, 2009; Carey et al., 2006; Dijkerman, Milner, and Carey, 1998). The study from Galati et al. (2000) showed a different lateralization of spatial coding networks across the cerebral hemispheres, with body-centered frames more lateralized in the right hemisphere. In line with this evidence are the neuropsychological data from Iachini et al., (2009), were patients with right parietal lesions failed in egocentric but not allocentric distance judgments, whereas those with left parietal damages have difficulties in both frames of reference.

From a developmental point of view, the body is the primary available spatial code for the infant and allocentric references develops later in life, having a longer maturational trajectory. However, Nardini et al., (2006) suggests that object-centered coordinates and the integration between different coding systems occur earlier than previously thought. Using a task in which children have to recall the location of hidden toys within an array, they showed that spatial representations based on the environment (allocentric frames) develop between years three and six. Such experimental paradigm has been applied also to the study of spatial localization in clinical population (Nardini et al., 2008), however it might have limited application to patients with motor and deambulation deficits as one of its key components is the 'subject-move' condition.

Here we study spatial cognition in children with Cerebral Palsy exploring their use of different spatial frames of references. CP is defined as ‘‘a group of permanent disorders of the development of movement and posture, causing activity limitation, that are attributed to non progressive disturbances that occurred in the developing fetal or infant brain’’ (Rosenbaum et al., 2007). In the framework of visual cognition, it has been shown that the dorsal visual system (with its connections to parietal, frontal and hippocampal areas and its relations to the egocentric frame of reference) is more vulnerable to insult occurring early in life than ventral visual system. Children with hemiplegic CP (e.g., a motor deficit characterized by paralysis of the arm, leg, and trunk on the same side of the body) perform significantly worse than controls in dorsal stream tasks (e.g., motion coherence task) than ventral stream tasks (e.g., form coherence task). While a subgroup of hemiplegic children performed better than the normal median level for their age on the form coherence task, all the hemiplegic children performed close to the median level, or worse, for their age on the motion coherence task (Gunn et al., 2002). CP children often presents with visual disorders comprising ophthalmological abnormalities and impairments in higher visuofunctional skills, which are considered a clinical manifestation of dysfunctions of visual associative areas of the dorsal visual path (Barca et al., 2010). The vulnerability of dorsal stream has been shown also in healthy children born preterm with no sign of neurological deficit, visual disturbances, or cognitive and motor deficits (Santos et al., 2008). Such findings suggest that the number of gestational weeks has an important influence on the normal development of visual cognition. Linking the vulnerability of the dorsal stream with the association of this brain regions with egocentric spatial representations, one can assume that mainly egocentric representations would be impaired in spatial processing of CP.

The aim of this study was to investigate the impact that brain injuries occurring early in life (e.g., prenatal or perinatal period) exert on the development of the different coordinate systems used for the coding of space, by studying the performance of hemiplegic CP children on a distance judgment task. Specifically, our main research question is: are egocentric (self-referred) and allocentric (object-referred) distance judgments similarly impaired? The dorsal/ventral distinction has been recently extended to spatial processing, suggesting that the dorsal circuit provides egocentric coding of space for motor control and action planning whereas the ventral circuit is tuned with allocentric coding of space (Medina et al. 2009). Hence, the dorsal stream vulnerability hypothesis would predict children with CP to have more difficulties in egocentric judgments and in the processing of peri-personal space than age matched controls. However, given the precocity of the cerebral insult, they might develop compensatory mechanisms that allow to correctly processing spatial representations, as has been shown in patients with idiopathic cervical dystonia (Ploner et al., 2005). Neuropsychological adult literature provides evidence of a link between dorsal stream lesions and impairments in egocentric judgments (Berryhill, Fendrich and Olson, 2009). However, patients with parietal damage having the opposite deficit (i.e., allocentric impairments with spared egocentric references) have also been reported (Carey et al., 2006), thus questioning the direct link between parietal lesions and body-centered perspective.

To test the prediction of a major impairment in egocentric than allocentric representations of space in children with CP, we conducted a behavioral study in which egocentric and allocentric stimulus coordinates were varied in order to individuate their contribution in making spatial judgments. The procedure of the experiment was motivated by the work of Iachini and colleagues (Iachini, et al., 2006; Iachini et al., 2009), as they were able to consistently and effectively induce a differential involvement of spatial coding systems with such procedure. However, several changes (which will be described in the following section) have been introduced to make the task feasible for a pediatric clinical population.

Method and Materials

Participants

A group of seven children with CP participated in the study. They were 3 male and 4 female, with mean chronological age of 7 years (range 5-9 years), with no spatial neglect, language or general intellectual impairments. Four child presents with Hemiplegia, and 3 with Diplegia. A control group of 5 children with typical development was used for comparison. Children of this group had no history of visual, motor or cognitive delay, and mean chronological age of 10 years (range 8-12 years),

Neuropsychological assessment

General cognitive level was assessed with the Raven's Colored Progressive Matrices, CPM (Raven and Raven, 1986), which has been recently shown to be a valid tool in the assessment of cognitive functioning in CP (Pueyo et al., 2008). To assess visuoperceptual and visuomotor integration skills we used the Developmental Test of Visual Perception, DTVP (Hammill, Pearson, and Voress, 1994). The Corsi block-tapping task (Corsi, 1972; Milner, 1971) was used as a measure of visuospatial working memory. Parents of the controls group fulfilled the questionnaire of Houliston et al., (1999), adapted to Italian and used as a screening measure of children's neurovisual behavior (e.g., questions regards child’s ability to recognize objects and faces, finding way in home, distinguishing line from steps and the perception of motion).

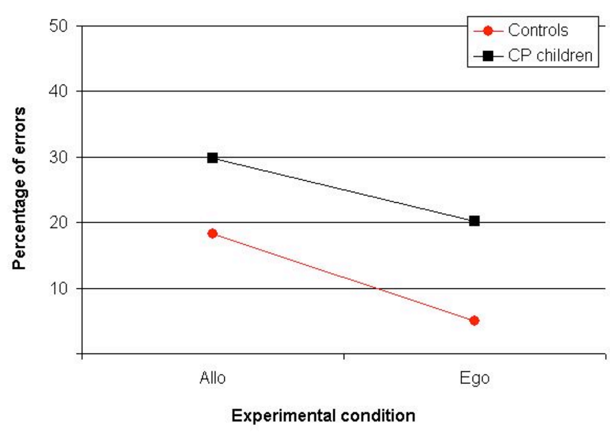
Experimental task

A Distance Judgment Task, adapted from Iachini et al. (Iachini et al., 2006; Iachini et al., 2009), has been used. Children were presented with triads of 3D objects in peri-personal space (within arm reach) and were asked to give egocentric and allocentric judgments. Materials comprised eighteen graspable objects divided in triads. They were geometrical shapes with different colors (e.g., cube, pyramid, and wheel), animals (e.g., duck, rabbit, and horse), vehicles (e.g., car, helicopter, and airplane) and everyday objects (i.e., key, cork and clothes-peg). Objects within triads had similar size. Each triad was spatially arranged so that distance between objects was clearly discriminable, and the amount of metric difficulty was the same for egocentric and allocentric judgments. Participants sat at 30 cm from the edge of the desk. Each triad was placed centrally on the desk and with respect to the participants’ mid-sagittal plane. A white cardboard measuring 50 x 50 cm was used to arrange stimuli. Children were instructed to study and memorize the position of the objects for 30 seconds. Then the objects were covered with cups and data acquisition started. There were eight judgments for each triads: two egocentric questions (‘‘Which object was closer/farther to/from you?”), two allocentric questions (‘‘Which object was closer/farther to/from the Cube (target)?”), and four distractors questions about objects' shapes and colors. For each judgment, accuracy was coded as dummy variable (1 = correct, 0 = incorrect) and the mean accuracy by subject was computed. The order of presentation of the questions was first randomized and then balanced across subjects. Before start with the session, the examiner spent some time to familiarize with the child and explained the nature of the experiment to the parents in order to have their consent.

Results

Neuropsychological assessment. CP children did not present cognitive delay as measured with the CPM (the cut-off point for clinically significant impairment was the 25th percentile) and have a visuospatial memory span adequate to their age. Although some variation emerged among patients, they did not present marked deficits in visuoperceptual and visuomotor integration skills as measured by the DTVP.
Regarding the controls group, parents’ questionnaire did not report any difficulties in visuoperceptual or visuospatial behavior (e.g., problems with shapes, objects and faces recognition, simultaneous perception, perception of movement, colors perception, and orientation).
Distance Judgment task. Patients and controls performance at the Distance Judgment Task are presented in Figure 1. Chi-square test was used to evaluate significance level of observed differences.

Figure 1: Results Distance Judgment task



Overall, both groups of children made few errors in completing the task (no child exceeded the chance threshold). The task resulted more difficult for CP than controls in that they were less accurate (12% and 25% errors, respectively in controls and patients). At the group level, controls have a Frame effect, with nearly no errors in responding to egocentric vs. 18% errors in allocentric condition (Chi-square = 5.2, $p < .05$). Differently, in CP children the egocentric-allocentric difference was less marked (20% and 30% of errors, respectively) and did not reach the significance level (Chi-square = 2, $p > .1$). A comparison between the two groups confirmed that CP children were less accurate than controls in responding to egocentric questions (Chi-square = 6.8, $p < .01$) whereas no differences emerged in allocentric questions (Chi-square < 2.4, $p > .1$).

Discussion

In the present study, children with Cerebral Palsy were asked to judge the position of graspable objects with respect to their body (egocentric condition) or with respect to landmarks (other objects) in the environment (allocentric condition). The first evidence is that such paradigm proved to be feasible to study spatial cognition in normally developing children and children with CP. Such paradigm, indeed, has been previously used with adult population (Iachini et al., 2006; Iachini et al., 2009) and this is the first time it is applied to developmental age.

Typically developing children were less accurate in recalling the position of objects using allocentric spatial coordinates then when using body-centered coordinates, confirming the predominance of egocentric coding in the developmental trend of spatial cognition (see Nardini et al., 2006). This was not the case for the group of children with CP. Indeed, they have similar performance when using egocentric or allocentric coding. Given that no differences emerged between groups with respect to the allocentric judgments, results suggest a specific deficit in using body-centered coordinates. One might argue that such difficulty reflects a deficit in visuospatial memory. However, such explanation is unlikely given that our sample of CP children have adequate score in visuo-spatial working memory task. Additionally, there is no reason to believe that (if present) a similar limitation would selectively affect egocentric vs. allocentric judgments. CP children's performance reflects preservation of categorical coding within the ventral stream, despite a loss of coordinate coding which is consistent with the hypothesis of dorsal stream vulnerability in such population (Atkinson et al., 2007; Fazzi et al., 2007). Deficits in spatial perception are usually matched with deficit in generating spatially directed actions. Patients have been described to neglect stimuli presented in peripersonal space and correctly perceive them when located in extrapersonal space, as well as the opposite pattern (Bisiach, Perani, Vallar, and Berti, 1986). Thus, information about how patients perceive the environment both in near and far space has implications in rehabilitation treatments of visuoperceptual and visuospatial impairments. We believe that this is an important issue that needs to be further explored in impaired population in developmental age. Findings of the study are preliminary as more participants are needed to broaden our conclusions.

The extent to which our results generalize to other aspect of spatial cognition and other types of CP are important further questions. Nico and Daprati (2009) propose a distinction between two separate egocentric mechanisms: one allowing construction of the immediate point of view and the other extracting a required perspective within a mental representation. This, for example, should be further addressed in our sample of patients. Moreover, Cerebral Palsy is an umbrella term which comprises different types of motor limitations which differently affect how children experience the external world and create internal representation of it. Children of our study can be considered 'high functional' cerebral palsied children in that they do not present language delay, general intellectual impairments and marked deficits in visuoperceptual and visuomotor integration skills. Notwithstanding such limitations, we believe the study provides interesting findings relevant for the field of spatial cognition in impaired population in developmental age.

To summarize, children with CP were impaired in a distance judgment task: Allocentric spatial representations were present even in the context of impaired egocentric coding. Further studies are needed to tackle this issue and to understand how a unitary perception of the world is achieved from its multiple representations.

Acknowledgments

The research leading to these results has been partially founded by the European's Community Seventh Framework Programme under the grant agreement no. PERG02-GA-2007-224919 to Laura Barca.

References

Atkinson, J. and Braddick, O. (2007). Visual and visuocognitive development in children born very prematurely. *Progress in Brain Research, 164*,123-149.

Barca, L., Cappelli, F.R., Di Giulio, P., Staccioli, S., and Castelli, E. (2010). Outpatient assessment of neurovisual functions in children with Cerebral Palsy. *Research in Developmental Disabilities*, 31, 488-495.

Berryhill, M. E., Fendrich, R., and Olson, I. R. (2009). Impaired distance perception and size constancy following bilateral occipitoparietal damage. *Experimental Brain Research, 194,* 381-393.

Bisiach, E., Perani, D., Vallar, G., and Berti, A. (1986). Unilateral neglect: personal and extra-personal. *Neurospychologia, 24*, 759-767.

Burgess, N. (2006). Spatial memory: how egocentric and allocentric combine. *Trends Cogn Sci,* 10, 551-557

Carey, D. P., Dijkerman, H. C., and Milner, A. D. (2009). Pointing to two imaginary targets at the same time: bimanual allocentric and egocentric localization in visual form agnostic. *Neuropsychologia, 47*, 1469-1475.

Carey, D. P., Dijkerman, H. C., Murphy, K. J., Goodale, M. A., and Milner, A. D. (2006). Pointing to places and spaces in a patient with visual form agnosia. *Neuropsychologia, 44*, 1584-1594.

Colby, C. (1998). Action-oriented spatial reference frames in cortex. *Neuron,* 20, 15-24

Corsi, P.M. (1972). Human memory and the medial temporal region of the brain. Unpublished doctoral dissertation. McGill University, Montreal, Canada.

Dijkerman, H. C., Milner, A. D., and Carey, D. P. (1998). Grasping spatial relationships: failure to demonstrate allocentric visual coding in a patient with visual form agnosia*. Conscious Cognition, 7*, 424-437.

Fazzi, E., Signorini, S. G., Bova, S. M., Piana, R. L., Ondei, P., Bertone, C., Misefari, W., and Bianchi, P. E. (2007). Spectrum of visual disorders in children with cerebral visual impairment. *Journal of Child Neurology, 22*, 294-301.

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

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

Gunn, A., Cory, E., Atkinson, J., Braddick, O., Wattam-Bell, J., Guzzetta, A., and Cioni, G. (2002). Dorsal and ventral stream sensitivity in normal development and hemiplegia. *Neuroreport, 13,* 843-847.

Hammill, D., Pearson, N., and Voress, J. (1994). *Developmental test of visual perception*; Edizione italiana: TPV. Trento: Edizioni Centro Studi Erikson.

Houliston, M. J., Taguri, A. H., Dutton, G. N., Hajivassiliou, C., and Young, D. G. (1999). Evidence of cognitive visual problems in children with hydrocephalus: a structured clinical history taking strategy. *Developmental Medicine and Child Neurology, 41*, 298-306.

Iachini, T. and Ruggiero, G. (2006). Egocentric and allocentric frame of reference: a direct measure. *Cognitive Processes, 7,* S126-S127.

Iachini, T., Ruggiero, G., Conson, M., and Trojano, L. (2009). Lateralization of egocentric and allocentric spatial processing after parietal brain lesions. *Brain and Cognition, 69*, 514-520.

Medina J, Kannan V, Pawlak MA, Kleinman JT, Newhart M, Davis C, Heidler-Gary JE, Herskovits EH, Hillis AE. (2009). Neural substrates of visuospatial processing in distinct reference frames: evidence from unilateral spatial neglect. *Journal of Cognitive Neuroscience, 21*, 2073-84.

Milner, A. D. and Goodale, M. A. (1995). *The visual brain in action*. Oxford University Press, Oxford.

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

Milner, B. (1971). Interhemispheric differences in the localization of psychological processes in man. *British Medical Bulletin*, 27, 272-277

Nardini, M., Atkinson, J., Braddick, O., and Burgess, N. (2008). Developmental trajectories for spatial frames of reference in williams syndrome. *Developmental Science, 11*, 583-595.

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

Nico D., Daprati E. (2009). The egocentric reference for visual exploration and orientation. *Brain and Cognition, 69,* 227-235.

Paillard, J. (1991). Motor and representational framing of space. In J. Paillard (Ed.), *Brain and space*. Oxford, UK: Oxford University Press.

Ploner, C. J., Stenz, U., Fassdorf, K., and Arnold, G. (2005). Egocentric and allocentric spatial memory in idiopathic cervical dystonia. *Neurology, 64*, 1733-1738.

Pueyo, R., Junquè, C., Vendrell, O., Narberhaus, A., & Segarra, D. (2008). Raven's Coloured Progressive Matrices as a measure of cognitive functioning in Cerebral Palsy. *Journal of Intellectual Disability Research, 52,* 437-445.

Raven, C. and Raven (1986). *Coloured Progressive Matrices*. Giunti O.S.

Rosenbaum, P., Paneth, N., Leviton, A., Goldstein, M., Bax, M., Damiano, D., et al. (2007). A report: The definition and classification of cerebral palsy. April 2006. *Developmental Medicine and Child Neurology. Supplement, 109*, 8–14.

Santos, A., Duret, M., Mancini, J., Gire, C., and Deruelle, C. (2008). Preterm birth affects dorsal-stream functioning even after age 6. *Brain and Cognition, 69*, 490-494.

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