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Chapter 2

SPATIAL MEMORY: THE ROLE OF EGOCENTRIC AND ALLOCENTRIC FRAMES OF REFERENCE

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ABSTRACT

A fundamental requirement of everyday life is that of encoding and remembering successfully the locations of objects, landmarks or buildings in space. This function is achieved by structuring spatial information in systems of coordinates. There are many ways to classify spatial reference systems (Paillard, 1991), but a useful one for understanding human spatial memory, divides them into two main categories. Egocentric frames of reference specify location and orientation with respect to the organism, and include eye, head, and body coordinates. Allocentric frames of reference specify location and orientation with respect to elements and features of the environment independently of the viewer's position.

Given the primary role that egocentric and allocentric processing systems play in perception and action (e.g. Milner & Goodale, 1995,

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2008; but see Schenk, 2006), they can be thought of as specialized cognitive mechanisms essential in performing and guiding spatial motor actions. Egocentric representations have a special relevance in controlling movement in surrounding space such as avoiding obstacles or reaching objects. All these actions are performed in near/peripersonal space, i.e. the space within arm-reaching distance, and require fine-grained metric information. On the other hand, allocentric representations have an important role in recognizing objects, scenes and planning future movements (i.e. the space outside arm-reaching distance) (e.g. Milner & Goodale, 2008). Spatial memory is intrinsically linked to frames of reference as it is not possible to store spatial information without structuring it according to specific frames. In this chapter we review evidence from behavioral and neurofunctional data about models of spatial memory, automatic and effortful encoding of spatial information, and spatial memory in elderly people. Furthermore, two experiments are reported that investigate memories for egocentric and allocentric frames of reference by means of a task requiring judgments of relative distance. Experiment 1 investigates the influence of near/far spaces on spatial frames of reference. Experiment 2 controls the influence of possible artifactual effects. Overall, the pattern of data shows that the egocentric processing is more accurate and faster than the allocentric one. The results are discussed in relation to models of spatial memory that emphasize the importance of egocentric experience (Kosslyn, 1994; Millar, 1994).

INTRODUCTION

A fundamental requirement of our daily life is spatial ability, that is the ability of encoding and remembering successfully the locations of objects, landmarks or buildings in space. In the literature, the definition of "spatial ability" is to some extent ambiguous as it has been used with different meanings and has been considered in a variety of ways. For example, spatial ability is associated with the processing of geometric (or metric) properties such as distance and size, as well as dynamic properties such as velocity and strength. The ability to encode the characteristics of objects such as size, orientation and location is also defined "spatial" (Pinker, 1984). Finally, the ability to navigate in the environment is also considered "spatial" because it requires an understanding of all these properties (Eilan, 1993).

Potentially, all kinds of processes and information useful to locate positions and directions in the environment can be defined spatial. The location and orientation of an object cannot be encoded without establishing a frame of reference, that is a coordinate that acts like anchor-point. Human memory must also use frames of reference to specify the locations of objects. Indeed, spatial information is structured in systems of coordinates within which spatial positions are represented.

In the domain of spatial cognition, spatial reference systems used to encode and organize in memory spatial information are commonly divided into two main categories: egocentric and allocentric (Kosslyn, 1994; Levinson, 1996; O'Keefe & Nadel, 1978; Paillard, 1991; Pani & Dupree, 1994; Piaget & Inhelder, 1967; for a review see Avraamides & Kelly, 2008).

Egocentric frames of reference use the organism as the center of the organization of surrounding space: retinotopic coordinates, head-centered and body-centered frames of reference may serve like anchor-points (Diwadkar & McNamara, 1997; Franklyn & Tversky, 1990; Kosslyn, 1994; Roskos-Ewoldsen, McNamara, Shelton, & Carr, 1998; Shelton & McNamara, 1997). Being sensitive to the subjective vantage point, egocentric spatial representations are often defined as “orientation-specific” or “orientation-dependent” (e.g. Presson, DeLange, & Hazelrigg, 1989). Consequently, access to spatial locations is biased by the relation between the required location and the organism.

Allocentric frames of reference have been defined in various ways, although they share a common aspect: spatial information is specified independently of the organism’s position (O’Keefe & Nadel, 1978). According to some theories, this implies that all spatial positions in the environment are equiavailable and derived spatial representations are called “orientation-free” or “orientation-independent” (Rieser, 1989; Waller, Montello, Richardson, & Hegarthy, 2002). Other theories highlight the importance of external objects chosen like anchor-points, such as: objects or parts of objects (Humphreys & Riddoch, 1994; Kosslyn, 1994), salient landmarks, local features like walls and global features like mountains (McNamara, 2003; McNamara, Rump, & Werner, 2003), intrinsic axes defined by inter-objects relations (Mou & McNamara, 2002), the Sun azimuth and the direction of gravity (Paillard, 1991). For these reasons, allocentric frames of reference are also called “environmental” or “geocentric” frames (see McNamara, 2003).

Some influential theoretical models assign a primary role to egocentric and allocentric processing systems in perception and action (e.g. Milner & Goodale, 1995, 2008; Schenk, 2006). Egocentric representations have a special relevance in controlling movement in surrounding space under perceptual guidance; for example, they are essential to avoid obstacles or to reach objects. All these actions are performed in near/peripersonal space (i.e.

the space within arm-reaching distance) and require fine-grained metric information. On the other hand, allocentric representations have an important role in recognizing objects and scenes, and in planning future movements in far/extrapersonal space (i.e. the space outside arm-reaching distance) (e.g. Berti, Smania, & Allport, 2001; Kosslyn, 1994; Milner & Goodale, 1995; Weiss et al., 2000). According to these considerations, egocentric and allocentric reference systems seem to be functionally related to other theoretical distinctions in the spatial processing domain. One is the distinction between coordinate and categorical spatial processing, that could be related to egocentric and allocentric frames respectively (Jager & Postma, 2003). According to Kosslyn (1987, 1994) categorical representations define invariant non metric relations between objects or between objects and the self (such as above\below, to the left\right of); instead coordinate representations define variable metric relations between objects or between objects and the self (such as the table is 1m far from the door). The other possible distinction is that between near/peripersonal space (i.e. the space where there is direct interaction between objects and body), in which the egocentric frame would predominate, and far/extrapersonal space (i.e. where objects are out of reaching), mainly related to allocentric frames (Berti et al., 2001; Weiss et al., 2000).

The fundamental role played by the frames of reference in several cognitive functions and in action has led to the hypothesis that they may form specialized cognitive mechanisms that rely on specific neural networks. Many studies investigating the cerebral organization of spatial processing in rodents, non-human primates and humans, and many behavioral studies have provided support for the hypothesis of specialization (Bird & Burgess, 2008).

Egocentric and Allocentric Spatial Frames of Reference: Neuroscientific Evidence

Electrophysiological studies in the monkey’s brain have shown that parieto-frontal circuits, ventral premotor cortex and posterior parietal cortex are involved in egocentric processing (Cohen & Andersen, 2002; Colby, 1998; Luppino, Murata, Govoni, & Matelli, 1999). In rats, the allocentric processing has been associated to the hippocampus (Espina-Marchant, Pinto-Hamuy, Bustamante, Morales, & Herrera-Marschitz, 2009; Olson & Gettner, 1995). Further, cells with allocentric properties have been individuated in the hippocampal formation of both freely-moving rats (O'Keefe & Dostrovsky, 1971; Taube, Muller, & Ranck, 1990) and monkeys (Rolls & O'Mara, 1995).

To date, only few studies have examined in a direct way the neural networks associated with egocentric and allocentric processing in healthy subjects. In an fMRI study, Vallar et al. (1999) showed that posterior parietal and lateral frontal premotor regions in the right hemisphere are activated more extensively by egocentric information. Galati et al. (2000) confirmed the association of the fronto-parietal network with the egocentric processing, and showed that a subset of these regions was also involved in allocentric tasks. Committeri et al. (2004) compared egocentric and allocentric spatial coding of realistic 3D-objects, and showed that egocentric coding activated mainly areas in the dorsal stream and in frontal lobes, whereas allocentric coding was associated with both dorsal and ventral regions. Zaehle et al. (2007) found a relevant involvement of the precuneus and the medial superior-posterior areas in the processing of egocentric spatial relations, whereas an additional involvement of the right parietal cortex, the ventral visual stream and the hippocampal formation was needed for the allocentric spatial coding.

Some studies investigated the neural bases of several navigational tasks. For example, Rosenbaum and collaborators (Rosenbaum, Ziegler, Winocur, Grady, & Moscovitch, 2004) found a common activation within the medial temporal lobe, in particular the right parahippocampal gyrus. Further, the medial and posterior parietal cortex were associated with egocentric processing, whereas the retrosplenial cortex was associated with allocentric processing. Ghaem et al. (1997) showed the presence of a specific mental navigation network which included the right hippocampus, the left precuneus and the insula. In a PET study, Maguire et al. (1998) found that if participants were involved into a direct mental navigation task the right hippocampus and the right inferior parietal cortex were strongly activated, whereas navigation with detour activated also the left superior and middle frontal gyri.

Although neuropsychological studies with brain-lesioned patients have not addressed directly this topic, they have reported egocentric or allocentric deficits in several disorders. For instance, in optic ataxia (inaccurate visuomotor coordination, Perenin & Vighetto, 1988) and unilateral neglect (failure to explore the contralesional side of space, Vallar, 1998) patients are impaired in perceiving their body mid-sagittal plane, that is a primary egocentric information (Pizzamiglio, Committeri, Galati, & Patria, 2000). Driver (1999) showed that the unilateral neglect may regard the contralesional side of objects independently of the observer's position (object-based neglect). Left "allocentric" neglect seems to be associated with hypoperfusion of right superior temporal gyrus whereas left "egocentric" neglect is more linked to hypoperfusion of the right angular gyrus (Hillis et al., 2005). More recently, Iachini and colleagues (Iachini, Ruggiero, Conson, & Trojano, 2009a) compared left- and right-parietal brain lesioned patients on an egocentric and allocentric spatial memory task. The results showed that right-patients dropped dramatically in egocentric judgments, but performed as well as healthy controls in allocentric judgements. However, left-patients showed a significant impairment in both spatial components. This pattern of results might be interpreted as evidence that the right hemisphere is relatively specialized in processing spatial information according to egocentric frames of reference.

In summary, neuropsychological data show a selective specialization for egocentric and allocentric processing that would be subserved by specific, although partially overlapping, neural areas. In particular, researchers concur on the central role played by the hippocampal (mainly allocentric) and fronto-parietal (mainly egocentric) circuits.

Levels of Attentional Resources: Behavioral Studies

Besides neural bases, egocentric and allocentric frames seem also to differ with regard to the level of attentional resources they require. In 1979, Hasher and Zacks proposed an important framework for research in memory that contrasted automatic and effortful processes. Within this framework they suggested that encoding and retrieving spatial information is so fundamental to the survival of living species that it works almost automatically. Following this suggestion, several studies have investigated the attentional demands of the spatial processes involved in spatial memory. The procedures adopted, however, did not explicitly control the egocentric or allocentric nature of the strategies deployed to solve the tasks and the kind of spatial information processed, although it is possible to make some inference. Tasks that seem to require allocentric processing show no evidence in favor of automatic processes (Andreade & Meudell, 1993; Köhler, Moscovitch, & Melo, 2001; Naveh-Benjamin, 1987, 1988), whereas tasks requiring more egocentric processing highlight the automatic nature of the processes involved (Ellis, 1990; Parkin, Walter, & Hunkin, 1995; Pouliot & Gagnon, 2005). The percentages of accuracy confirm that the two processing systems may differ in terms of attentional demands. For instance, highly accurate performances would be more automatic, while less accurate performances would be more effortful. Accuracy for allocentric tasks usually varies from 37.7% to 56%, whereas for egocentric tasks it ranges from 80 to 90.5% (see Table 1). The fact that the allocentric processing seems to be more effortful is consistent with the idea that it requires more resources to detach from egocentric perspectives.

The Effect of Age on Frames of Reference

The study of the developmental course of egocentric and allocentric spatial processing systems could give useful insights into their characteristics. If it were demonstrated that they are differently affected by aging processes, it would be a further evidence in favor of relatively specialized systems.

So far, age-related changes in basic visuo-spatial abilities, mental imagery and navigational abilities have been investigated (see Iachini, Poderico, Ruggiero, & Iavarone, 2005; Ruggiero, Sergi, & Iachini, 2008). The results obtained are still controversial and it is not yet clear which spatial processes decline with age and which ones are preserved. As regards the egocentric/allocentric distinction, to the best of our knowledge the literature on aging and spatial memory has not directly addressed this issue. In general, several spatial tasks have been used, such as pointing tasks, and the results are interpreted as consistent with the allocentric or the egocentric organization of spatial knowledge. Parkin et al. (1995) used a spatial discrimination task that involved egocentric spatial memory to compare healthy elderly and young people. They found no significant negative effect of age on the spatial performance, but only a slight decline. Instead, Hort et al. (2007) compared healthy elderly, patients with Mild Cognitive Impairment (MCI) and with Alzheimer's disease (AD) on a navigational task that involved either egocentric or allocentric components. Interestingly, they found a significant deficit in the allocentric component in patients but not in healthy elderly people. More recently, Iachini and co-workers (Iachini, Ruggiero, & Ruotolo, 2009b) compared healthy participants aged from 20 to 89 years in a spatial task that required egocentric and allocentric spatial judgments. The results showed that aging had a selective negative impact on the egocentric component starting from the seventies, whereas the allocentric component looked relatively preserved. This suggests that the two components are supported, at least partially, by neural areas that are differently vulnerable to normal aging processes.

Table 1. Percentages of accuracy in previous studies about spatial judgments

	Spatial relations		Task	
	Categorical	Coordinate	Egocentric	Allocentric
Naveh-Benjamin (1988)	+			50%
Ellis (1990)	+		80-90%	
Andreade & Meudell (1993)	+			37.7%
Köhler et al. (2001)		+		56%
Pouliot & Gagnon (2005)	+		90.5%	

OVERVIEW OF THE EXPERIMENTS

The body of neuroscientific and behavioral evidence reviewed in this chapter is consistent with the idea of two specialized systems of spatial processing. Our main purpose is to describe a spatial task devised to measure behaviorally the capacity to use egocentric and allocentric frames of reference and that requires coordinate metric information (Iachini & Ruggiero, 2006).

In the domain of spatial memory, many studies have investigated the influence of several factors on egocentric and allocentric frames of reference. For example, the way of learning spatial information (Presson & Hazelrigg, 1984), the size of spatial layouts (Presson et al., 1989; Roskos-Ewoldsen et al., 1998), the geometric structure of the environment (McNamara et al., 2003) and the degree of familiarity (Evans & Pezdek, 1980; Iachini, Ruotolo, & Ruggiero, 2009c; Ruggiero & Iachini, 2006; Thorndyke & Hayes-Roth, 1982) have been studied. The majority of these studies have adopted pointing tasks that take the following form: "you are (or imagine being) at X, in front of Y, where is Z"? Latency and errors of localization are taken as dependent variables. Overall, the results suggest that familiarity, regularity of the environment and locomotor exploration under multiple perspectives would mitigate orientation-dependent effects and thus favor an allocentric representation. However, it is important to point out that depending on the theoretical definition, different patterns of data may be interpreted as verifying the "allocentric" view. According to the "equiavailable" definition of allocentricity, the position of target-objects should not affect the performance (a flat trend is expected). On the contrary, "environmental" theories point out that the ease of accessing memorized positions depends on whether they are aligned or not with salient axes (e.g. McNamara, 2003). Therefore, a certain degree of ambiguity is intrinsic in these data and this highlights the importance of devising a behavioral task that is able to compare directly both egocentric and allocentric spatial components.

The task we propose here, called "Ego-Allo Task" (EAT), is based on spatial judgments of distance between memorized 3-dimentional real objects previously presented on a desk. Frames of reference are manipulated by asking spatial judgments of relative distance requiring either an egocentric or an allocentric frame. Spatial judgments have been largely adopted to study categorical and coordinate relations (for a review see Jager & Postma, 2003). In general, these studies adopted several "bar and dot" tasks that involved simplistic spatial stimuli presented on papers or computer screens and that required mostly categorical-like judgments (e.g. Bruyer, Scailquin, & Coibion, 1997; Fink et al., 2000; Galati et al., 2000; Sterken, Postma, De Haan, & Dingemans, 1999; Vallar et al., 1999). Instead, our task is clearly coordinate-like as it requires the comparison of subtle metric distances. Egocentric and allocentric frames of reference were manipulated by asking participants to provide spatial judgments either in relation to the viewer ("Which object was closest/farthest to/from you?") or to an object ("Which object was closest/farthest to/from the Cube?"). In humans, egocentric frames of reference represent the primary inter-face between the organism and the environment (e.g. Millar, 1994). For this reason, more processes would be necessary to work out allocentric spatial representations from egocentric representations. This leads to the general hypothesis that the egocentric performance should be more accurate and faster than the allocentric one.

EXPERIMENT 1

In this Experiment we explored the possible influence of near and far spaces on egocentric and allocentric processing of coordinate metric information. A reduced version of this task has already been presented (Iachini & Ruggiero, 2006). We expected that egocentric judgments should be more accurate and faster in near than far space, whereas allocentric judgments should be better in far than near space.

Method

Participants

Forty students (20 males and 20 females) took part in the experiment on a voluntary basis (M_{age}= 25.2 years, *SD* = 1.72). They were drawn from the Second University of Naples. They understood the instructions without difficulty and none of them were aware of the hypotheses at the time of testing. Further, they were right-handed and had normal or corrected to normal sight.

Setting and Materials

The experiment was carried out in a sound-proofed, comfortable room. Participants sat on a straight-back chair placed centrally at 30 cm from the edge of a desk measuring 100 cm × 150 cm. Six geometrical 3-dimensional objects were chosen like stimuli on the basis of the following criteria: they had simple and elementary geometrical shapes; they were easily recognizable; they could be named without difficulty. These objects were grouped in two series: Series A (Pyramid, Parallelepiped, and Cone) and Series B (Cube, Sphere, and Cylinder). Moreover, these objects could vary on the basis of two physical characteristics: Size and Color. The size comprised two dimensions: Big and Small. Big-objects measured 8 cm × 8 cm except the Parallelepiped and the Cylinder (8 cm × 11 cm), whereas Small-objects measured 6 cm × 6 cm except the Parallelepiped and the Cylinder (6 cm × 9 cm). The color comprised three different tonalities of grey corresponding to dark, medium, and light grey (respectively 75-50-25% of grey). By combining objects, size and color, 9 objects for each series were achieved. For example, the Cone could be small-light or big-dark etc. Still, each series was subdivided in 3 sub-series, respectively A1, A2, and A3; B1, B2, and B3. Each sub-series had a Target-object (T), that is the object with respect to which the allocentric judgments were made. The sub-series A1 comprised: Pyramid-Big-Dark (T), Parallelepiped-Small-Medium, Cone-Small-Light. The sub-series A2 comprised: Pyramid-Small-Medium, Parallelepiped-Big-Light, Cone-Big-Dark (T). The sub-series A3 comprised: Pyramid-Small-Light (T), Parallelepiped-Small-Dark, Cone-Big-Medium. On the other hand, B1 included: Cube-Small-Medium (T), Sphere-Small-Dark, Cylinder-Small-Light; B2 comprised: Cube-Big-Dark, Sphere-Small-Light (T), Cylinder-Small-Medium; B3 included: Cube-Small-Light, Sphere-Big-Medium, Cylinder-Big-Dark (T). These triads were presented according to different spatial arrangements, defined on the basis of three pilot studies, each comprising 15 participants. These studies were carried out in order to: (a) define distinguishable metric distances among objects; (b) determine different levels of metric difficulty; (c) establish the duration of learning time; (d) define the same level of metric difficulty for egocentric and allocentric judgments. The metric difficulty was based on the difference in centimeters between the two distances to be compared; it increased as the difference decreased. For example (see Figure 1), within the sub-series B1, the Cube (T) was 11 cm far from the Sphere and 17 cm from the Cylinder. In this way, the allocentric spatial judgments (e.g. “Which object was closest to the Cube?”) were based on a metric difference of 6 cm. On the other hand, the Sphere was 12 cm far from the edge of the cardboard, while the Cylinder was 6 cm; therefore, the egocentric spatial judgments were also based on a metric difference of 6 cm. The six triads of objects (A1, A2, and A3; B1, B2, and B3) were placed centrally on the desk and with respect to the participants’ mid-sagittal plane.

To ensure that all triads were presented in the same way for all participants, a cardboard (measuring 50 cm × 30 cm) was used. On this cardboard the shape of the objects was cut out and there was a mark on the lower horizontal side that corresponded to a mark on the desk.

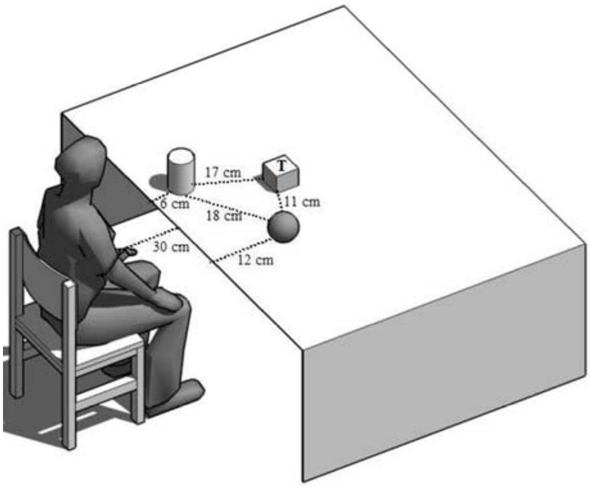

Figure 1. Example of the setting and stimuli used in Experiment 1. The triad was centered on the desk in correspondence with subjective mid-sagittal plane. This configuration illustrates the B1 sub-series in near space. “T” represents the target-object, that is the object used to provide the allocentric judgments.

In the near condition, the cardboards were placed at 30 cm far from the edge of the desk and within the arm-reaching space (50 cm). In the far condition, the cardboards were positioned at 100 cm far from the edge of the desk, that is out of the arm-reaching space.

Procedure

At the beginning of the experiment, participants received written instructions about the task. They were instructed to memorize as accurately as possible the positions and the characteristics of the objects (color and size) that were to be presented. The instructions were then revised orally by the experimenter and a training session started. During training an example of the entire procedure was given by using three common objects (for example: a glass, a cup and a small box). When the procedure was clear, the experimental session began.

Learning phase. At the beginning of each trial, three geometrical 3-dimensional objects were randomly placed on the desk and named. In this way we excluded possible effects due to difficulties in naming the objects. Then the experimenter asked participants to close their eyes and arranged the triad on the desk by means of the proper cardboard. Afterwards, participants had to open their eyes and to memorize the objects and their characteristics. They had to learn each triad while seating still and without turning their heads. The learning phase took 20 sec. Finally, participants had to close their eyes and the experimenter removed the triad. After 5 sec, the testing phase started. This procedure was repeated for all 6 triads.

Testing phase. The experimenter asked participants to give 8 judgments for each triad. There were two egocentric questions: “Which object was closest to you?” and “Which object was farthest from you?”; two allocentric questions: “Which object was closest to the Cube (i.e. Target-object, as shown in Figure 1)?” and “Which object was farthest from the Cube?”. In addition, there were four distractors: “Which object was tallest?” and “Which object was largest?”; “Which object was darkest?” and “Which object was lightest?”. For each judgment, accuracy and latency were recorded. Latency was recorded by means of a hand-held stopwatch, starting from when the experimenter named the required frame (e.g. Cube) or characteristic until the participant gave the response. Spatial judgments were firstly randomized and then balanced on the basis of a Latin square design. Half of participants started with the series A and half with the series B. Moreover, each participant learned one series in near space and the other in far space. Near/far spaces and the two series were balanced over all participants. At the ending of the testing phase, participants were interviewed to be sure that they had followed the instructions accurately. They were also asked to describe the way in which they performed the task and if there were positions more difficult than others to retrieve. Two participants who did not memorize accurately the stimuli were discarded and replaced. The Experiment was fully completed in approximately 20 minutes.

The experimental design comprised 2 (Egocentric and Allocentric spatial judgments) × 2 (Near and Far spaces) within variables. As dependent variables we had accuracy (mean of correct judgements) and mean latency for correct responses (sec).

Results

Two 2 × 2 ANOVAs (Egocentric/Allocentric and Near/Far) for within subjects designs were used to analyze the data. As regards accuracy, the ANOVA revealed a significant main effect of judgments, $F(1, 39) = 39.99$, $\eta^2 = .51$, $p < .001$, with egocentric judgments ($M = .904$, $SD = .15$) being more accurate than allocentric ones ($M = .73$, $SD = .26$). No significant main effect of Near/Far spaces ($F < 1$) and no interaction ($F < 1$) emerged (see Table 2).

As regards latency, similar results were observed. The ANOVA revealed that egocentric judgments ($M = 1.13$, $SD = 0.43$) were faster than allocentric judgments ($M = 1.82$, $SD = 0.77$), $F(1, 39) = 48.55$, $\eta^2 = .55$, $p < .001$. Neither main effect of Near/Far spaces, $F(1, 39) = 1.20$, $p = .28$, nor interaction ($F < 1$) were significant. As it is common in spatial tasks, we also checked the sample for gender differences. The results did not show significant differences in accuracy, $F(1, 38) = 1.02$, $p = .319$, and latency ($F < 1$).

Overall, the pattern of data shows that the task based on spatial judgments of distance is able to distinguish between egocentric and allocentric processing of metric information. A strong facilitation of the egocentric judgments over the allocentric ones in accuracy and latency emerged. Percentages of accuracy were quite similar to previous studies, respectively 90% vs 73%. In line with our hypothesis, the results confirm that the allocentric processing is more difficult than the egocentric processing. The strength of the effect sizes confirmed the robustness of the results and consequently the discriminatory power of the task in distinguishing egocentric and allocentric processing. In contrast, the manipulation of the distance between objects and the observer (near/far spaces) did not affect the performance. Probably, this result is due to the low ecological impact of the experimental manipulation that operationalized the two spaces. Indeed, all stimuli were easily visible and participants were seated throughout the experimental session. However, before taking for granted the reliability of the task, a criticism must be faced: the results could have been determined by an experimental artefact that facilitated the egocentric coding. More precisely, the position of the egocentric frame was always stable as participants seated still throughout the experimental session, while the positions of the allocentric targets were different for each triad. This variability of the allocentric positions could have undermined the allocentric performance whereas the stability of the body could have favored the egocentric performance. Experiment 2 was aimed at controlling this spurious factor.

EXPERIMENT 2

In order to eliminate the possible facilitating effect due to the stable egocentric position, in this experiment each triad was studied from a different learning position. In this way, both egocentric and allocentric frames of reference varied for each configuration. Further, stimuli were all presented in near space. Two conditions were compared named “Stable” (the same as Experiment 1) and “Variable” in which participants had to move with respect to each triad of objects. If the stability of the egocentric position facilitates the performance, then the egocentric advantage should disappear in the “Variable” condition. This hypothesis should be verified by a significant interaction.

Method

Participants

Forty students (20 males and 20 females; M_{age} = 24.97 years, *SD* = 2.69) from the Second University of Naples were recruited on a voluntary basis and randomly assigned to the “Stable” or “Variable” conditions. They were right-handed and had normal or corrected to normal sight.

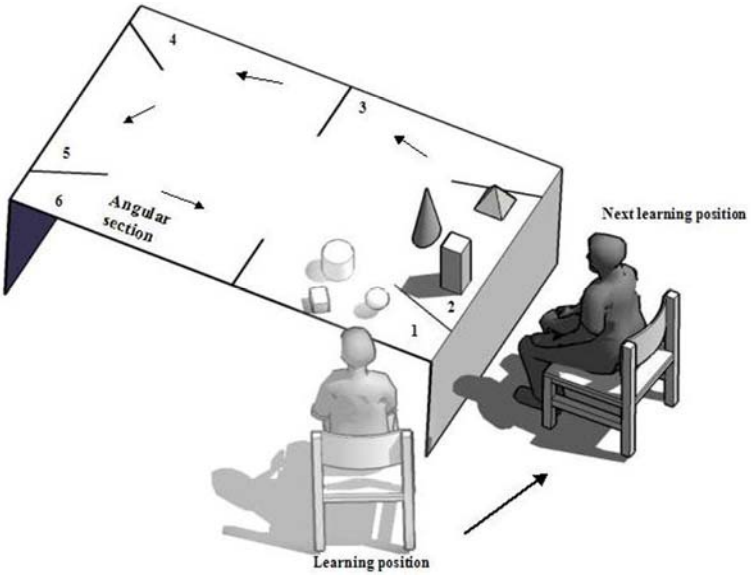

Figure 2. Example of the setting and stimuli used in the Variable condition of Experiment 2. The numbers from 1 to 6 indicate the angular sections worked out on the desk. Participants had to seat in front of the first angular section randomly assigned (for example, the section n° 1) and from this position they had to move to the next position in a counter-clockwise order, as illustrated by the black arrows.

Setting and Materials

As regards the "Stable" condition, setting and materials were identical to those of Experiment 1 in near space. As shown in Figure 2, in the "Variable" condition six different sections (each one of 60 degrees) were worked out on the desk (invisible for participants) and each triad was placed on one of these sections. Participants had to study the six triads of objects by seating in front of the assigned section. In this way, both egocentric and allocentric frames of reference varied for each configuration. The order of learning positions was counterbalanced across participants.

Procedure

The "Stable" group followed the same procedure as in Experiment 1. In the "Variable" group, participants sat in front of the desk in correspondence of each section. The chair was located in a pre-marked position. At the ending of the testing phase, the experimenter asked participants to move to the following learning position and so forth. The starting position was counterbalanced within participants. The testing phase was identical to that of Experiment 1 in both conditions.

The experimental design comprised a within variable (Egocentric/Allocentric) and a between variable (Stable/Variable).

Results

Analyses were based on two 2-way ANOVAs for mixed designs with a 2-level within factor (Egocentric/Allocentric) and a 2-level between factor (Stable/Variable learning conditions).

ANOVA on mean accuracy revealed that egocentric judgments ($M = .901$, $SD = .146$) were more accurate than allocentric ones ($M = .69$, $SD = .199$), $F(1, 38) = 28.514$, $\eta^2 = .42$, $p < .001$. No significant difference emerged between Stable and Variable learning conditions ($F < 1$) and no significant interaction ($F < 1$; see Table 2).

ANOVA on latency confirmed that egocentric judgments were faster than allocentric ones, $F(1, 38) = 31.084$, $\eta^2 = .45$, $p < .001$. The related means were: egocentric = 1.28, $SD = 0.445$; allocentric = 1.88, $SD = 0.814$. Further, the Stable ($M = 1.34$, $SD = 0.418$) was significantly faster than the Variable condition ($M = 1.82$, $SD = 0.716$), $F(1, 38) = 9.122$, $\eta^2 = .20$, $p < .005$. Finally, no significant interaction was found, $F < 1$. As in the previous experiment, no gender differences appeared on both accuracy, $F < 1$, and latency, $F(1, 38) = 1.441$, $p = .24$.

Table 2. Percentages of accuracy in the Ego-Allo Task (EAT)

	Task	
Experimental conditions	Egocentric	Allocentric
	Experiment 1	
Near space	91%	72.5%
Far space	90%	74.2%
	Experiment 2	
Stable	93%	73%
Variable	88%	65%

The results confirm the reliability of the task as the egocentric advantage in accuracy and latency is not disrupted when the egocentric learning position varies for each triad of objects. However, the data show that the judgments are provided more slowly in the variable than in the stable condition. It is likely that more time is needed to update the spatial relation between the observer and external frames of reference, such as the desk and the walls (see McNamara, 2003). Even though the variable spatial relationship between environment and observer lengthened global processing time, it did not alter the egocentric facilitation. Again, the strength of the effect sizes confirmed the robustness of the data and the clear egocentric primacy over the allocentric processing.

CONCLUSION

The principal goal of the experiments reported here was to compare directly memories for egocentric and allocentric processing of coordinate metric relations in an experimentally controlled situation that was as closer as possible to everyday situations. The EAT involved real 3-dimensional stimuli that were displaced on a desk. The procedure was simple as required learning and then retrieving spatial relations between the stimuli and the subject (egocentric judgments) or another object (allocentric judgments). The task was ease to administer and behavioral responses were recorded with no aid of technical devices. For all these reasons, this task could be adopted with different populations such as children, elderly people (Iachini et al., 2009b) and patients suffering from brain-damage (Iachini et al., 2009a).

The results we obtained confirm the good discriminatory power of the task. Indeed, in the two experiments the difference between allocentric and egocentric judgments was always strong and always in favor of egocentric judgments. This robust effect was supported by high effect sizes and was not influenced by artifactual factors.

Experiment 1 showed a clear advantage of the egocentric processing over the allocentric one in terms of both accuracy and latency. This advantage was not altered by the distance between individuals and objects, that is the spaces of coding within or outside arm-reaching. Probably, this is due to the capacity of normal healthy adults to process spatial information equally well in different spaces of coding. On the other hand, it could also be due to a low ecological relevance of the experimental manipulation: in all cases participants learned spatial information while seated and stimuli displayed in "far space" were easily perceivable (Iachini et al., 2009b). The question of the processing of egocentric and allocentric information in near and far spaces has been recently addressed by Iachini and colleagues (Iachini et al., 2009a). In their study, left and right brain-lesioned patients showed selective impairments in egocentric and allocentric processing. More specifically, the left hemisphere patients revealed difficulties in processing both egocentric and allocentric information, especially in far space. Instead, the right hemisphere patients were specifically impaired in egocentric judgments and this effect was particularly strong in near space. These observations would suggest that different categories of patients might be selectively affected by the range of space.

Experiment 2 discarded the possibility that the results were due to spurious factors, such as the stability vs the variability of the frames of reference. Even though a general slowing was observed when the learning positions were variable, this could be ascribed to the spatial processes needed to update the relationship between the observer and external allocentric cues. However, these processes did not alter the egocentric advantage over the allocentric component.

Overall, the two Experiments confirm the primacy of the egocentric frames which represent the primary inter-face between the organism (the viewer's body) and the environment (Millar, 1994). In clarifying some aspects of the perception\action model, Milner and Goodale (2008) hypothesize a close link between the egocentric and allocentric processing and the functions of visual streams. The model proposes a distinction between two visual streams: a dorsal stream that processes information useful to control action, and a ventral stream that processes information useful to recognize objects. The ventral stream should transform visual information into allocentric perceptual representations, while the dorsal stream should use on-line information about the egocentric organization of objects. Interestingly, Sterken et al. (1999) suggested that the egocentric system is specialized in processing information to guide motor behavior by analyzing the metric properties of spatial relations. In contrast, spatial representations allocentrically specified are needed to plan trajectories and to recognize objects (Sterken et al., 1999; see also Kosslyn, 1994).

According to an evolutionary framework, the capacity to perceive and represent spatial information is affected by the adaptive specializations of the species in their interaction with the environment. In a seminal comparative experiment, Delius and Hollard (1995) presented rotated stimuli to human beings and pigeons. The results revealed that humans were affected by the degree of rotation, whereas pigeons recognized stimuli independently of the variance of rotation. Since humans assumed the erected position, spatial information has been acquired frontally, that is egocentrically. Instead, pigeons perceive spatial relations horizontally from a survey view. For this reason, they are able to capture easily the invariant allocentric characteristics of spatial information. On contrast, as suggested by Millar (1994), in humans more processes are needed to detach from the egocentric perspective in order to represent spatial information allocentrically and this computational effort should be paid in terms of errors and latency.

Coming back to our results, they could provide a potential contribution to the literature about automatic vs effortful encoding of spatial information. According to Hasher and Zacks (1979), the automatic and effortful distinction is not a dichotomous one, rather encoding processes are situated along a continuum of attentional demands. As suggested by Ellis (1990) and, more recently, by Pouliot and Gagnon (2005), the percentage of accuracy can be taken as an index of the rather automatic nature of a process. In the present experiments the percentages of accuracy in the egocentric processing are extremely high (about 90%), whereas in the allocentric processing they range from 69% to 73%. As shown in Table 2, they are similar to the percentages reported in previous studies where egocentric accuracy ranged from 80% to 90.5% and allocentric accuracy varied from 37% to 56% (see Table 1). However, we must be cautious in comparing our data with previous ones given relevant differences. For instance, in previous studies there was no direct comparison between egocentric and allocentric processing and the nature of the spatial tasks was not clarified (see Pouliot & Gagnon, 2005). Further, categorical-like tasks (i.e. right/left of ...) requiring the relocation or the discrimination of pictures, drawings and so forth were adopted (Andreade & Meudell, 1993; Ellis, 1990; Naveh-Benjamin, 1988; Pouliot & Gagnon, 2005). Instead, our task involves coordinate spatial relations, compares directly the egocentric and allocentric frames of reference and the amount of metric difficulty is the same for both judgments. This last factor is crucial if we want to be sure that differences in performance are due to intrinsic characteristics of egocentric and allocentric processing and not to the presence of spurious factors. At this stage, we can accept the idea that when the task requires spatial judgements and involves real 3-D objects there is a facilitation for egocentric rather than allocentric processing. Further studies would be necessary to disentangle whether this advantage is due to attentional factors or to a mere spatial component.

In conclusion, in this chapter we reviewed several lines of evidence that converge on the idea that egocentric and allocentric spatial processing may represent specialized systems. It can be speculated that this selective specialization results from evolutionary pressures. The necessity to perform and control actions and to recognize objects and scenes represent two primary adaptive functions. These functions may have led to the specialization of dedicated systems in neighboring areas of the brain according to a "snowball mechanism" as suggested by Kosslyn (1987). Egocentric and allocentric components may represent two key processes in the service of the primary functions of action and recognition.

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