Space Boundaries in Schizophrenia

Voluntary Action for Improved Judgments of Social Distances

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Abstract. The present study evaluates whether in schizophrenia deficits in specifying social distances appropriately for interindividual interactions might be related to abnormal capabilities in specifying the boundaries of reachable space. Using a stop-distance paradigm, 20 patients with schizophrenia and their controls judged from seven preselected angles when a target reached the boundaries of peripersonal space. Results revealed that spatial perception was similar for patients and controls throughout the workspace with more accurate judgments in the preferred hemi-field. Nevertheless, patients were significantly more variable in their judgments; this variability was correlated with the PANSS disorganization cluster. In task 2, participants were required to judge either the boundaries of reachable space (target was an object) or to evaluate social distances (target was a person). Results revealed here again increased judgment variability in schizophrenia, in both situations. Of key importance was that results were normalized in the patients, when judgments were made through voluntary movement. These results argue for a similar brain mechanism for the determination of space and social distances. Furthermore, they suggest an important role of voluntary movement for the creation of stronger motor representations of action goals, which provide the basis for more accurate judgments of space boundaries during both physical and social interactions. The findings are discussed in light of the embodied theory of cognition and their implications for social skills in patients suffering from mental illnesses.

Keywords: schizophrenia, social distances, space boundary, action capabilities, embodied cognition

Introduction

Personal space is a portable, invisible, and emotionally filled boundary around the human body. A primary function of personal space is to act as a buffer protecting people from potential threats, overstimulation, and overarousal. However, in an ever-changing social world, it is also necessary to find a compromise between individual and social spaces in which physical interaction with others is still possible. Indeed, social interaction cannot confine itself to verbal communication. Much social sharing goes through a socially well-adapted use of action space, e.g., walking toward a person to ask a question but staying at an adequate distance for comfort, shaking hands, or giving someone an object. In all of these examples, the correct determination of space boundaries for physical interaction with a person is thus required. The present paper assesses the ability of patients suffering from schizophrenia to determine the boundaries of action space for physical interactions, both in a social context (“Can I touch that person?”) and a nonsocial context (“Can I touch that object?”).

The Origin of the Concept

The issue of interaction between spatial perception and physical contact in a social context was originally investigated in ethology through the concept of flight initiation distance in animals. Based on the pioneering work by Hediger (1934) concerning biological social distance in animals, an optimal flight initiation distance is thought to exist in all species representing the distance at which the animal accepts the presence of conspecifics but initiates flight in the presence of an objective threat. Hediger distinguished between flight initiation distance, critical distance (attack boundary), personal distance (distance separating members of noncontact species), and social distance (intraspecies communication distance). Considering that one of the basic functions of the motor system in all animals is to protect the body from unwanted attack (Graziano & Cooke, 2006), the optimal escape theory (Ydenberg & Dill, 1986) would confirm that an animal should commence escape from an approaching intruder when the latter reaches a point at which the risk of being reached equals the behavioral cost of escape. This aptitude emphasizes the capacity in every

animal to evaluate spatial distances according to its own motor capacities.

The idea that spatial boundaries depend on social context and motor capabilities was later extended to human social behavior (Hall, 1966). Human beings belong to the family of noncontact animals who nevertheless need to stay in touch with others. A psychological distance for social interactions must thus be specified. Many researchers noted that humans have an invisible bubble of protective space surrounding the body, generally larger around the head, extending farthest in the direction of sight (e.g., Dosey & Meisels, 1969; Horowitz, Duff, & Stratton, 1964). When that personal space is violated, the person steps back to reinstate the margin of safety. This is the case, for example, in a crowded elevator: As soon as people step off, the remaining occupants step away in order to make space for the invisible bubble of safety and comfort. Personal space, therefore, can be considered the flight zone of a human, with respect to conspecifics. Interestingly, the size of the personal space may vary depending on the situation: A person placed in a potentially threatening context has an expanded personal space; a person in friendly company has a reduced personal space (Dosey & Meisels, 1969; Felipe & Sommer, 1966).

Reachable Space and Action Capabilities

Because of the limited disposition of the body for action, interactions with the external world and other individuals depend on our ability to discriminate objects and individuals that can be easily reached from those that are beyond our sphere of influence (Previc, 1998). It has thus been proposed that the brain represents peripersonal space as a function of and in relation to action capabilities (Coello & Delevoye-Turrell, 2007).

Peripersonal space has been defined as the participative area in which interactions with a person or an object can occur in the present time; more simply put, peripersonal space can be considered as the area in which things are within arm's reach (Berti et al., 2002). Beyond peripersonal space there extends extrapersonal space, where objects cannot be reached without moving toward them. Both experimental (Bjoertomt, Cowey, & Walsh, 2002) and clinical (Mennemeier, Fennell, Valenstein, & Heilmann, 1992) studies have suggested that these two action spaces involve different and specific brain processing areas (Previc, 1998). This distinction is crucial not only for the regulation of interactions with nearby objects, but also for our social life, because social distance depends on the type of expected relationship with conspecifics (Hall, 1966). In this context, perceptually delimiting peripersonal space requires combining the optically specified geometry of visual scenes and objects, with current behavioral goals and the potential to achieve this goal.

The present paper considers experimental results in the framework of embodiment, in order to further investigate the hypothesis that the delimitation of the boundaries of peripersonal space may depend directly on a subject's capacity to

create and maintain an active motor representation of action goal during motor planning and execution. In a previous paper we presented a neurocognitive model to account for the perceptual judgment of what is reachable on the basis of action representations and motor imagery (Coello & Delevoye-Turrell, 2007). In the present study, we tested our hypothesis in a pathology characterized by dysfunctional anticipatory mechanisms for motor planning (e.g., Delevoye-Turrell, Giersch, Wing, & Danion, 2007) and abnormalities in motor imagery (e.g., Danckert, Rossetti, d'Amato, Dalery, & Saoud, 2002). Because patients with schizophrenia are impaired in their use of motor representations, we predict weak and more variable performances in patients compared to normal controls, when required to determine the boundaries of peripersonal space. Furthermore, we defend the idea that the capacity to differentiate peripersonal from extrapersonal spaces depends essentially on our ability to maintain the motor representations active and unified in order to integrate predicted sensory and spatial consequences of deployable actions, whether interacting with objects (reachable space) or with individuals (social distances). The act of moving causes the brain to maintain representations of action goals active in a spontaneous manner. Thus, by requiring judgments through voluntary action, it may be possible to lead participants, and especially patients with schizophrenia, to be more accurate and produce less variable judgments of space boundaries for physical and social interactions.

Space Boundaries, Social Distance and Schizophrenia

"As many psychiatrists know, patients with schizophrenia have trouble with the intimate and personal zones and cannot endure closeness to others" (Hall, 1966, p. 115).

This quote from Hall (1966) leads us to the question of a functional link between the organization of space and social behavior. From a purely clinical perspective, therapists working with patients suffering from schizophrenia report their patients experiencing something that seems very similar to the flight reaction described above. Indeed, when approached too closely, these patients panic in much the same way as an animal recently locked up in a zoo would (Hall, 1966). In describing their feelings, such patients refer to anything that happens within their "flight initiation distance" as taking place literally inside them, as if the self extended beyond the body. These experiences suggest that the realization of the self – as we know it – is intimately associated with the capacity of making boundaries explicit.

Although peripersonal space is an important nonverbal component of social skills (Bellack, Mueser, Gingerich, & Agresta, 1997), how it becomes problematic in schizophrenia has not been studied thoroughly. A number of clinical studies reported that interpersonal interaction and social stimulation have an impact on the onset and progress of schizophrenia (Mintz, Nuechterlein, Goldstein, Mintz, & Snyder, 1989;

Parker, Johnston, & Hayward, 1988; Vaughn & Leff, 1976). Studies on social stimuli and schizophrenia reported that patients were more sensitive to social stimulation and demonstrated a need for larger peripersonal spaces than mentally healthy individuals (Nechamkin, Salganik, Modai, & Ponzovsky, 2003; Stratton & Horowitz, 1972). Using stop-distance techniques, a few experimentally driven studies reported similar findings. One study using photographs confirmed the clinical observations, suggesting that patients prefer greater interindividual distances (Deus & Jokic-Begic, 2006; Srivastava & Mandal, 1990). Using pictograms, another study reported an inverse correlation between negative syndrome and social distance from neutral and threatening figures (Nechamkin et al., 2003). Recently, these correlation findings were confirmed using a virtual reality system (Park et al., 2009). However, an important methodological limitation of these studies is that actual interaction did not take place; indeed, in this study, patients were facing only an avatar, and it is difficult to speculate whether similar findings would be observed in a true interactive situation. Furthermore, from a theoretical point of view, very little discussion has been proposed for a better understanding of the psychological dysfunction that may underlie the abnormal social interactions reported in schizophrenia.

The present article evaluates whether deficits in patients with schizophrenia in specifying social distances appropriately for interindividual interactions might be related to abnormal capabilities in specifying peripersonal space boundaries. Through experimental manipulations, we investigated the pattern of peripersonal space boundary delimitations in patients and control participants throughout a large angle range to test whether abnormal peripersonal space delimitations may be the consequence of a distorted spatial perception in schizophrenia, and whether this is correlated to specific clinical symptoms. Second, to gain a better understanding of the specificity of peripersonal space distortions in schizophrenia in the context of social skills, we conducted a second task for which subjects judged either the boundaries of reachable space (target was an object) or evaluated social distances (target was a person). Finally, by contrasting situations in which the participants were actors ("I move toward the target and stop where I think I can touch it") or observers ("I remain immobile and say stop when I judge that I can touch the moving-target"), we investigated whether the fact of being an actor – with the need to plan and execute a voluntary movement – proves to be crucial to the patients' performance patterns, subtending a more accurate specification of the boundaries of peripersonal space when agent of the interaction.

Materials and Methods

Participant Population

Twenty patients with schizophrenia and pair-matched controls for age and years of education (see Table 1 for full demographic description) participated in this study. All re-

ported being neurologically healthy with normal or corrected-to-normal vision; all participants had an IQ above 70. All participants provided written informed consent after the procedure had been fully explained and completed the assessment of handedness preference of the Edinburgh Test Inventory (Oldfield, 1971). Throughout the unique session, participants were tested individually, in an isolated room, using two different tasks.

Patients with Schizophrenia

Twenty patients were recruited at the Centre Hospitalier Régional Universitaire of Lille, France (CHRU de Lille) and diagnosed according to DSM-IV criterion. They had no other concurrent diagnoses. Schizophrenic symptoms were assessed using the Positive and Negative Syndrome Scale (PANSS; Kay, Fiszbein, & Opler, 1987). Because of the possibility that specific subsymptoms affect social distances in a contrasting way, the patients' scores were decomposed into five clusters of symptoms: negative, positive, disorganization, depression, and excitability (for more details, see Lançon et al., 1998).

Control Subjects

Participants were recruited from the local community. Between-group differences in gender, mean age, and education were not significant.

Task 1

The objective of this first task was to evaluate the boundaries of reachable space using the classical approaching/departing method, and to assess the participants' capacity to judge these boundaries in both preferred (right hemi-field for right-handed subjects) and none preferred hemi-field (left hemi-field for right-handed subjects), when interacting with an object.

Apparatus

Participants sat comfortably facing a table on which a rectangular plank of wood had been placed horizontally (1.60 × 0.80 m). This board was covered with two sheets of white paper between which a carbon fiber sheet was inserted so that the experimenter could code the participants' responses using a nonmarking pen on the lower sheet, without visible traces on the upper one. A rod (120 cm long) was moved in line with the participants' midline at a constant speed of 1 cm/s, so that its end (a red target with a 5 mm diameter) moved either toward or away from the participants. The direction of rod displacement defined two experimental conditions and for both, participants were asked

Figure 1. Illustration of the experimental setup used in Task 1 to evaluate the organization of reachable space, i.e., to assess the participants' capacity to judge space boundaries in both preferred and nonpreferred hemi-field. The classical approaching/departing method was used following three target angles in nonpreferred hemi-field, one central target (0°) and three target angles in the preferred hemi-field of space (left for left-handed participants). Throughout this task, participants were required to give a judgment of the boundary of reachable space without moving their finger from the resting starting position (black dot).

to make reachability judgments from a seated position assuming that only arm extension was permitted. The perceptual judgment task was performed according to the preferred hand, but participants were never allowed to truly move the hand in direction of the target.

Task and Procedure

Because of the biomechanical constraints of upper limb function, the majority of our interactions are performed within a 120° area of space, centered on the medial body axis. To gain insight in the perceptual organization of peripersonal space throughout action space, we probed peripersonal space by dividing the area into eight equal triangles, which afforded a total testing period to less than 40 min. The seven preselected angles were -67.5° , -45° , -22.5° in the nonpreferred hemi-field of the participant; 0° for the central angle aligned with mid-body axis; 22.5° , 45° , 67.5° on the preferred hemi-field of the participant. Participants were required to place the finger of their preferred hand on a mark – the resting point – placed at the center of their medial body axis. The target object was moved in and out of action space according to these seven angles and, in all trials, the target was moved along the direction that converged toward the finger resting point.

Under the condition for which the target moved toward the participant (*approaching condition*), the task for the participants was to say “stop” at the first instant for which they thought they could contact the target with their fingertip by full arm extension (see Figure 1). Under the condition for which the target moved away from the participant (*departing condition*), the task was to say “stop” as soon as they thought that they could contact the target with their

fingertip. In other words, the participants' task was to determine on each and every trial when the target reached the limits of reachable space. The participants' responses will be in the following referred to as the *estimate of reachability*. Two estimates from approaching targets and two estimates from departing targets were obtained in semirandomized order, for the seven predefined angles. At the end of the session, the actual boundary of what is reachable was determined by measuring the span from the outer edge of the shoulder joint (acromion) to the tip of the middle finger, to the nearest millimeter. This measure will be in the following referred to as the *true reachability*.

Task 2

We wanted here to investigate whether the boundary of reachable space would be similar if participants were required to (1) move through space and (2) interact with a person rather than with an object. This task took approximately 20 min.

Task and Procedure

Participants were invited to stand up and go in the room next door, in which a second experimenter was waiting, standing with a neutral expression in the middle of the room. There were three situations to this task. In situation 1, participants were asked to walk toward the person and to stop as soon as they thought they could touch him, with the right arm stretched out. In situation 2, the person walked toward the participants who were asked to say stop as soon as they thought that they could touch the person,

with the preferred arm stretched out. In situation 3, an object hanging from the ceiling replaced the person, and participants were asked to walk toward the object and to stop as soon as they thought they could touch it, with the preferred arm stretched out. After each trial, participants were required to walk back to the door. Two trials for each situation were performed in a semi randomized order. The participants were never allowed to actually stretch their arm out to check the accuracy of their responses.

As the participants were the same in both tasks, the results for the central target of Task 1, was used in combination of the results obtained in Task 2 to constitute a set of 4 experimental conditions (see Figure 2). First, participants provided a verbal judgment of the limits of reachable space for an object (*object to me*) or for a person (*person to me*) entering their peripersonal space. Second, participants provided a motor judgment by walking toward either an object (*Me to object*) or a person (*Me to person*) and stopping when the target reached the limit of peripersonal space.

Data Analysis

Estimates of reachability were compared to true reachability by computing a judgment error (JE) in percentage of actual reachability ($JE = [\text{estimate} - \text{true}] * 100 / \text{true}$). As such, positive values corresponded to overestimations. This method was chosen in order to scale judgments as a function of body capabilities.

Because JE could be positive (overestimation) or negative (underestimation), mean JE is an estimation of constant error, which is a composite of both the direction and the amplitude of judgment errors. Thus, we calculated the absolute value of each response in order to compute JE-absolute, which is a pure indicator of the magnitude of the JEs. Hence, high JE-absolute values indicate low accuracy in

estimating the boundaries of peripersonal space. The standard deviation of responses was also calculated for each participant and experimental condition in order to compute JE-variance, which is a pure evaluation of the variability characterizing the participants' responses. Hence, high JE-variance values indicate low repeatability in estimating the boundary of a given section of peripersonal space.

Results

The two tasks were conducted within a single experimental session. All participants performed the tasks without apparent difficulty. Major results for both tasks are presented in Figure 3 and Figure 4.

Task 1

In Task 1, all dependent variables were analyzed through a 2 (Group) $\times$ 2 (Direction) $\times$ 7 (Angle) analysis of variance with repeated measures for Direction and Angle. For all analyses, the significance level was set at $p = .05$. Group main effect on mean JE was not significant, $F(1, 38) = 3.350$, $p = .075$, $\eta^2_p = 0.081$, indicating that on average patients (-2.5 SD 2.8%) and controls ($+4.8$ SD 2.8%) evaluated the limits of peripersonal space with a similar level of accuracy, both with less than 5% of error. However, analysis of JE-absolute revealed to be not negligible for both experimental groups; JE-absolute was greater in the patient than in the control group, $F(1, 38) = 9.760$, $p = .003$, $\eta^2_p = 0.204$. More specifically, patients were characterized with greater JE-absolute (19.4 SD 2.1%) than the controls (10.0 SD 2.1%), indicating that patients made in absolute terms greater errors than controls when judging the limits of peripersonal space. Group effect was also significant for JE-variance, $F(1, 38) = 15.181$, $p <$

Figure 2. Schematic illustration of the four experimental conditions of Task 2. In the VERBAL Mode (left), subjects provided a verbal judgment of the limits of reachable space for an object (*object to me*) or for a person (*person to me*) entering their peripersonal space. In the ACTION Mode (right), subjects provided a motor judgment by walking toward either an object (*me to object*) or a person (*me to person*), and stopping when the target reached the limit of peripersonal space.

Figure 3. Mean absolute error of judgment (in %) for patients with schizophrenia and control participants, for the seven target angles of Task 1 (NP: nonpreferred hemi-field; P: preferred hemi-field). There is a similar pattern of results throughout action space for both groups, albeit with a systematically greater error in judgments of the boundary of peripersonal space for patients with schizophrenia.

Figure 4. Mean absolute error of judgment (in %) for patients with schizophrenia and control participants, in the four different experimental conditions of Task 2. In the verbal mode, during which participants were OBSERVERS (top), they were required to remain immobile and to say stop when the moving object (object to me) or moving person (person to me) touched the boundary of reachable space. In the action mode, for which participants were ACTORS (bottom), they were required to stop walking as soon as they judged that the object (me to object), or the person (me to person) could be touched with their arm outstretched, i.e., touched the boundary of reachable space. The results are presented for the patients in dark gray and the controls in light gray, for physical interaction (top – A) and for social interaction (bottom – B).

.001, $\eta^2_p = 0.285$, indicating that the patients were more variable in their judgments (7.7%; range: 6.2–9.2%) than the controls (3.6%; range: 2.2–5.1%).

ANOVA conducted on mean JE revealed a significant Direction effect, $F(1, 38) = 8.832$, $p = .005$, $\eta^2_p = 0.188$. All participants underestimated the boundary of peripersonal space in the Departing condition (-4.3 SD 2.6%) and overestimated this boundary in the Approaching condition ($+6.6$ SD 2.8%). These findings confirmed published results in the literature (e.g., Fischer, 2005). A similar pattern of results was observed for controls ($+10.5\%$; -0.9%) and for patients ($+2.6\%$; -7.6%), $F(1, 38) = 0.031$, $p = .863$, $\eta^2_p = 0.001$. Direction effect was not significant for both the mean JE-absolute, $F(1, 38) = 1.44$, $p = .238$, $\eta^2_p = 0.036$, and the mean JE-variance, $F(1, 38) = 1.150$, $p = .290$, $\eta^2_p = 0.001$. These results suggest that the effect of Direction was systematic and similar for both experimental groups.

Statistical analysis of mean JE revealed a significant Angle effect, $F(6, 228) = 22.553$, $p < .001$, $\eta^2_p = 0.188$. There was a side effect with smaller mean JE for those angles located in the preferred (-1.6%) than in the nonpreferred ($+4.8\%$) hemi-field, $F(1, 38) = 26.27$, $p < .001$, $\eta^2_p = 0.408$. These effects were similar for both experimental groups, $F(6, 228) = 1.991$, $p = .068$, $\eta^2_p = 0.049$. The analysis of the magnitude of judgment errors confirmed the side effect with smaller JE-absolute values for the preferred hemi-field (controls: 8.6%; patients: 18.8%) than for the nonpreferred hemi-field (controls: 11.7%; patients: 20.7%), $F(1, 38) = 5.910$, $p = .049$, $\eta^2_p = 0.110$. Posthoc analysis (Scheffé) revealed furthermore that participants were more in difficulty when the target was moving in the 45° direction and specifically when that target was in the nonpreferred hemi-field of space (see Figure 3). Finally, this analysis of mean JE-absolute confirmed a similar effect in both experimental groups with a nonsignificant Group $\times$ Angle interaction, $F(6, 228) = 1.042$, $p = .394$, $\eta^2_p = 0.027$.

For the patient group, correlation analyses were conducted in order to assess a functional association between the capacity to specify accurately the limits of peripersonal space, and clinical symptoms. Results revealed that mean JE-absolute values were correlated to the general PANSS score, $R_{210} = 0.590$, indicating that the more severe the symptoms, the more patients tended to provide abnormally large errors when judging the limits of peripersonal space. Most interestingly, mean JE-variance values were significantly correlated to the disorganization cluster of the PANSS, in both the Approaching direction ($R_{49} = 0.604$), and the Departing direction ($R_{49} = 0.583$). These results indicate that the patients' capacities in judging repeatedly the limits of peripersonal space decreased with increasing disorganized thoughts and behavior.

Task 2

In a second task, participants were invited to judge the limits of peripersonal space when interacting with an object or

with a person in order to evaluate the effects of social context. This task was conducted after Task 1 for all subjects, and lasted approximately 20 minutes. In Task 2, JE measures for each participant were computed and analyzed through a 2 (Group) $\times$ 2 (Situation: object; person) $\times$ 2 (Mode: verbal; motor) analysis of variance with repeated measures for Situation and Mode.

Group main effect on mean JE was nonsignificant, $F(1, 38) = 0.339$, $p = .564$, $\eta^2_p = 0.009$. Nevertheless, ANOVA on mean absolute-JE revealed a significant effect of Group, $F(1, 38) = 4.401$, $p = .043$, $\eta^2_p = 0.104$, with greater absolute errors for patients (18.9%) than for controls (15.1%). The analyses of variance-JE confirmed this effect by showing that the patient group provided more variable responses (6.7%) than the controls (4.0%), $F(1, 38) = 6.039$, $p = .019$, $\eta^2_p = 0.137$.

Situation main effect (social vs. none social interaction) was significant for mean JE, $F(1, 38) = 70.368$, $p < .001$, $\eta^2_p = 0.649$, and for mean JE-absolute, $F(1, 38) = 77.360$, $p < .001$, $\eta^2_p = 0.669$. More specifically, controls and patients were more accurate in their judgments when interacting with a person (9.0%; 12.4%) than with an object (21.2%; 25.4%). As shown in Figure 4, similar patterns of results were obtained for patient and controls, $F(1, 38) = 0.087$, $p = .769$, $\eta^2_p = 0.002$. The effect of Situation was not significant for the variability of response, $F(1, 38) = 1.267$, $p = .267$, $\eta^2_p = 0.032$.

Finally, the mean effect of Mode (verbal vs. action) was not significant for mean JE, $F(1, 38) = 1.291$, $p = .263$, $\eta^2_p = 0.033$. However, Mode effect reached a significant level for JE-absolute, $F(1, 38) = 4.192$, $p = .048$, $\eta^2_p = 0.099$, indicating that overall participants made smaller errors in the action mode (15.5%) than in the verbal mode (18.1%). Most interestingly was the significant interaction Group $\times$ Mode, $F(1, 38) = 09.517$, $p = .004$, $\eta^2_p = 0.200$. Posthoc tests revealed that in the verbal mode, JE-absolute was significantly greater in the patient group (21.5 SD 2.3%) than in the control group (14.2 SD 2.3%). An absence of Group differences was revealed in the action mode (16.3; 15.6%) for controls and patients, respectively; this was the case whether interacting with an object (21.6%; 22.2%) or with a person (9.6%; 10.3%).

Judgments were less variable in the action mode (3.8%) than in the verbal (6.9%) mode, $F(1, 38) = 10.981$, $p = .002$, $\eta^2_p = 0.224$. A similar pattern of results was observed for the action and verbal modes, respectively, in both the patient group (4.6%; 8.8%) and in the control group (3.1%; 5.0%) as suggested by a nonsignificant interaction, $F(1, 38) = 1.490$, $p = .230$, $\eta^2_p = 0.038$.

Discussion

Schizophrenia is a severe mental disorder characterized by three kinds of symptoms: (1) positive psychotic symptoms that include thought disorder, delusions, hallucinations, and paranoia; (2) negative symptoms that affect the emotional range, energy, and enjoyment of activities as well as

social drive; (3) disorganization symptoms characterized by behavioral maladaptation, physical agitation, and incoherence of speech. For a formal diagnosis, these symptoms must persist for at least one month and usually result in severe impairments in job and social functioning. The aim of the present work was to evaluate whether deficits in appropriately specifying physical (interaction with an object) and social distances (interaction with a person) are related in patients with schizophrenia to abnormal capabilities to organize and structure the surrounding environment when judging the boundaries of personal space.

Using a stop-distance paradigm, the findings reported in the present study revealed that peripersonal judgments were significantly more inclined to error and more variable in the patients than in the age-matched controls. Furthermore, the magnitude of error was positively correlated with general PANSS score, and the variability of error was positively correlated with the importance of the disorganization symptom. Both of these findings reveal a possible relationship between the capacities to organize information and the ability to use the information to determine in a systematic fashion the limits of peripersonal space. Within the same patient group, social distances were assessed during a second task for which participants were required to interact with a person. Here again, results showed that patients were characterized with abnormally high judgment errors compared to those observed in the controls. Taken together these results suggest that the difficulty experienced in patients suffering from chronic schizophrenia in judging what are socially acceptable interindividual distances may be due to their difficulty in structuring and organizing those sources of information needed to evaluate the consequences of deployable actions.

In a last experimental condition, we investigated the effect of the nature of the response on judgment errors. As such, we contrasted judgment errors toward the same target either in a VERBAL mode or in an ACTION mode. More specifically, in the latter situation, participants were asked to provide their judgments through movement by walking toward the target and to stop when it touched the boundary of reachable space. Results demonstrated that, for the controls, the response mode did not modify the accuracy of judgment errors. However, action significantly improved judgment capacities for the patients, rendering their results close to normalized both when interacting with an object and with a person. Overall, these findings support the hypothesis that voluntary body movement may provide helpful guidance in the grouping of those unstructured and disorganized processes that handicap patients suffering from mental disorders.

Systematic Biases when Judging the Boundaries of Peripersonal Space

When a target was moving toward or away from the participants (Task 1), results showed that all participants were able to provide a judgment of the limits of peripersonal

space throughout the 40-min testing period. Interestingly, participants showed an overall tendency to overestimate actual reach, i.e., they judged the boundary of peripersonal space to be further than actual. This is consistent with many previous studies that used multiple types of protocols: reaching for pegs (Heft, 1993); reaching for objects (Bootsma, Bakker, van Snippenberg, & Tdlohreg, 1992; Carello, Groszofsky, Reichel, Solomon, & Turvey, 1989; Coello & Delevoye-Turrell, 2007; Rochat & Wraga, 1997); walking toward objects (Mark et al., 1997). We furthermore replicated in both controls and patients, the directional effect reported by Fischer (2003) such that approaching objects led to stronger overestimation of peripersonal boundary compared to departing objects. Nevertheless, patients revealed to be less accurate and more variable than age-matched controls throughout the workspace (Figure 3).

In clinical settings, patients suffering from schizophrenia report a difficulty in maintaining a stable and organized perception of the surrounding world. The image that is often used is that of seeing the trees and not the forest (Shaw, 1950) because of a difficulty in schizophrenia to group and make structural links between the multitudes of elements in the environment. It is thus conceivable that interactions directed toward objects (or people) are dysfunctional because of abnormal multidimensional perception. In the present study, we adopted a methodology that provided the tools required to test directly the working hypothesis that the abnormally high errors in the delimitation of the boundaries of personal space in schizophrenia may be due to a difficulty in the construction and organization of perceptual space.

A Perceptual Origin of Biased Judgments

It is widely acknowledged that biased judgments of what is reachable can have a perceptual origin, as it is well known that spatial distances are more sensitive to error judgments in impoverished visual contexts (Coello & Iwanow, 2006; Treisilian, Mon-Williams, & Kelly, 1999). Thus, with less information, decision-making becomes more variable and less accurate. Schizophrenia is a pathology that perturbs the grouping mechanisms necessary to structure the world around us (e.g., van Assche & Giersch, 2011; Giersch, van Assche, Huron, & Luck, 2010). It could thus be that judgment errors in determining the limits of peripersonal space are related to perceptual deficits of the multidimensional structure of the surrounding environment.

Classically, reachability studies have studied judgment biases in the central mid body axis only (0°). In the present study, we reported experimental results throughout a -90° to +90° area of space, centered on the midsagittal axis. Our results indicate that even in healthy controls, judgment biases are the smallest for 0°, and are significantly greater when targets are presented in the nonpreferred hemi-field of space. This finding can be associated to the fact that we

do not explore our 360° peripersonal space in an identical fashion. As stated by Anderson (2005), spatial cognition evolved in organisms with specific physical attributes, bodies of a certain type with given structural features, and can therefore be expected to have been shaped by and to take advantage of these features. As such, judgments of action space can be expected to be more accurate in those areas of space where one has the most motor experience.

Central to the subject of the present paper, patients with schizophrenia were revealed to have similar patterns of results as controls. Indeed, they overestimated approaching targets, and underestimated departing ones. They were also revealed to be more accurate and less variable in their judgments for targets moving in the preferred hemi-field (Figure 3). As such, the abnormally high variability and greater absolute error that was nevertheless observed in these patients are unlikely to be the consequence of a general perception bias of the structure of peripersonal space. In the following paragraph, we propose an embodied view of perception that may provide the theoretical framework for a better understanding of the abnormal performances in the determination of the boundaries of personal space reported in patients with schizophrenia.

A Motor Origin of Biased Judgments

Action representations can be viewed as a component of a predictive system that includes a neural process, which simulates through motor imagery the dynamic behavior of the body, in relation to the environment (Grush, 2004; Jordan, 1995; Wolpert, Ghahramani, & Jordan, 1995). It is acknowledged that the presentation of a visual stimulus can automatically evoke a potential motor action, which regardless of whether the action is subsequently executed or not, maps the spatial stimulus position in motor terms (Jeannerod, 2001). Coding a visual stimulus in motor terms enables optimal planning of action as well as the anticipation of sensory and spatial action consequences (Choudhury, Charman, Bird, & Blakemore, 2007; Grush, 2004; Wolpert & Kawato, 1998), providing then the self with information on the feasibility of deployable actions (Jeannerod, 2006). Such distinction between possible and impossible actions might represent the underlying principle for subdividing external space into peripersonal and extrapersonal spaces (Coello & Delevoye-Turrell, 2007).

Within the embodied concept of cognition, the capacity to provide accurate judgments of peripersonal space boundaries would thus depend on the capacity to create an organized and structured mental representation that integrates signals from the motor system with afferences coding for the visual structure of the environment. In the past, it was suggested that schizophrenia represents a pathology characterized with an impaired capacity to integrate information from multiple sources (Dreher et al., 1999; Tononi & Edelman, 2000), in order to create and/or maintain vivid representations of action goals (Delevoye-Turrell et al.,

2007). It was also suggested that deficits in the integration of motor efferences with endogenous sensory feedback would contribute to abnormal consciousness of the self, both at a reflective (Blakemore, Wolpert, & Frith, 2002; Shergill, Samson, Bays, Frith, & Wolpert, 2005) and at a prereflective level of body experience (Bulot, Thomas, & Delevoye-Turrell, 2007; Jardri et al., 2009).

In the present study, patients with schizophrenia made significantly more absolute errors and were significantly more variable in their judgments of the boundary of peripersonal space. The fact that positive correlations were found between the disorganization cluster and the variability in the patients' judgment errors argue furthermore in favor of a specific deficit affecting the capacity to structure and maintain an integrated sensory-motor representation, on which to base judgments about the boundaries of reachable space. Though the present study provides strong arguments in favor of this interpretation, further studies are needed to confirm a functional association between the deficit in motor representations and the clinical symptoms of disorganization. In particular, it would be of great interest theoretically to assess whether impairments in schizophrenia are directly related to a difficulty in the explicit use of motor representations for explicit judgments, or rather a problem of allocating attentional resources for maintaining stable and vivid representations through time (Wilquin, Delevoye-Turrell, Ameller, Wing, & Thomas, 2010).

Judging Through Action to Confirm the Motor Origin of Biased Judgments

In the present study, the key question was to assess whether abnormal social distances would be observed in those patients revealing impaired spatial cognition. Hence, in the second half of the study, participants were invited to perform the stop-distance protocol in an active body posture, i.e., standing either facing an object (spatial distances: "How far is that object from my personal space?") or facing a person (social distances: "How far is that person from my space of comfort?"). Furthermore, in order to test the role of voluntary movement for the organization of surrounding environment, participants were required to perform the task either from an observation (verbal mode) or an actor (action mode) point of view.

In the verbal mode (Figure 4, panel A), the participants remained immobile throughout the series of trials. Results showed that judgment errors for both spatial and social distances were significantly greater in the patient group than in the control group. Responses were also significantly more variable. Overall, these results confirm those studies previously reporting abnormal judgments of boundaries of peripersonal space (Delevoye-Turrell, Bartolo, & Coello, 2010) as well as those reporting abnormal judgments of social distances (Nechamkin et al., 2003; Park et al., 2009; Srivastava & Mandal, 1990). Our findings further suggest

that the two types of judgment tasks, which involved object interaction (action capabilities) and social interaction (social distances), may involve common cognitive brain mechanisms.

In the action mode (Figure 4, panel B), participants did not speak. They were simply required to walk slowly and to stop when (1) the object or (2) the person touched the boundary of their own peripersonal space. The results revealed two important findings. First, healthy controls showed significantly greater errors in determining the boundaries of reachable space when interacting with an object than with a person. It is possible that because of the lower risk associated with making a mistake of distance judgment with an immobile object, participants were less attentive in this condition. If this were the case, however, results should have been more variable, which was not the case. Another possibility is that the threat associated to misjudging physical distance is greater for a moving object than an immobile one. Thus, our cognitive system would have memorized more life experiences in order to protect the body from impending collisions with moving objects. Finally, it is possible that in a true ecological situation, one moves toward an object to lift it for future manipulations. In such case, one does not want to lift an object with the arm outstretched for dynamical reasons. A more force-efficient arm position is in fact an angle of 120°. Participants may thus have been, in this specific condition only, in an unnatural posture that impaired judgment capacities. This later hypothesis is supported by the fact that in the situation for which the participants were to move toward a person, judgment errors were small (< 10%). This person-interaction task is most ecological as it corresponds to those frequently experienced situations of every day life, e.g., walking toward someone to shake hands.

The second important finding revealed in the action mode (Figure 4, panel B), was the fact that the results in the patients suffering from schizophrenia were similar in all points to that observed in the controls. Errors were of similar magnitude but also of similar variability in patients and in controls, which contrasted significantly to that observed in the verbal mode. Furthermore, this normalized level of performances was observed in the patients both when they were to interact with an object (left) and with a person (right). These findings suggest an important role of voluntary action for an accurate judgment of the boundaries of peripersonal space. Though this study involved a group of 20 participants, these preliminary results need to be confirmed in a bigger patient group in order, among other questions, to gain a better insight on the correlation functions that associate clinical symptoms, judgment errors of the boundaries of peripersonal space and abnormal social distances in schizophrenia.

Within the embodied concept of perception, we proposed that the capacity to differentiate peripersonal from extrapersonal spaces depends essentially on our ability to anticipate the sensory and spatial consequences of deployable actions, and that these spaces exist only by virtue of

this potentiality (Delevoye-Turrell et al., 2010). If this is indeed the case, then peripersonal space perception would depend not only on optically specified geometry of visual scenes and objects, but also on the capacity to maintain structured and vivid motor representations for action (Coello & Delevoye, 2007). Assessing the perception of what is reachable represents then a fruitful tool for identifying deficits based on motor representation impairments, as it seems to be the case in schizophrenia. The innovating aspect revealed through the present study is also the potential of voluntary movement to structure disorganized thoughts. As such, brain exercises based on voluntary movement may in future times reveal themselves to be a powerful tool for cognitive remediation.

Motor control is a complex cognitive function that requires organization, grouping, and planning of sequential actions. When one walks toward an object or a person for future interaction, the brain must, at an unconscious level, structure and plan forthcoming movements in context with the surrounding world. It is thought that the dorso-lateral region of the frontal lobes is required for the execution of interactive skills. An increasing number of studies have been reporting the effects of movement (exercise sports) on cognition (Davranche & McMorris, 2009; Joyce et al., 2009). In the present study, our results suggest also an important role of voluntary action on social function. Indeed, when required to walk toward the human target, patients revealed normalized capacities to determine the boundaries of personal space. It is as if the act of producing a voluntary action helped the patients to organize and structure the world around them. The power of voluntary movements for biological processes was recently reported (Voss et al., 2010); more work is now needed to confirm its effect on behavior. In clinical settings, patients are often observers of the situation. Inhibited by their illness, patients are known to be passive, waiting for the caretakers or a family member to tell them what to do, and when to do it. Our findings are the first to suggest that social interactions may be helped in psychiatry if patients are encouraged to actively take part in the interactive process, by become actors of the situation.

Conclusions

In the present study we showed that both personal space and social space are influenced by mental health. Abnormally large errors for determining the boundaries of peripersonal space were observed in patients suffering from schizophrenia both when interacting with an object and with a person. Psychologically, these observations predict that in a social context, patients with schizophrenia will suffer from a difficulty in social integration because of being unable to adapt the social “norms” spontaneously adopted by mentally healthy individuals. Social isolation is known to be one of the most primary causes of poor quality of life in mental illnesses, and a better understand-

ing of the mechanisms for abnormal interactive behavior could provide significant valid guidelines for innovating insertion programs. Most specifically, the present study demonstrated that the impaired cognitive process for social distance is not perceptual in nature, but may rather be associated to a difficulty in the organization of thought for decision-making. Brain exercises based on voluntary movement may reveal in future times as a powerful tool for cognitive remediation.

Acknowledgments

This study was conducted in the University Hospitals of Lille (CHRU). We thank Prof. P. Thomas and his clinical group of the University Hospitals of Lille (CHRU de Lille, France) for helping access to patients. We thank M. Gaudin for her help in data collection. Finally, we thank the native English speaker for the linguistic review of the manuscript. Research was supported by grants from (1) European Science Foundation, Eurocores CNCC CRP and (2) MESHS-USR 3185-Région Nord Pas de Calais, France. The authors of the article report no competing interests.

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Received May 18, 2010

Final revision received January 8, 2011

Accepted January 8, 2011

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