Flexibility of the cognitive system to use various spatial coding: Implication for driving situation

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Abstract – *Driving is a spatial behaviour that requires fast and accurate spatial coding in order to anticipate and respond appropriately to expected or stunner event. Convergent evidences from animal and human studies support that different reference frames can be used to code our surrounding environment. Although recent works argued in favor of the parallel encoding of space in both egocentric and allocentric coordinates and showed that humans enable to alternate between both these spatial knowledge, the flexibility of the cognitive system to switch between each other remains largely undocumented. The current study aimed to address this issue by investigating, among twenty eight healthy participants, the temporal cost linked to switch from one reference frame to another in memory. Experimental procedure consisted in two stages: (1) a first navigation phase in a virtual town during which participants had to learn the localization of several closed places that we generally encounter in a conventional city (e.g., shops, post office) and, (2) a spatial memory test involving egocentric or allocentric spatial knowledge about these closed places. The methodology of this memory test allowed to estimate the temporal cost needed to switch between egocentric and allocentric knowledge by comparing response times in two conditions: a '*repeat' *condition in which the trials involve the same reference frame in memory as the previous trials with an '*alternate' *condition in which the trials rely on different spatial memory as the previous trials. As expected, results showed that participants were faster on* 'repeat' *trials than on* 'alternate' *trials, revealing a strong temporal switch cost of 585 milliseconds (± 144.75). This limited flexibility of the cognitive system to switch between various spatial coding in memory could cause some insecurity problems in driving situation that requires very low reaction times.*

Résumé - *La conduite automobile nécessite un codage spatial précis et rapide en vue d'anticiper et répondre aux divers événements pouvant survenir. De nombreux résultats issus des travaux chez l'homme et l'animal défendent l'idée selon laquelle différents cadres de référence peuvent être utilisés pour coder* *l'environnement qui nous entoure. Bien que ces études récentes ont argumenté en faveur de l'encodage simultané de l'espace en coordonnées égocentriques et allocentriques et ont montré que l'homme était capable d'alterner entre ces deux types de connaissances spatiales, la flexibilité du système cognitif pour passer de l'une à l'autre reste peu documentée. Notre étude vise à aborder cette question en examinant parmi vingt huit adultes sains le coût temporel lié au changement de référentiels spatiaux en mémoire. La procédure expérimentale prévoyait deux sessions : (1) une première phase de navigation dans une ville virtuelle au cours de laquelle les participants devaient apprendre la localisation de lieux citadins (e.g., des magasins, la poste) et, (2) un test de mémoire spatial impliquant des connaissances spatiales égocentrées et allocentrées de ces différents lieux. La méthodologie de ce test a permis d'estimer la latence temporelle de changement de référentiel en comparant les temps de réponse dans deux conditions: une condition de répétition dans laquelle les essais impliquaient le même type de référentiel spatial que l'essai précédent avec une condition d'alternance dans laquelle les essais impliquaient un référentiel différent de celui mobilisé par l'essai précédent. Comme attendu, les résultats ont montré des temps de réponse plus rapide pour les essais de répétition par rapport aux essais d'alternance, révélant une latence temporelle importante de changement de référentiel d'environ 585 millisecondes (± 144.75). Cette flexibilité limitée du système cognitif à changer de codage spatial en mémoire pourrait causer quelques problèmes d'insécurité dans les situations de conduite automobile qui nécessitent des temps de réponse très courts.*

Introduction

Perceiving our surrounding environment in a rapid manner is essential for driving behaviour that requires low reaction times. Understanding the flexibility of the cognitive system in navigational dynamic situation is thus a crucial issue in this precise context. It is now well establish that different forms of spatial coding and reference frames can be used to code spatial information about our navigational environment (Avraamides & Kelly, 2008; Berthoz, 1991; Trullier, Wiener, Berthoz, & Meyer, 1997). Recent evidences assume that these spatial coding co-exist in memory, suggesting that they may be combined and used simultaneously or sequentially to support spatial behaviour (see Burgess, 2006 for review). Investigating the cognitive flexibility particularly involved in using reference frames could thus have major implications in driving and navigation situations especially when very fast responses are needed.

As evidenced by studies showing that knowledge dependant upon specific viewpoint is maintained in memory (Diwadkar & McNamara, 1997; Schmidt *et al*., 2007), space can be referenced to the body in an 'egocentric' reference frame. Convergent evidence including the discovery of neurons coding our absolute location in space (Ekstrom *et al*., 2003; O'Keefe & Dostrovsky, 1971) have demonstrated that spatial information can also be coded by the brain independently of our body's position or orientation, in 'allocentric' coordinates. In expended and complex environment, flexible guidance of behaviour would be supported by this latter allocentric high-level cognitive comprehension of environment that is supposed to rest upon a ‘cognitive map’ (Etienne & Jeffery, 2004; O'Keefe & Nadel, 1978).

Although human adults show some general preferences to use a particular reference frame (e.g., Gramann, Muller, Schonebeck, & Debus, 2006), recent works have shown that both egocentric and allocentric reference frames can co-exist in memory (Igloi, Zaoui, Berthoz, & Rondi-Reig, 2009; Waller & Hodgson, 2006): the brain would be enable to encode both these forms of spatial coding in parallel, retrieve and switch between them. For example, during a spatial navigation task in a ‘starmaze’, Igloi and collaborators (2009) have shown that some participants rely on both egocentric and allocentric strategies by shifting from one strategy to another. Importantly, this switching behaviour has been observed during spontaneous as well as imposed behaviour in both directions of switch, showing that both strategies are available at any time during navigation. Although these works support the parallel encoding of space in both egocentric and allocentric coordinates and showed that humans enable to retrieve and switch between both these knowledge, no experimental study has directly investigated the dynamic interaction between the ego- and allocentric reference frames in memory.

Here, we describe a multidisciplinary experiment aiming to investigate the flexibility of the brain to use these two co-existent spatial coding. By combining a virtual reality approach with a task-set switching paradigm, the study focuses upon the time scale of the cost linked to switch between egocentric and allocentric spatial knowledge in memory. We addressed this issue by submitting healthy adults to a spatial memory test that involves the recall of egocentric and allocentric spatial distances between locations previously encountered during navigation in a virtual town.

Method

Participants

Twelve healthy females and sixteen males volunteered to participate in the study, yielded a total of twenty eight participants. Participants were 23 to 36 years of age (mean age: 28.7 SD: 3.5) and had normal or corrected-to-normal vision. The experiment was approved by the ethic committee of the region (Comity of human protection in experimental research (CPP) of Ile de France VI) and was conducted with the understanding and the written consent of participants who were naive with regard to the precise purpose of the study.

Apparatus and procedure

The procedure was composed of two successive sessions: a learning phase of the virtual reality environment and a spatial memory test phase. The total duration of the experiment was approximately one hour and 40 minutes.

The navigational virtual environment

The navigational environment was a fully coloured and textured virtual town with buildings, places and roads. It was generated by Virtools™ 4 software and displayed with a high resolution on a large hemicylinder-shaped screen with 185° field of view (270 mm radius and 274 mm height). It was presented in a first-person view and adjusted for the viewpoint height of the participants (Figure 1).

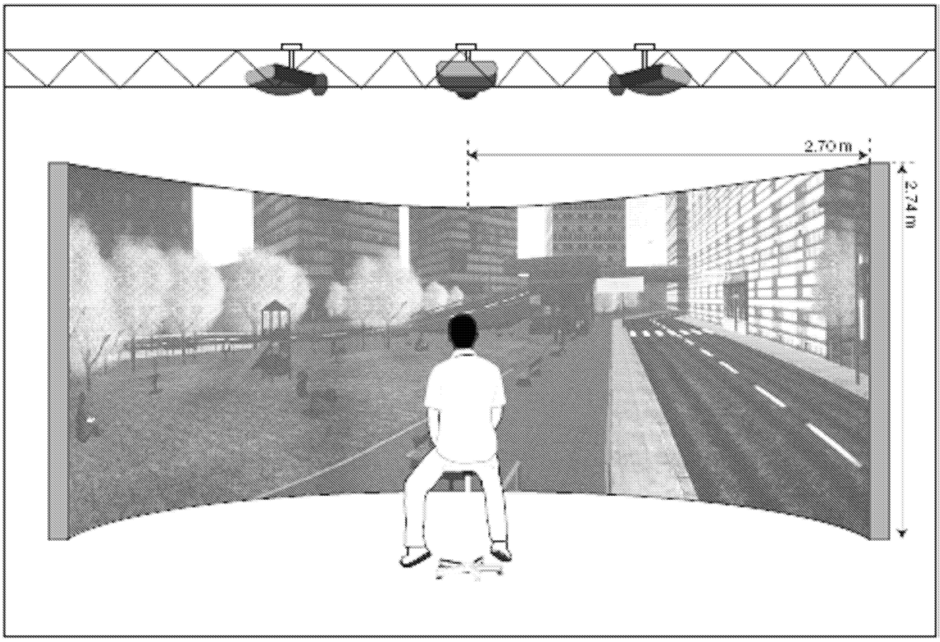

Figure 1. Schematic representation of the large hemicylinder-shaped screen on which the virtual environment was projected in first-person view

The learning phase

After a 5-minutes familiarization phase with the navigational environment and the virtual set-up, the learning session involved navigation through 3 pathways (a, b, c) for approximately one hour and twenty minutes. It simulated a walk path centred on either (left and right) sidewalk in the virtual city. Participants explored each pathway twenty times, yielded a total of sixty exploration trials of the virtual city experienced in a random order. This navigation session allows the participants to explore attentively the virtual city and to learn the position of signs appearing on either side of each of the three pathways. Participants can move forward using the joystic but can not control the navigation trajectory, guarantying that information available during learning was equivalent across participants. There was no overlap between each pathway except the starting place, ensuring that a global allocentric comprehension of the navigational environment can only be developed by integrating those different navigation experiences in memory.

There were thirty distinct closed places in the environment (e.g., butcher shop, pharmacy, bank, police station, museum). Ten closed places appeared on the left and right sidewalk of each pathway and were identified by fully coloured signs mounted at the top of windows. Those thirty signs were fully coloured large rectangular 3D objects on which the name of the closed place is written. Every time participants encountered signs during navigation on the pathways, participants were stopped for 2 seconds. At each stop, two signs were always apparent, one on the left sidewalk and one the right sidewalk (see Figure 1).

The '*stop distance'* (i.e. the spatial distance between the sign and its respective stop) differed between the different signs of the environment but was maintained strictly constant for a same sign across the different navigation trials.

Participants were informed that the learning navigation session is followed by a memory test. They were instructed to learn the position of the thirty distinct close places relative to their position when they were stopped in front of the signs, and relative to the whole environment and the other signs (i.e. independently of their position).

The test phase

The second session is a spatial memory test performed on a separate standard flat computer screen (19 inch, 1280 x 1024 pixels, 75 Hz). It consisted to retrieve in memory both the "egocentric" and "allocentric" position of the signs. It was composed of two blocks of thirty one stimuli displayed in immediate succession using E-prime2 software.

In each block, half of stimuli intended to involve allocentric spatial memory access. These "allocentric" stimuli consisted to compare spatial distance between signs previously seen during navigation in the virtual city. As shown on the Figure 2, stimuli contained three signs vertically aligned replicating those seen during the navigation. Each one represented a sign appearing on each navigation pathway (a, b, c). Participants had to choose among the bottom and the top signs, which one was closest to the sign displayed at the screen centre. Spatial distances had to be estimated at crow flies on the basis of the spatial knowledge acquired during the learning session in the navigational environment. To the best of our knowledge, the sole way to succeed at that test requires accessing to a global allocentric comprehension of the virtual city formed upon the integration of spatial knowledge acquired from the navigational experience on the three pathways.

The remaining half stimuli intended to involve egocentric spatial memory access. They consisted to compare egocentric spatial distance of signs, namely the spatial position of signs with respect to the participant's position when they were at a specific location in the environment. As illustrated in the Figure 2, "egocentric" stimuli contained two signs at the top and bottom and, a human figure representing the participant in the centre. For these stimuli, participants had to choose among the top and bottom signs, which one was the closest to them when they were stopped in front of those signs during the navigation in the virtual city. They had thus to retrieve in memory both the *'stop distance'* of the top and the bottom signs and compare them in order to decide which one was the shortest.

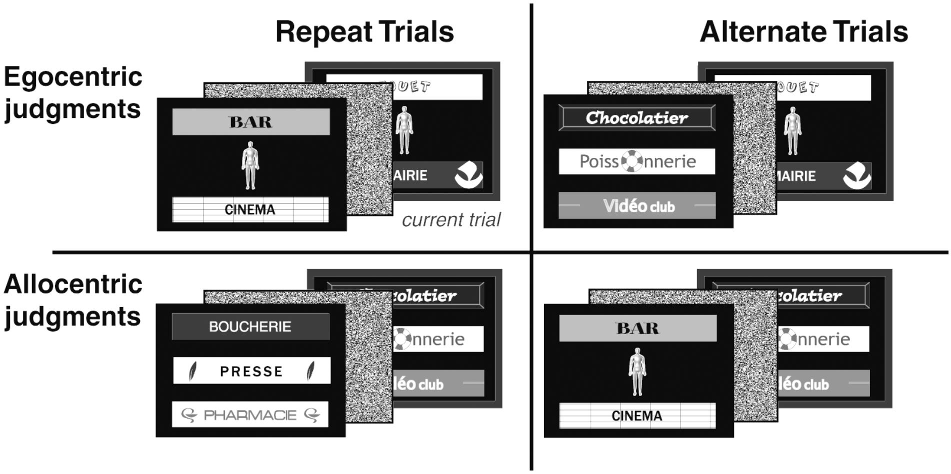

Figure 2. Schematic representation of the experimental design. The figure sum up the trial conditions as a function of the Reference frame of the current trial (egocentric vs. allocentric) and the nature of the previous trial, i.e. the Switch variable (repeat vs. alternate)

The stimuli were displayed until the participants responded by pressing as accurately and quickly as possible one of the two keys corresponding to the top and bottom signs on the screen. Stimuli were then followed by a mask displayed for 200 ms in order to erase the visual previous stimulus.

In order to estimate the eventual temporal cost due to switch from one strategy to another, we manipulated the random order of the “egocentric” and “allocentric” trials in each block. It allows us to compare response time (RT) of trials in two conditions: (1) a first one in which the trials involve the same reference frame in memory as the previous trials (*repeat* trials) with 2) a second one in which the trials rely on different spatial memory as the previous trials (*alternate* trials). Each block thus consisted of a successive set of alternate ‘egocentric’ trials, repeat ‘egocentric’ trials, alternate ‘allocentric’ trials and repeat ‘allocentric’ trials (see Figure 2).

Data Analysis

The presence of a temporal switch cost was tested by comparing RTs in alternate and repeat trials. Mean RTs were submitted to a two way ANOVA with Reference frames judgements (egocentric *vs.* allocentric) and Switch (alternate *vs.* repeat trials) as within-subject factors. Analyses were performed using STATISTICA v5.5 and 8.0 and the alpha was defined at .05. One participant was excluded from the analysis because his performance in the memory task was below the chance level.

The value of the switch cost was estimated by subtracting mean RT in *repeat* condition from mean RT in *alternate* condition. Positive differences would thus correspond to temporal cost due to switching from a reference frame to another in memory, while negative differences would correspond to switch benefit.

Results

Participants well succeed to the memory task as shown by the good performance recorded in “egocentric” and “allocentric” trials. The mean percentages of correct egocentric and allocentric judgments were 81.9% (SE = 1.3) and 80.8% (SE = 2.0), respectively.

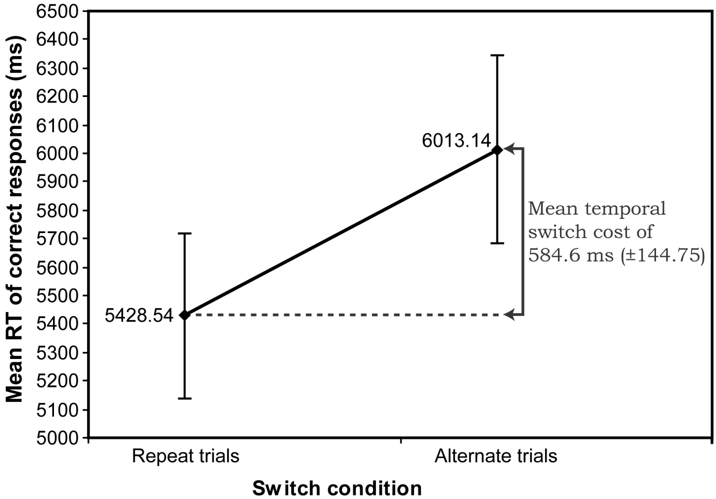

Figure 3. Mean RTs in the spatial memory task as a function of the Switch condition (repeat *vs.* alternate trials). The positive difference of 584.6 ms between both these conditions (alternate trials mean RTs superior to repeat trials mean RTs) indicates a temporal cost due to the switch between both egocentric and allocentric knowledge in memory

Regarding the temporal cost due to switching from one reference frame to another, the ANOVA on mean RT revealed a main effect of the switch ($F(1, 26) = 16.90$; $p < .0005$). As illustrated in the Figure 3, mean RT were faster in *repeat* trials (5428.54 ms; SE = 291.29) as compared to *alternate* trials (6013.14 ms; SE = 329.05), showing that switching between reference frames in memory takes in average 584.6 milliseconds (SE = 144.75). The analysis revealed also a main effect of the reference frame ($F(1, 26) = 39.91$; $p < .0001$), with longer RT for allocentric judgements (6358.94 ms; SE = 358.42) than for egocentric ones (4676 ms; SE = 225).

Discussion

The current study aimed to investigate the temporal cost linked to switch between egocentric and allocentric reference frames in memory in the context of complex navigation situation. Firstly, we found high accuracy in both ‘egocentric’ and ‘allocentric’ judgments, demonstrating the human ability to form and use ego- and allocentric knowledge of a complex navigational environment. The time difference in processing ego- and allocentric judgments is not unexpected as the current egocentric and allocentric judgments are not comparable at many levels.

These results may be caused by the material we used in the current experiment: participants had to retrieve spatial knowledge of three signs in allocentric judgments, while they were required to only retrieve those of two signs in egocentric judgments.

Regarding our main issue, we show that alternation between both egocentric and allocentric spatial coding takes a substantial amount of time (in average 585 milliseconds). These results demonstrate the limited flexibility of the cognitive system to use and switch between various spatial coding in memory.

The underlying process causing the switch cost

Our findings are consistent with the results of Carlson-Radvansky & Jiang (1998) showing that switching between reference frames takes times. The current study significantly extends these previous results by addressing this switching dynamic to the context of navigation and by reporting the time scale of that switch cost.

Regarding the underlying processes causing this switching cost, we could suggest the role of some reconfiguration mechanisms of reference frames in memory via executive control process (Monsell, Sumner, & Waters, 2003; Rogers & Monsell, 1995; Schneider & Logan, 2007). Reconfiguration processes would include reference frame selection, task-set[1] updating and inhibition of the previous reference frame in memory (Sakai, 2008). Reconfiguration processes is assumed to occur only for alternate trials, explaining the longer response times on alternate trials as compared to repeat ones (Monsell *et al*., 2003; Rogers & Monsell, 1995; Rubinstein, Meyer, & Evans, 2001; Schneider & Logan, 2007).

Interestingly, the current study revealed a strong switch cost of 585 milliseconds as compared to previous study dealing with switching phenomena between other various cognitive processes (Altmann, 2007; Brockmole & Wang, 2002, 2003). For example, switching between different spatial representations has evidenced to require a temporal cost 109.4 milliseconds. In comparable switching paradigm applied to simple (non-spatial) tasks, switch cost was shown to vary between 6 and 201 ms, with an average of 94 ms (Altmann, 2007). This suggests that switching between reference frames involved particular strong cost as compared to switching between other cognitive processes.

Implication for driving situation

Significant implications can be advanced in driving situation. In particular, using GPS (Global Positioning System) to guide automobile navigation could involve a permanent switch between egocentric and allocentric coordinates: The 'route' perspective experienced by the driver could preferentially involve egocentric spatial coding whereas the spatial information resulting from the map displayed on the GPS could involve allocentric coding (Mellet *et al*., 2000). Drivers using GPS involving map display could thus suffer from this 'dual' task,

[1] A task set is defined as "a configuration of cognitive processes that is actively maintained for subsequent task performance" (Sakai, 2008)

egocentric and allocentric coding, due to the temporal cost linked to permanent switch between them. More generally, this temporal switch cost could involve longer reaction times, thereby leading to some insecurity problems in driving situation. This study suggests that recent GPS using a kind of route perspective are likely to be more compatible with human cognition.

Keyword: Spatial memory; reference frame; egocentric; allocentric; temporal switch cost; virtual navigation

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