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# Collective interactions, collaborative inhibition, and shared spatial knowledge

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## ABSTRACT

Research on spatial mental representations focuses on individual mental maps and spatial knowledge. This exploratory study investigates instead collective interactions, collaborative memory, and the sharing of spatial knowledge. Based on the principle of collaborative inhibition (i.e., people recall information less effectively in groups), we posed the following research question: *How do collective interactions, occurring during environmental exploration and group drawing sessions, affect collaborative inhibition, and the quality of sketch maps designed collectively?* We conducted in situ explorations in Plaine St-Denis (France) with real-time tracking, followed by individual and group drawing sessions. This experiment involved 118 participants divided into three groups: (1) solo explorations without devices; (2) solo explorations with a mobile mapping application; (3) collective explorations using the same application enhanced with interaction features (viewing collective routes and photos of visited places). The comparison of the total number of entities found on individual mental maps with those included in collective sketch maps reveals that collaborative inhibition applies to spatial memory. Additional findings indicate that the use of a map, combined with collective interactions, mitigates collaborative inhibition and increases the accuracy of the sketch maps. However, the effect of such interactions on group dynamics remains unclear as of now.

## ARTICLE HISTORY

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## KEYWORDS

Collaborative inhibition; collective navigation; group dynamics; mental maps; shared spatial knowledge

## Introduction

### *Cognitive maps, spatial knowledge, and mental maps*

The concept of “cognitive map” goes back to the seminal work of Tolman (1948). Nadel (2013) defines it as

a mental representation of the environment that captures, in some specifiable way, the spatial relations among things in the world. Such a mental representation can be used to recognize places, to compute distances and directions, and in practical terms, to help an organism find its way from where it is to where it wants to be. [...] the mental representation and neurobiological substrates that underlie a cognitive map act like, rather than literally look like, a map. (p. 156).

As a mental representation – pictorial, propositional or otherwise – of the external environment, the cognitive map refers to a particular internal arrangement of spatial knowledge. In his pioneering work on imageability and legibility of the city, Lynch (1960) developed a typology of the constitutive elements of urban cognitive maps externalised in the form of sketch maps: paths, which are generally the first elements that individuals draw to structure their spatial externalizations; nodes, which refer to the junctions of the paths where the level of decision-making

is high (e.g., a crossroads); edges, which are especially used for defining districts, which are visually homogeneous areas; landmarks, which are highly visible cues that people use to find their way.

In the decade following Lynch’s study, Siegel and White (1975) introduced the Landmark-Route-Survey (LRS) theory on spatial knowledge acquisition. The LRS theory assumes that knowledge about our surrounding environment is acquired sequentially, through our experiences, and in particular through our physical movements. According to Siegel and White, landmarks are the basic unit of cognitive maps since they are acquired first. Over time, individuals acquire knowledge of routes that link the landmarks they are familiar with. The final step of acquisition is the configurational or comprehensive (survey) knowledge of the environment. At this stage, spatial relationships between places (landmarks) are known. Individuals can take shortcuts to reach their destination faster. While this theory was once widely accepted, its sequential nature has faced scrutiny. Notably, several studies demonstrated that limited familiarity with a region can yield accurate metric knowledge (Ishikawa & Montello, 2006). Indeed, with minimal exposure to a new environment (minutes or even seconds), people are able

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to perform tasks that require some knowledge of the metric configuration such as taking shortcuts, returning directly to the starting point, and estimating distances and directions between locations (Kitchin & Blades, 2002). These studies support Montello's spatial microgenesis framework (1998) that postulates a continuous development of metric knowledge, rather than a discrete one, as the dominant framework suggests. More recently, some researchers, such as Warren et al. (2017, 2019), argued that the cognitive map differs from an Euclidean map and is rather a labelled graph, i.e., a network of paths between places enhanced with local metric information.

Either way, it is important to keep in mind that the acquisition of spatial knowledge is typically approached *via* two modes. The primary mode of spatial knowledge acquisition occurs through the direct experience of an environment, without intermediaries. In contrast, the secondary mode of acquisition involves the use of an intermediate support; physical exploration of the environment being not necessarily required. In this case, the map remains the most illustrative example. While paper maps (plans, topographic maps, etc.) were once preferred, we now observe a clear preference for GPS systems and online mapping platforms, as well as location-based services enhanced with landmark-based instructions (Quesnot, 2016a, 2016b). Verbal directions and texts are not used as much, but can obviously convey spatial knowledge. Conversely, maps, navigation instructions, and textual information can be used for accessing human spatial knowledge. In that vein, hand drawings (sketch maps) are widely used for such a purpose. For clarity, we will henceforth use "mental maps" to describe *individual* hand drawings that reflect internally stored spatial knowledge as a cognitive map.

### **Impacts of mapping devices on the acquisition of spatial knowledge**

Maps and navigation aid systems remain recent artifacts. Previously, spatial knowledge acquisition was achieved through direct exploration of the environment and, to a lesser extent, the exchange of verbal navigation instructions. This primary mode of acquisition relied (and still relies) on several spatial abilities such as visualisation, mental rotation (i.e., the ability to mentally rotate an object), spatial orientation, and visuospatial memory (especially location memory) (Allen, 1999). The introduction of paper maps in the last century altered our relationship with space. Convenient, paper maps quickly established themselves as a reliable mean of spatial knowledge acquisition, before being gradually replaced by embedded GPS car systems, and more recently, by mobile mapping applications (Quesnot, 2016a; Speake & Axon, 2012). That being said, their use is not necessarily straightforward. Indeed, map reading requires familiarity with Euclidean geometry (Lobben, 2004), while the use of applications like Google Maps requires skills in using

smartphones, which are predominantly found among the younger generation. Paper maps and digital mapping platforms also have impacts on the way we store spatial knowledge and convey it, especially in the form of sketch maps.

The first studies addressing such impacts date back to the early 1980s. In 1982, Thorndyke and Hayes-Roth investigated whether there was a significant difference between spatial knowledge acquired through the use of a paper map, and primary acquisition through direct experience. The "direct experiencers" who participated in this experiment were divided up according to their familiarity with the building to be explored, while the "map learners" learned its configuration from a map. Subjects were then tested individually on the following estimations: (1) route distance; (2) Euclidean distance; (3) orientation; (4) simulated orientation (in a closed office, pointing to the destination from an imagined start point); (5) location. With regard to location and Euclidean distance estimations, results showed that the map learners' performance surpassed those of the direct experiencers who were unfamiliar with the study area. In general, the direct experiencers outperformed the map learners on route distance estimations and orientation tasks. However, map learners' superiority decreased when their estimations were compared to those of the direct experiencers who were familiar with the building. More recently, Willis and colleagues (2009) focused on map learning by conducting an experiment where people had to learn an environment either in an isolated room, using a paper map, or dynamically, during an exploration, using a classic map on a mobile device. Their study showed that sketch maps drawn by mobile map users were a lot less accurate than those by the paper map users.

Adding to this, Krüger et al. (2004) found that users of mobile pedestrian navigation systems learned route knowledge much better than survey knowledge. Afterwards, Munzer et al. (2006) studied spatial knowledge acquisition among visitors to a zoo using either a paper map (first group), or a navigation assistance system based on photographs of decision points (i.e., places where the walker had to change direction to follow the itinerary) (second group). People in the first group acquired excellent route knowledge and a good configurational knowledge of the zoo. Participants from the second group developed a fairly good route knowledge, but a poor survey knowledge. Similarly, Ishikawa et al. (2008) compared navigation performance and the quality of spatial knowledge acquired during explorations of the city of Kashiwa using six different routes. Three groups were created according to the navigation type: (1) GPS-assisted using a basemap along with turn-by-turn instructions; (2) map-supported; and (3) direct, without any support or assistance. Their results showed that the best navigation performances (speed, number of stops, etc.) and spatial knowledge acquired (accuracy of the mental maps) were all from direct navigation. Participants who

used a map covered shorter distances, but did not acquire good topographical knowledge of the routes taken. The scores obtained from GPS navigation were far below the two other modes of navigation, although the tool used offered a conventional basemap (i.e., bird's-eye view) as a support for assisted navigation.

In essence, mobile navigation systems appear to lead to a fragmented knowledge of the environment, in contrast to conventional maps which seem to promote a better survey knowledge and distance estimation. This might be because the latter allow simultaneous, rather than sequential or fragmented (in the case of map-based mobile interfaces), visualisation of the entire environment. Direct experience seems to be the most effective way to acquire accurate spatial knowledge, likely due to the active engagement of the individual. However, it is important to keep in mind that other factors than mapping devices impact the acquisition of spatial knowledge. Three interdependent parameters come into play (Ahmadpoor & Shahab, 2019; Quesnot & Roche, 2015): (1) physical characteristics of the environment (architecture, location, colour, etc.); (2) spatial familiarity (length of residence, frequency of visits, reputation of the place, etc.); (3) individual characteristics (age, sex, education, disabilities, etc.). Media that indirectly help spatial knowledge acquisition (maps, GPS systems, verbal instructions, etc.) and environmental characteristics both fall into the category of “external factors”, while spatial familiarity and individual characteristics are actually considered as “internal factors”. In the end, collective interactions generated during group navigation can be considered as factors that are both external (the collective dynamics impacts individual spatial knowledge acquisition) and internal (individual behaviour, in turn, shapes the collective dynamics).

### **Social navigation and collaborative inhibition**

Although most of the research on spatial cognition adopted an individual approach towards the study of orientation – thereby isolating planning and decision-making processes in a single navigator entity – there is growing interest in the social and collaborative aspects involved in perception and orientation in space. In the neuroscience field, Dorfman et al. (2021) showed that humans and animals have collective spatial representations of the environment, as well as a social cognitive map. Some authors even went as far as to define the hippocampus as a cognitive map of social space (Eichenbaum, 2015; Tavares et al., 2015). Collaborative aspects in spatial navigation have also motivated artistic and playful experiments for some years (Debord, 1958; Guelton, 2017, 2018, 2020; O'Rourke, 2013), but the studies that tried to measure their contexts, impacts and implications are recent (see Castro et al., 2022 for the relationships between geography and collective memory through art).

More closely aligned with our study, Dalton et al. (2019) highlighted the various ways in which a person's

orientation is not a solitary psychological process, but is influenced by the actions of other people, including their mere presence. They challenged the common assumption that wayfinding is primarily an “asocial” activity, and argued that in many real-world scenarios, wayfinding has a critical social dimension. Their study emphasised the need to incorporate social aspects into our understanding of decision-making during wayfinding to establish a comprehensive model of wayfinding behaviour. This enriched understanding could inform architectural planning, signage design, and the development of digital devices such as mobile maps. It could also enhance simulation models for capacity planning and building evaluation.

From an experimental perspective, Reilly et al. (2009) studied group navigation in pairs, collaboration in route finding, and telephone interactions. They established a classification of activities (mobile and stationary), strategies, and roles (leader, follower, independent, and collaborative) observed during the navigation. They also analysed how the phone, which contained the map and navigation instructions, was handled. Their findings indicate that the strategies used depended on the environment (e.g., the presence of signs in the study area significantly reduced the use of the phone), and that textual information was generally conveyed verbally, while the transmission of cartographic information required the sharing of the phone. Similarly, He et al. (2015) examined the types of information given in the orientation and reception processes among individuals guiding themselves to a destination with a mobile phone in a new environment. Their results showed that mutual assistance between two individuals who both struggle with direction were more effective than help provided by an individual with a strong sense of direction to someone who lacks it. In a similar context of dual interactions, Bae and Montello (2019) focused on collective decisions in orientation situations. They studied pedestrian navigation for subjects who had to plan and enact routes in pairs, and looked at the differences between prospective planning (before an exploration) and situated planning (during an exploration). The researchers found that the pairs' performance was not linked to gender pairings within the dyads, their average sense of direction, or their personality. They also discovered that pairs who chose the simplest routes had the highest chances of successfully following their planned itinerary, demonstrating that complexity could negatively impact navigation.

On the memory front, Kampis and Southgate (2020) emphasised our innate ability to recognise and adapt to the contexts of those around us, coining it “alter-centric cognition”. This adaptability impacts our perceptions, mental depictions, and memory, regardless of whether our immediate objectives require collaboration or not. Recently, Greeley et al. (2023) investigated how collaborating with the same or different partners influences the organisation of collective memory. They found no significant difference between single and

multi-partner collaborations in terms of synchronising post-collaborative retrieval. However, collaborating with different partners offers more synchronisation options, as it exposes individuals to different strategies. Their study also showed that regardless of the number of times a person collaborated in the past, the individual's memory was significantly influenced by the most recent collaboration. This "collaborative recency effect" suggests that the most recent collaborative recall has a substantial impact on individual recall. In a complementary way, research on memory has uncovered a somewhat unexpected phenomenon related to collaboration. Contrary to intuitive assumptions, individuals often remember information less effectively when recalling it within group discussions (Rajaram, 2011). In fact, the aggregate memory performance of a group is often less than the combined memory performance of its individual members if they were to recall separately (Congleton & Rajaram, 2014). This phenomenon is termed "collaborative inhibition". Notably, this effect is observed in spatial memory tasks concerning the positioning of objects within confined spaces (Sjolund et al., 2014), and interestingly, it does not intensify with the increasing size of the group (Gates et al., 2022). In addition, the experiments of Greeley et al. (2022) highlighted that both environment and motivation influence memory. They found that individuals working alone in a demotivating and isolated environment obtained lower recall scores. However, when the conditions were adjusted to increase their motivation, their performance matched those observed in a collaborative setting, thus counterbalancing the collaborative inhibition in an isolated work context.

### Objective and research question

Reilly et al. (2009), He et al. (2015), and Bae and Montello (2019) all tackled themes echoing those in our research. These studies have collaboration, navigation, wayfinding, and the use of mapping devices in common. For those authors, reciprocal guidance between partners, strategies adopted, and aptitudes are the main objectives as these allow to categorise interaction type in the analysed dyads. The way in which mobile phones are used is also studied and taken into consideration. One distinction to note is that while all the studies were situated in unfamiliar environments, Reilly et al. centred their research indoors (e.g., convention centres and department stores) without tapping into geolocation capabilities. Bae and Montello's recent work focused on successfully planning a route and the sources of uncertainty in navigation, assessing the differences between situated and prospective planning, as well as the strategies of social role-taking (leading and following) within these dyads. Nevertheless, there are significant differences with our novel objectives, methods, and results.

Firstly, regarding collaboration, it must be noted that these studies are all limited to the analysis of interactions

between two participants (dyads). Larger groups are not considered. Furthermore, these collaborations are exclusively developed in situ, unlike the method we adopted which investigates collaboration at two different levels: during the in situ exploration, and during the drawing of collaborative sketch maps. In fact, collective memorisation and representation are key issues that are not studied in these three studies, in which navigation is essentially considered through the mode of wayfinding. In contrast, our study relies on a free exploration of an urban territory in order to produce a collective spatial representation. In addition, we targeted three main groups of walkers through the following exploration modes: (1) without navigation tools; (2) with a mobile mapping application; (3) with the same application, enhanced with some collective interaction features. Walkers' routes were also recorded in real time using individual and collective tracking devices.

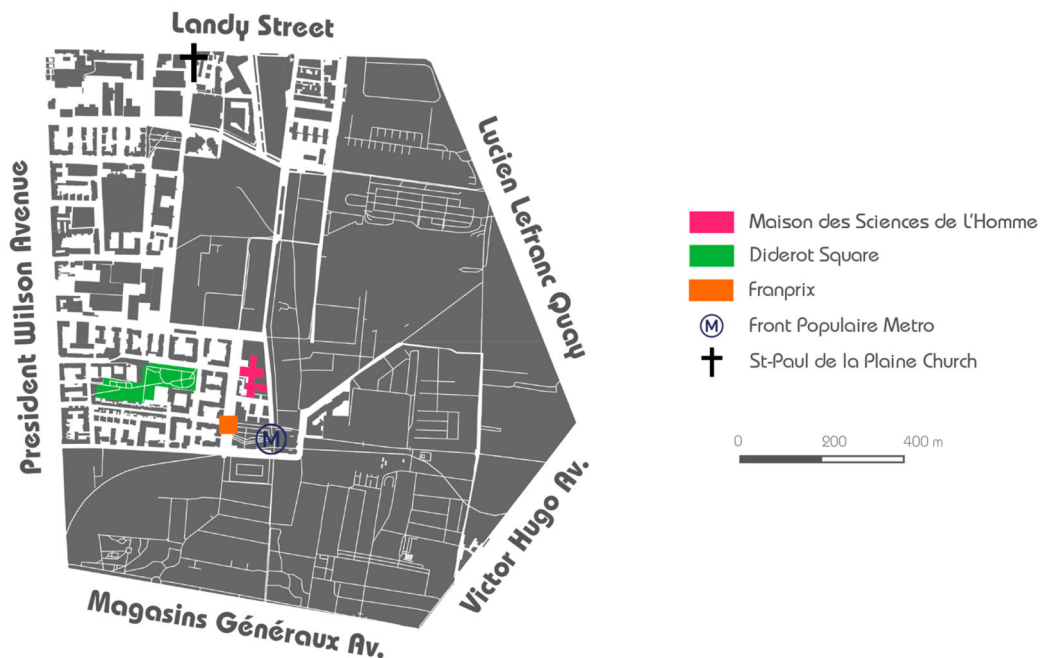
Finally, we assumed that a "collective cognitive map" could not be obtained by merely aggregating individual mental maps. We explored instead the concept of "collaborative sketch map" that we define as the pooling of individual spatial knowledge on a single sketch map. From now on we will use the term "collaborative sketch maps" rather than "collaborative mental maps", since these artefacts result from the sharing of individuals' spatial knowledge through collaborative activities. Consequently, our main interest was directed towards the collaborative construction of these sketch maps, rather than the internal organisation of spatial knowledge that remains individual per se. In line with the studies carried out on collaborative inhibition and the social dimension of wayfinding and navigation, our main objective was to assess the impact of collective interactions on the collaborative inhibition phenomenon, as well as the quality of the sketch maps designed collectively. In this regard, we conducted this exploratory study with the following research question in mind: *How do collective interactions, occurring during environmental exploration and group drawing sessions, affect collaborative inhibition and the quality of sketch maps designed collectively?*

## Materials and methods

### Study area

The study area is the Plaine Saint-Denis district located in northern Paris. Covering a surface of 1.5 km<sup>2</sup>, it is bordered by five main roads: Rue du Landy (North), Quai Lucien Lefranc (East), Avenue Victor Hugo (South-East), Avenue des Magasins Généraux (South), and Boulevard Wilson (West) (Figure 1). We selected this area for the diversity of its places (shops, schools, residences, places of worship, leisure areas, green spaces, etc.), the quality of routes for pedestrian navigation (wide and safe), its accessibility (proximity to central Paris), and the fact that the area remains largely unknown.

## PLAINE SAINT-DENIS DISTRICT



Source: OpenStreetMap (ODbl Licence)  
 Design: Teritutea QUESNOT, Ph. D.  
 Date: 2023-07-20

Figure 1. Scope of the study area.

### Operationalisation of the research question

To begin with, “collective interactions” refer here to both (i) the sharing of photos and routes using a mobile application during the in situ exploration, and (ii) the interactions made while drawing the sketch maps collectively. Next, we define a “collaborative sketch map” as a hand drawing that reflects the spatial knowledge of a given space shared by more than 2 individuals. Thirdly, the “collaborative inhibition” will be evaluated by comparing, within the same subgroup, the sum of entities drawn collectively (places and main roads) to the total number of unique entities drawn individually (Indicator 1). Lastly, two complementary indicators will be used to assess the “quality” of the collaborative sketch maps: (i) the accuracy of the estimated straight-line distances between global landmarks (i.e., common places that appear on every collaborative sketch maps) (Indicator 2), and (ii) the appearance speed of these specific landmarks (Indicator 3).

As a matter of fact, the quantity of landmarks on a map can be considered as an indicator of the richness of the information it contains. A greater quantity of landmarks indeed suggests a more detailed and complete representation of the explored environment. Comparing the quantity of unique landmarks within the individual mental maps of the same subgroup ( $Q_1$ ), with the quantity of landmarks appearing on the ad hoc collaborative sketch map ( $Q_2$ ),

allows for the measurement of collaborative inhibition ( $Q_1 > Q_2$ ), or conversely, a kind of “collaborative impulse” ( $Q_2 > Q_1$ ). Indicator 1 has the advantage of moving away from the topographic nature of the mental map, which is relevant if one wishes to consider the theory of cognitive graphs of Warren et al. (2017, 2019), as well as the fact that creating sketch maps requires drawing skills that cannot be taken for granted. Nonetheless, it should be noted that the most recent and promising advancements in the understanding of spatial memory, which pertain to the neurophysiology of the brain, demonstrate no opposition between the topographical and topological approaches. It is, in fact, a dual functioning that favours one approach or the other depending on the type and scales of the locations to be explored (Peer et al., 2021). In this sense, a quality sketch map should not only encompass a sufficient amount of information, but also ensure that this information is topographically accurate, thereby providing a faithful representation of the environment. The evaluation of the accuracy of distance estimates between landmarks common to all collaborative sketch maps (Indicator 2) therefore complements Indicator 1. The same applies to the third and final indicator that focuses on the speed at which different groups are able to recall and locate global landmarks. Despite its reductive nature, this indicator can be assimilated to a quantitative understanding of the group dynamics that rules the

co-design of sketch maps. Taken together, these indicators effectively evaluate the collaborative inhibition as well as the quality of a collaborative sketch map by focusing on three aspects: the memorisation of places and their toponyms (Indicator 1), their geographical location (Indicator 2), and the related speed of recall in a collaborative design context (Indicator 3).

### Sampling and design

We recruited 118 participants – 68 women and 50 men – with an average age of 24 years. These people were hired via electronic mailing lists with two conditions: (1) the participant had to be at least 18 years old; (2) she or he was supposed to be unfamiliar with the study area. Their written consent was obtained for all stages of the experiment (i.e., tracking, sketch maps, and video sessions), and at the end of the experiment, each of them received a payment of €75 for their participation. More specifically, our experiment was conducted with the following conditions:

- **Condition 1 (direct experiencers):** participants from group 1 (21 women and 19 men divided into 8 subgroups of 5 persons) explored the study area *alone* without using any devices;
- **Condition 2 (mobile map learners):** participants from group 2 (20 women and 20 men divided into 8 subgroups of 5 persons) explored the study area *alone* using a mobile mapping application;
- **Condition 3 (collective learners):** participants from group 3 (27 women and 11 men divided into 8 subgroups of up to 5 persons) explored the study area *collectively* in subgroups using the same mobile mapping application as that of Group 2, but with features dedicated to collective interactions.

Every participant, across all three conditions, first drew an individual mental map, and then collaboratively created a sketch map in subgroups.

### Devices

#### Tracking device

During the *in situ* exploration, each participant was equipped with a GPS-enabled smartphone (iPhone) so we could follow his/her movements in real time. The tracking allowed us to ensure that participants walked within the boundaries of the study area, and to record their movements for later comparison with the individual sketch maps.

#### Navigation devices

**Location map.** Before exploring the Plaine Saint-Denis district, participants from Group 1 were provided with a paper map only showing the study area's boundaries without any internal geographical details (Figure 2).

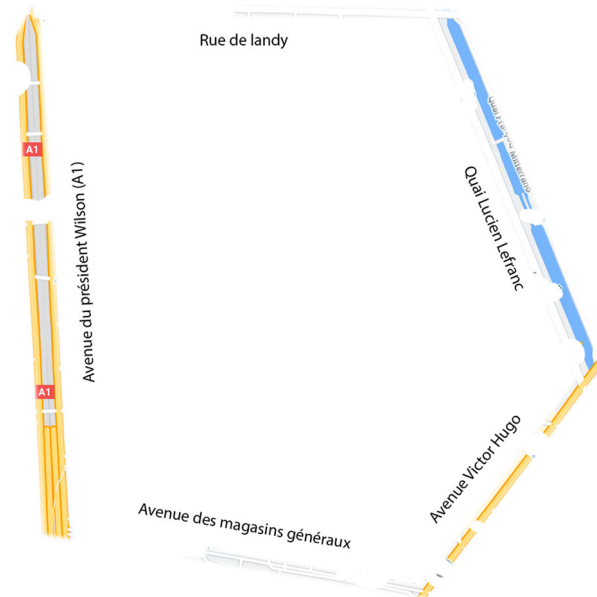


Figure 2. Map given to individuals from Group 1.

**Mobile mapping application.** Participants from Group 2 had access to a smartphone loaded with a mapping platform developed by the Parisian company ORBE, featuring real-time geolocation (Figure 3).

**Shared mapping application.** Participants from Group 3 used a shared mapping application also developed by ORBE. This tool allowed them to visualise others' routes within their subgroup (3–5 persons) and to exchange geolocated photos. Unlike the photos, real-time itineraries were constantly displayed on the map, with no possibility for participants to hide them (Figure 4).

#### Individual and collaborative sketch maps

**Recording device.** Drawing of individual and collaborative sketch maps during the post-exploratory phase was filmed on smartphones. These devices were mounted on a specially designed holder to ensure participants were not disturbed. Stop-motion (15 fps) was used for the individual mental maps, while the design of the collaborative sketch maps was recorded at normal speed in order to capture the verbal exchanges.

**Papers and pencils.** All participants (Groups 1, 2, and 3) were given a single sheet of A4 paper and a set of coloured markers to draw their individual mental maps. Collaborative sketch maps were designed on a unique A1 sheet of paper, also using a set of coloured markers.

#### Procedure

The experiment took place between October 2020 and March 2021. The procedure we adopted was divided into five main stages:

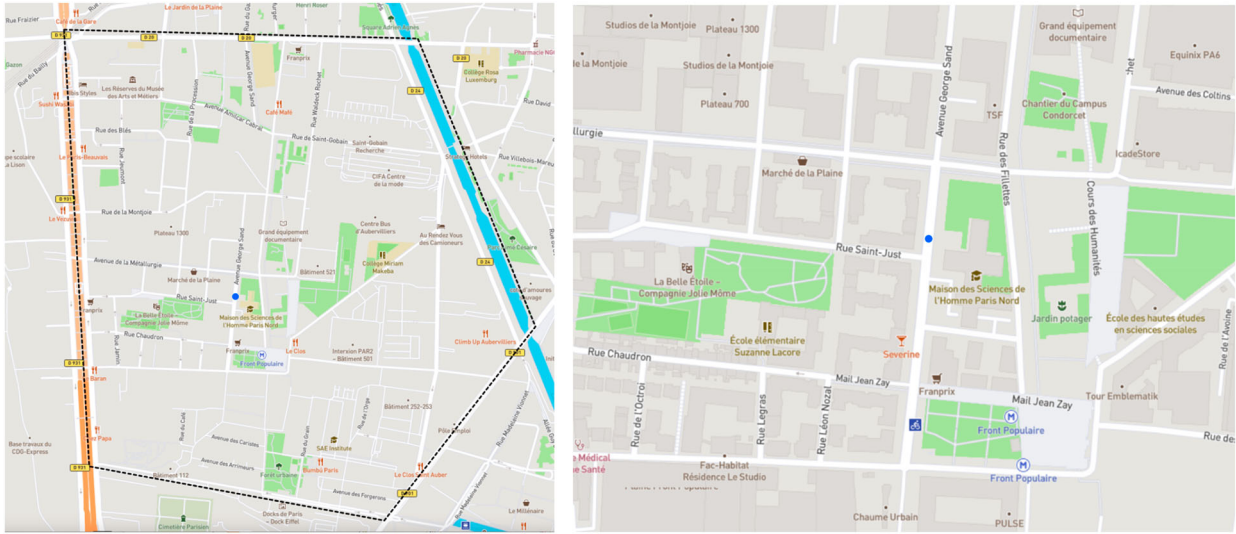


Figure 3. Screen shot of the mapping application (Group 2): extended to the study area (left) and zoomed in (right).

- 1) **Reception:** we received the participants at the Paris Nord Human Sciences Institute (Maison des Sciences de l'Homme – MSH). After reminding them of the objective of the experiment, we obtained their written consent, and then equipped them with a smartphone for the real-time tracking.
- 2) **Instructions:** participants were given the following instructions in French:

“Somebody you know wants to move into the Plaine Saint-Denis district. She lives too far away to come and have a look herself. She asks you to do some exploring and draw a map for her. Please indicate any useful landmarks when you are out exploring the district so that she can see what the environment is like.” [Translated by the authors<sup>1</sup>]

The instruction for Group 3 included a supplement:

“To meet these objectives, you will explore the area with 4 other participants – but with everybody at a distance from one another – by using the interactive smartphone application that has been given to you. The map on the mobile phone enables you to share your routes and your photos to interact with your teammates. Observe the district, find, and photograph places of interest in coordination with your teammates.” [Translated by the authors<sup>2</sup>]

- 3) **Equipment:** participants were firstly equipped with a tracking smartphone. Group 1 received a location map, while Groups 2 and 3 were shown and told how to use the mobile application.

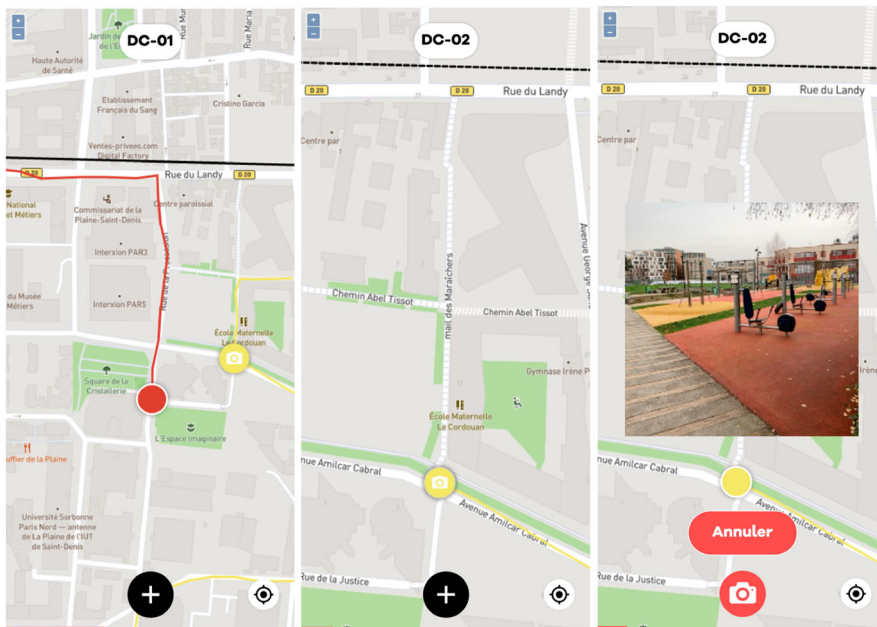


Figure 4. Screenshot of the shared mapping application (Group 3).

- 4) **Exploration:** participants explored the Plaine Saint-Denis district on foot for roughly one hour before returning to the MSH. Participants from Group 3 explored the district collectively in randomised subgroups of 3–5 people.
- 5) **Mental maps:** once back at the MSH, each participant was first invited to create an individual sketch map. Subgroups were then randomly created, with the exception of individuals in Group 3, who remained in the subgroup to which they were initially assigned during the in situ exploration. A collaborative sketch map was produced by each subgroup, inside a dedicated room of the MSH (one subgroup per room). To avoid imposing specific group dynamics, participants were given no explicit instructions about the collaborative activity, nor was a time limit set for the completion of this task. Also, everyone had the freedom to use the marker of their choice and switch it whenever desired, without any specific colour being assigned to any participant. Once the video recording device was activated, the experimenter left the room to prevent any disturbance to the participants and potential influence on the drawing process.

## Analysis methods

### Tracking data

Data from the tracking feature of participants' phones were gathered in GPX format and stored on a dedicated computer server. These data were then integrated into a Geographic Information System (QGIS – version 3.16) in both point (track points) and linear (tracks) forms. Track points included timestamps, enabling the determination of each participant's travel time and walking speed. The tracks were used to measure the distance travelled and the overall coverage rate of the routes taken for each main group. To achieve this, we first grid the study area using 50 metres by 50 metres meshes. Such spatial resolution was deemed suitable as participants took roughly one minute to move across a grid of this size. Subsequently, the tracks were segmented, producing an average number of route sections per grid for each main group.

### Mental maps

**Individual mental maps.** Mental maps were analysed manually. Given the large number of maps to analyse, our content analysis focused solely on easily identifiable locations and the five main roads surrounding the study area. Ephemeral entities and places (e.g., a construction zone, or a parked car) were not taken into account, nor were the streets and alleys that dot the area of Plaine Saint-Denis. After being geolocated – that is, linked to a physically existing place – each listed entity was assigned a unique code. We then gradually enriched a list of places

linked to unique codes that were subsequently used for the analysis of collaborative sketch maps. In doing so, we were able to calculate the total number of entities for each individual mental map, as well as the sum of unique places drawn by participants belonging to the same subgroup.

**Collaborative sketch maps.** We conducted a content analysis built upon the list of distinct locations established earlier, using the same selection criteria (i.e., only clearly identifiable places that can be geolocated, and the five major roads that define the study area). This approach allowed us to determine the total number of entities collectively drawn, and to compare it with the sum of unique entities drawn at the individual scale (Indicator 1). In addition, we identified the places common to every collaborative sketch maps (global landmarks), and measured the distances separating these landmarks from one another, in order to compare them with the “actual” straight-line distances computed from a basemap (Indicator 2).

### Videos of collaborative sketch maps

To calculate Indicator 3, we watched the videos of the collaborative drawing sessions one by one, noting the time of appearance of each global landmark previously identified. Here, Time 0 denotes the initiation of the drawing on the A1 paper, while appearance time marks the moment a global landmark is depicted (either by name or symbol). All appearance times were calibrated against Time 0, rather than any preceding appearance time.

### Power analysis

The a priori power analysis conducted for an ANOVA/Kruskal–Wallis test on 3 groups, with an assumed medium effect size (0.25), a standard alpha of 0.05, and a robust power of 0.8, gives us a sample size of 159 statistical individuals, that is, 795 people if we consider 5 individuals for 1 collaborative sketch map. A small size effect (0.15) for the same criteria increases the number of statistical individuals (collaborative sketch maps) to 432, i.e., 2160 participants (5 people for 1 collaborative sketch map). Reducing the number of participants per collaborative sketch map to 3 would still necessitate recruiting 477 participants, retaining the original parameters (i.e., effect size of 0.25, power of 0.8, and alpha of 0.05). Altering from 3 groups to 2 (i.e., without vs. with tools) would have decreased the required participants to 640, or 384 when considering 3 individuals per collaborative sketch map, which does not provide a significant improvement. Running an experiment involving such a vast number of participants posed logistical challenges, considering the financial implications (recruitment of participants and experimenters, purchase of instruments and computer servers, rental of rooms, etc.). Additionally, given the current lack of artificial intelligence that can consistently identify objects and place names on sketch maps, processing such a large dataset would have demanded

considerable manpower for content analysis. The available funds did not allow us to carry out such a massive experiment. From a statistical perspective, we assumed that a successful test (i.e.,  $p < 0.05$ ) would demonstrate sufficiently robust power (Hoening & Heisey, 2001). In the case of an inconclusive test (i.e.,  $p > 0.05$ ), we would restrict ourselves to the interpretation of the confidence intervals, as recommended by Dziak et al. (2018). We would also complete the analysis using a Bayesian approach with prior structures (intercepts and standard deviations) that allow the data to play a more significant role in determining the posterior estimates of the parameters, while maintaining some constraints on the plausible values for the parameters.

## Results

Overall, the results first indicate that the participants explored the district under similar conditions (speed, distances, and travel time), with the exception of Group 3, which covered a wider area. In addition, comparison between individual mental maps and collaborative sketch maps shows that collaborative inhibition was significantly stronger in Group 2. Furthermore, the distances estimated in Groups 2 and 3 appear similar, and significantly more accurate than those in Group 1. Finally, we found no difference regarding the speed of appearance of global landmarks among the three groups.

### Behavioural dimension: in situ explorations

In addition to last-minute cancellations, unpredictable weather conditions forced us to delay some explorations and in cases of snow, to cancel them entirely. We also encountered intermittent losses of server connectivity, disrupting real-time tracking. These interruptions affected one participant in Group 1, two in Group 2, and one in Group 3. This resulted in a total of 114 analysed routes (39 for G1, 38 for G2, and 37 for G3). Table 1 details the explorations based on the tracking data:

In summary, we observe an average route time of 66.33 min across all groups. Notably, Group 1 participants exhibited a longer average route duration and covered a more substantial distance. Conversely, participants from Group 3 undertook, on average, shorter routes than those in Groups 1 and 2. That being said, based on the one-way ANOVA tests we conducted, we cannot definitively determine whether or not there is a significant difference among the three groups in terms of walking speed, distance travelled, and travel time ( $p > 0.05$ ). As expected,

the aggregated tracking data show that the participants who navigated without any devices crossed the boundaries of the study area more frequently than the others. Interestingly, two individuals from Group 2 significantly exceeded these boundaries (1180 and 1600 metres) despite having access to the mobile mapping application. In stark contrast, all members of Group 3 remained within the designated study area.

Finally, spatial analysis of the tracking data shows some interesting differences in density (number of route portions by 2500 m<sup>2</sup> mesh) (Figure 5). Actually, all walkers overlooked the southern part of the study area (south of rue Proudhon and rue Gardinoux). As anticipated, the highest densities were found around the MSH, which is the start and finish point of the in situ exploration. When considering geographical coverage, individuals from Group 3 spanned, on average, a broader area than their counterparts, a trend that could be attributed to specific instructions they were provided.

### Memory dimension: collaborative inhibition

#### Individual mental maps

Insofar as Indicator 1 involves a comparison with the number of entities present in the collaborative sketch maps, we began by reviewing these drawings. A portion of them turned out to be unusable (hard-to-geolocate places, illegible toponyms, crossings out, etc.), which ultimately led us to analyse a total of 24 collaborative sketch maps (i.e., 6 per group). We therefore carried out a content analysis of the corresponding 90 individual mental maps (5 mental maps per subgroup). On average, Group 2 participants produced the most detailed mental maps with 44.5 entities, followed by Groups 3 and 1 with 34.8 and 30.8 entities respectively. Diving deeper, the analysis of the stop-motion videos indicates that Group 3 was on average faster than Groups 1 and 2 in completing the individual mental maps (8.8 min versus 10.6 and 12.4 min, respectively) (Table 2).

#### Collaborative sketch maps

Table 3 presents the raw data that we gathered from the content analysis of the 24 collaborative sketch maps. Echoing the patterns observed at the individual level, Group 2 participants consistently generated more intricate collaborative sketch maps in comparison to their counterparts in Groups 1 and 3, averaging 25 entities as opposed to 19.5 and 23.1 entities respectively. This time, Group 2 was the quickest to finalise the collaborative sketch

**Table 1.** Descriptive statistics of the individual (Groups 1 and 2) and collective (Group 3) explorations.

Group	Average route time (mins)	Average distance travelled (m)	Average speed (km/h)	Number of routes outside the area	Average distance travelled outside the area (m)	Area covered (50 m x 50 m mesh)
1	71	4958.30	4.20	13	1683	473
2	64	4628.22	4.30	2	1390	454
3	64	4447.04	4.10	0	0	503
Average	66.33	4677.85	4.20	5	1024.33	476.66



**Figure 5.** Density maps of completed routes.

maps with an average time of 21.3 min. Participants of Group 1 were still slower than the members of Group 3 (26.5 min versus 23.6, respectively).

**Intergroup comparisons**

After identifying all the places that were drawn in the individual mental maps, we retained the number of unique locations (toponyms and main roads) in each subgroup (Q1). We then compared Q1 with the sum of places drawn on the corresponding collaborative sketch map (Q2) to derive the deltas (i.e.,  $Q2 - Q1$ ) (Table 4). At a glance, we can see that the phenomenon of collaborative inhibition is present within the three groups (i.e.,  $Q1 > Q2$ ). An outlier in this pattern was witnessed within subgroup 1 of Group 3. Their collaborative map interestingly

encompassed three specific locations absent in the individual mental maps of that subgroup: (1) the Centre National des Arts et des Métiers de Saint-Denis, located in the northwest of the study area, which was visited by only one participant within this subgroup; (2) Icade Park at the Gates of Paris, located in the southeast of the study area, which was also visited by only one participant; (3) a skate park, which is actually inside the Square Diderot, a large park located near the MSH that the majority of participants cited without specifying its components.

More specifically, the distributions observed in the deltas of the three groups are all asymmetric, and

**Table 2.** Content summary of the individual mental maps.

Group	Average number of entities (toponyms and major roads)	Average completion time (minutes)
1	30.8	10.6
2	44.5	12.4
3	34.8	8.8
Average	36.7	10.6

**Table 3.** Content summary of the collaborative sketch maps.

Group	Average number of entities (toponyms and major roads)	Average completion time (minutes)
1	19.5	26.5
2	25	21.3
3	23.1	23.6
Average	22.5	23.8

**Table 4.** Content comparison between collaborative sketch maps and individual mental maps.

Group	Subgroup	Number of entities (Collaborative maps)	Average number of entities (Individual maps)	Delta
1	1-1	20	26	-6
	1-2	21	38	-17
	1-3	12	33	-21
	1-4	24	33	-9
	1-5	21	29	-8
	1-6	19	26	-7
2	2-1	41	23	-18
	2-2	47	29	-18
	2-3	41	21	-20
	2-4	41	23	-18
	2-5	42	25	-17
	2-6	55	29	-26
3	3-1	21	24	+3
	3-2	33	22	-11
	3-3	42	21	-21
	3-4	31	23	-8
	3-5	36	23	-13
	3-6	46	25	-21

**Table 5.** Statistics associated with the observed deltas (collaborative inhibition) for Groups 1, 2, and 3.

	Group 1	Group 2	Group 3
Mean	-11.33	-19.5	-11.66
Median	-8.5	-18	-12
Confidence intervals of the median (Bootstrap resampling)	[-19;-6.5]	[-23;-17.5]	[-21;-2]

therefore do not follow a normal distribution. The homogeneity of variances also not being respected, we performed Kruskal-Wallis tests, all of which were inconclusive ( $p > 0.05$ ). The analysis of medians and their confidence intervals (Bootstrap resampling) suggests at first glance that there is no significant difference between the three groups in terms of observed deltas (Table 5) (Figure 6-R). To supplement this initial observation, we used a more robust Bayesian model, with (i) a Student-t distribution to account for the non-normal nature of the data, (ii) 4 Markov chains (MCMC), and (iii) the following priors: a normal prior with a mean of 0 and an SD of 100 for the intercept, and a Cauchy prior with a location of 0 and a scale of 2 for the SD. 4000 iterations with a warmup of 2000 iterations and a thinning factor of 1 were necessary to run the model efficiently. In the end, the results show a significant effect: the posterior estimates for Group 2 (-8.31, 95% Credible Interval [-15.91; -0.52]) reveal that the deltas are, on average, lower than those of the reference Group 1 (-11.02, 95% CI [-16.58; -5.62]). The 95% CI for Group 3 (-11.02, 95% CI [-8.92; 7.00]) contain zero, indicating no difference from the reference group G1. The hypothesis test we performed subsequently shows that the estimated difference between Group 2 and Group 3 is -7.17, with a standard error of 4.07. The 95% CI for this difference ranges from -15.41 to 0.64. The presence of 0 indicates that there is

no significant difference between Group 2 and Group 3. In other words, collaborative inhibition appears to be higher among participants of Group 2 than those of Groups 1 and 3.

### Spatial dimension: spatial knowledge accuracy

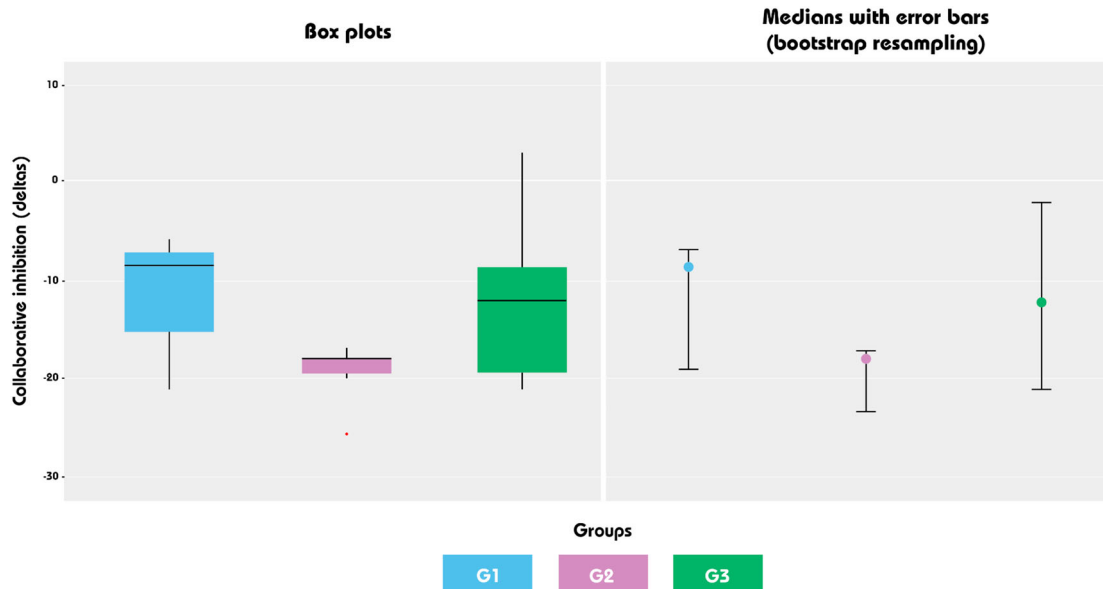
#### Global landmarks

We first identified the global landmarks, i.e., places that consistently appeared on the collaborative sketch maps and covered the study area sufficiently (Figure 7). Table 6 provides information on the global landmarks we selected.

#### Comparison of collaborative sketch maps: standard distance and proportions

We measured<sup>4</sup> the straight-line distances from the global landmarks on each collaborative sketch map. Given that each sketch map has its own scale, we used a standard distance as the straight-line distance separating the Front Populaire subway station and the MSH to make the estimated distances comparable. These two places were selected because most of the participants arrived from this station and all started from the MSH during the in situ exploration. We then computed proportions by using this standard distance from all the collaborative sketch maps. We did the same from a conventional map (Google basemap). The actual proportions were used as a reference to calculate deltas with the estimated proportions of the sketch maps (Table 7).

For example, Table 7 highlights that the individuals from subgroup 1-1 significantly underestimated the distance separating Lucien Lefranc Quay (Q) and Diderot Square (S) ( $\text{delta} = -5.78$ ). Conversely, participants from subgroup 1-4 showed a slight tendency to overestimate

**Figure 6.** Collaborative inhibition observed on Groups 1, 2, and 3: box plots (left) and medians with error bars (right).

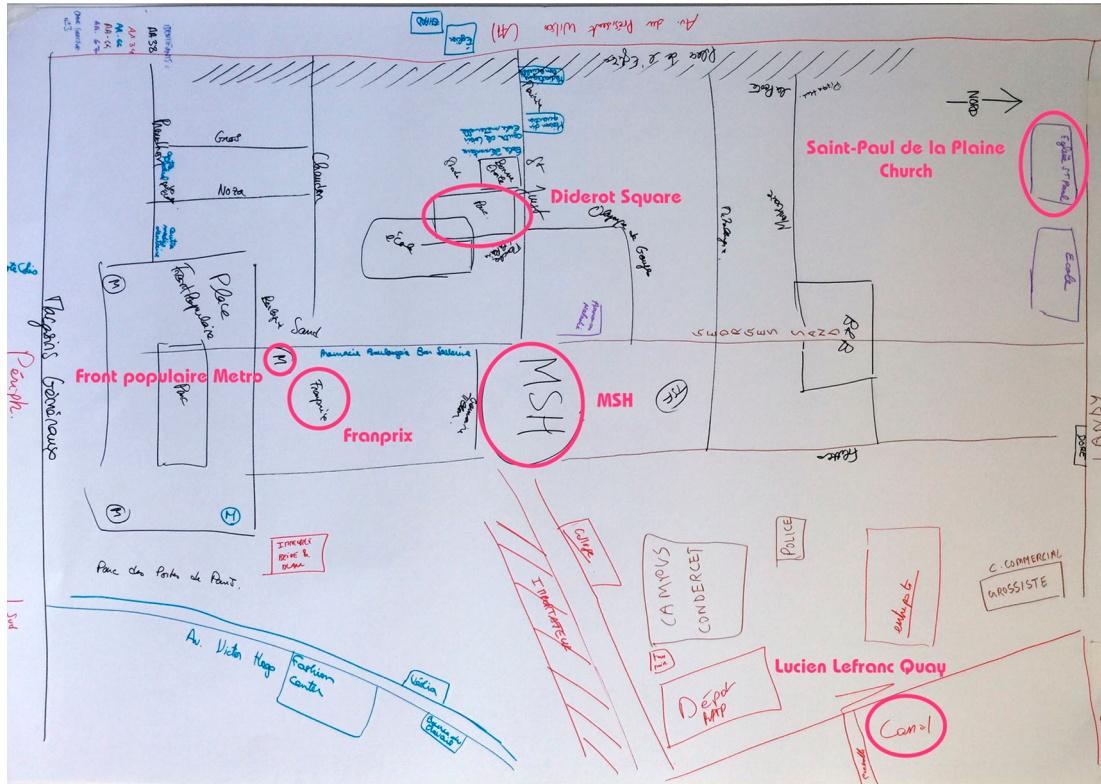


Figure 7. Collaborative map completed by subgroup 3 of Group 1, with the 6 global landmarks highlighted in pink.<sup>3</sup>

Table 6. General information on the global landmarks.

Landmark	Code	Category	Address
Saint-Paul de la Plaine Church	E	Place of Worship	29 rue du Landy, 93210 Saint-Denis
Lucien Lefranc Quay	Q	Wharf	Quai Lucien Lefranc, 93000 Aubervilliers
Front Populaire	M	Subway station	Station Front Populaire, 93210 Saint-Denis
Human Sciences Institute (MSH) – Paris Nord	MSH	Research Institute	20 Avenue George Sand, 93210 Saint-Denis
Diderot Square	S	Park	Square Diderot, 93210 Saint-Denis
Franprix	F	Grocery shop	8 Avenue George Sand, 93210 Saint-Denis

the distance between the Franprix grocery shop (F) on Avenue George Sand and the MSH ( $\Delta = +0.82$ ).

**Intergroup comparison**

Means presented in Table 8 convey a common trend among participants to underestimate distances between global landmarks. On detailed inspection, these medians point towards a higher frequency of distance estimation errors in individuals from Group 1. Conversely, participants from Group 2 and Group 3 recorded the lowest error rates, with their respective medians being notably similar (see Figure 8-L). An in-depth look at the confidence intervals further illustrates that the medians of Groups 1 and 3

Table 7. Deltas observed between the estimated Euclidean proportions within the subgroups of Group 1.<sup>5</sup>

Pair	Group 1-1	Group 1-2	Group 1-3	Group 1-4	Group 1-5	Group 1-6	Google
E-Q	-4.5965939	-2.2398783	-3.0315804	-3.588829	-4.1019017	-2.9184925	5.40530303
Q-F	-5.3547823	-4.4331222	-2.9239051	-2.6539017	-3.4307823	-2.1591727	5.375
Q-M	-3.1707137	-3.8870467	-2.5882161	-2.7634218	-2.8051484	-1.8455145	5.33712121
Q-MSH	-3.476018	-4.0761923	-3.1483908	-3.1754467	-3.3060451	-2.0858132	4.96590909
Q-S	-5.7817169	-3.8115996	-3.4263548	-3.7814854	-3.8002165	-1.7223131	5.96212121
E-F	-4.1700893	-3.244846	-2.7500055	-2.9291689	-4.2153216	-2.3553793	5.89015152
E-M	-4.3491152	-6.1476031	-3.1647036	-3.8146129	-4.0673006	-2.8685143	6.41287879
E-MSH	-4.3098343	-3.0047814	-3.0878843	-3.8861228	-3.9409555	-1.8045291	5.4280303
E-S	-4.0360585	-5.0913438	-2.9253207	-3.3693948	-3.5939239	-1.1027087	5.25378788
F-M	-0.0671568	0.06408346	-0.3151958	-0.2274041	0.03982684	-0.1951166	0.63636364
F-MSH	0.04417032	-0.237084	0.25864853	0.82269224	-0.2128942	0.05848049	0.5530303
F-S	-0.5538963	-0.0133507	-0.2574596	-0.2074575	-0.9279994	-0.3335786	1.31439394
M-MSH	0	0	0	0	0	0	1
M-S	-0.6230089	-0.4095256	-0.9472849	-1.2159529	-1.1451299	-1.2137835	1.93560606
MSH-S	-0.7514551	0.01148783	-0.4348098	-0.8679497	-0.7272573	0.22582843	1.25378788

**Table 8.** Statistics associated with the observed deltas (estimated distances) for Groups 1, 2, and 3.

	Group 1	Group 2	Group 3
Mean	-2.32	-1.73	-1.60
Median	-2.78	-1.18	-1.32
Confidence intervals of the median (Bootstrap resampling)	[-3.08;-1.83]	[-2.42;-0.57]	[-1.66;-0.73]

show a pronounced difference, unlike the comparisons between Groups 1 and 2, or 2 and 3 (Figure 8-R).

In addition, the tests for normality (Shapiro–Wilk) and homogeneity of variances (Bartlett) show that the distributions do not respect the application conditions for conducting a one-factor ANOVA test ( $p > 0.05$  and  $p < 0.05$ , respectively). Given the size of our sample, we relied on a Bayesian approach, instead of a Kruskal–Wallis test. In specific, we ran a Bayesian hierarchical linear model with a Student-t distributed response variable, with 4 MCMC chains, each consisting of 2000 iterations with a warmup of 1000 iterations and a thinning factor of 1. This model was built with the same priors as the previous one: a normal prior with a mean of 0 and an SD of 100 for the intercept, and a Cauchy prior with a location of 0 and a scale of 2 for the SD. The results demonstrate significant effects: the posterior estimates for Group 2 (0.64, 95% CI [0.12;1.16]) and Group 3 (0.76, 95% CI [0.25;1.27]) reveal that the distance estimations are, on average, more accurate compared to the reference Group 1 (-2.32, 95% CI [-3.08;-1.57]), as their values are closer to 0. The 95% credible intervals for both Group 2 and Group 3 do not contain zero, indicating a significant difference in accuracy from Group 1.

To further investigate the potential differences in distance estimation accuracy between Groups 2 and 3, we conducted a hypothesis test within the Bayesian model

framework. The result shows an estimated difference of -0.13 with a standard error of 0.27. The 95% CI for this difference ranged from -0.64 to 0.4. Given that the interval contains 0, we cannot conclude that there is a significant difference between Groups 2 and 3 in their distance estimation accuracy. This result indicates that these two groups performed similarly in terms of distance estimations, suggesting that the presence of an Euclidian basemap during the exploration played a positive role in the sharing of individual spatial knowledge.

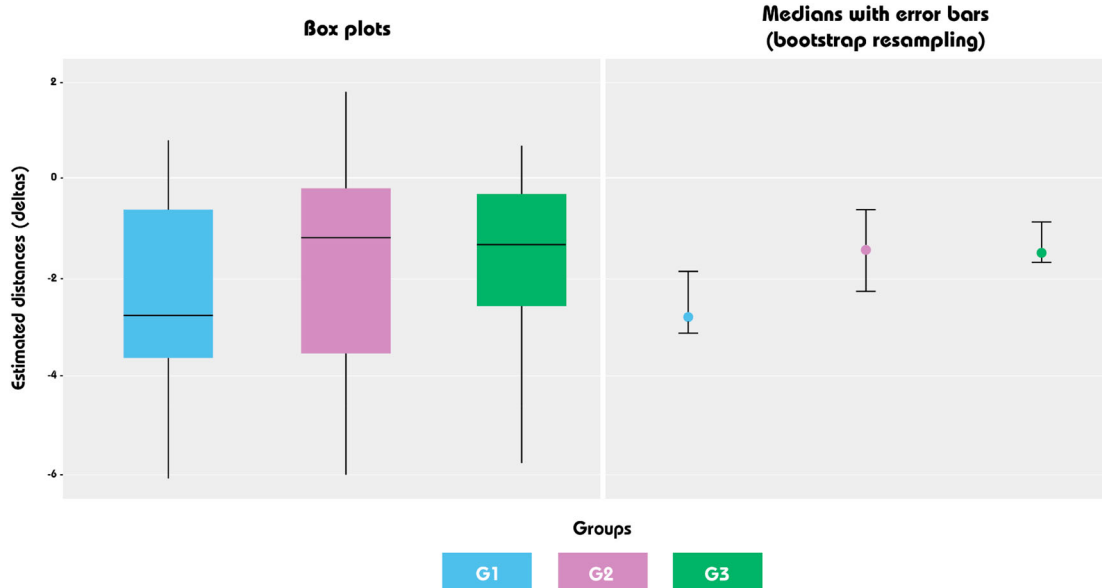
### Temporal dimension: group dynamics

#### Appearance of global landmarks

We analysed the videos showing the design of the collaborative sketch maps by recording the speed at which each global landmark appears on the drawing (Table 9). Each video began when a pencil touched the paper and ended with the drawing of the last element, which was not necessarily a global landmark.

#### Intergroup comparison

Means and medians reported in Table 10 show that participants from Group 1 took more time than the others to draw the global landmarks on their collaborative sketch maps. The scores of Groups 2 and 3 are relatively close, but the analysis of the confidence intervals suggests that there is no significant difference between the three groups (Figure 9-R). To further investigate these results, we performed a complementary Bayesian analysis using a hierarchical linear model with a log-normal distributed response variable. We used the same parameters as in the second Bayesian analysis (4 MCMC chains of 2000 iterations with a warmup of 1000 iterations and a thinning



**Figure 8.** Deltas in estimated distances observed on Groups 1, 2, and 3: box plots (left) and medians with error bars (right).

**Table 9.** Occurrence time of global landmarks in Group 1 (seconds).<sup>6</sup>

Landmark	Group 1-1	Group 1-2	Group 1-3	Group 1-4	Group 1-5	Group 1-6
Lucien Lefranc Quay	428	80	137	102	7	87
Saint-Paul de la Plaine Church	1134	816	541	1090	669	1258
Franprix grocery shop	932	256	513	465	302	1005
Front Populaire subway station	1058	689	537	1069	660	1081
Human Sciences Institute (MSH) – Paris Nord	436	100	380	384	104	424
Diderot Square	1324	1215	1465	1	1	1369
End	1527	1224	1507	1824	1268	2219

**Table 10.** Statistics associated with the occurrence times of global landmarks for Groups 1, 2, and 3.

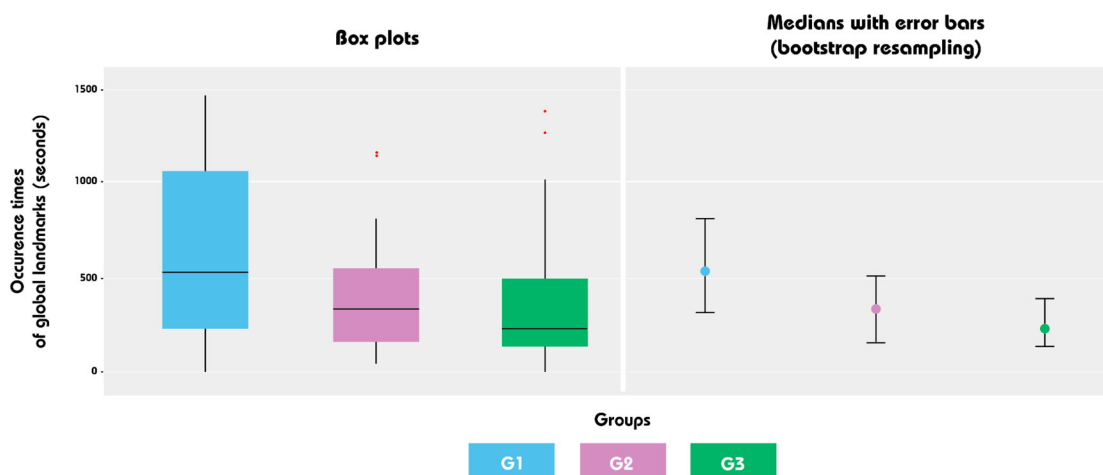
	Group 1	Group 2	Group 3
Mean	614.41	389.44	378.88
Median	525	324	218
Confidence intervals of the median (Bootstrap resampling)	[384;816]	[192;518]	[169;405]

factor of 1), as well as the same priors (a normal prior with a mean of 0 and an SD of 100 for the intercept, and a Cauchy prior with a location of 0 and a scale of 2 for the SD). The results of the analysis demonstrate no significant effects: the posterior estimates for Group 2 (−0.09, 95% CI [−0.90;0.72]) and 3 (−0.33, 95% CI [−1.14;0.47]) do not show substantial differences in the occurrence time of landmarks compared to Group 1. Therefore, the group dynamics (verbal exchanges, negotiations, corrections, etc.) seems to have affected the rate of appearance of global landmarks in the same manner across all three main groups.

### General discussion

The main results demonstrate that collaborative inhibition is applicable to spatial memory. Though the study by Sjolund et al. (2014) confirmed this in a limited spatial configuration (i.e., recalling objects arranged within a small room), our research suggests that this phenomenon is also observable at a larger scale, specifically when individuals attempt to remember and transcribe into a

sketch map locations they have previously visited. It is intriguing to observe that individuals in Group 2, that is, those who navigated alone using a mobile map, exhibit a significantly stronger collaborative inhibition than the reference Group 1 (solo in situ explorations without a map) and Group 3 (collective in situ explorations using a shared mobile mapping application). A parallel can be drawn with the study by Greeley et al. (2022), showing that motivation plays a decisive role in either attenuating or amplifying collaborative inhibition. They found that weak personal motivation leads to weaker individual recall, which ultimately may reduce or even annihilate collaborative inhibition. In contrast, collaborative inhibition tends to accentuate when individuals, more motivated, exhibit increased individual recall. In the context of our study, having a map during the exploration apparently aided participants of Group 2 in acquiring more spatial knowledge (with 44.5 entities on average, versus 34.8 for Group 3 and 30.8 for Group 1), which, following the rationale of Greeley et al., could explain the more intense collaborative inhibition in this particular group. Furthermore, we believe that there are determining factors unique to the practice of mental mapping. For example, having to transcribe a spatial configuration onto a restricted surface (i.e., the drawing sheet) involves managing the placement of the objects to be drawn. The extent allocated to the demarcation of the area to be mapped (i.e., the five main roads), and the positioning of the initial landmarks (such as the MSH) from which other entities will be placed, prove to be decisive. In this context, as suggested



**Figure 9.** Occurrence times of global landmarks: box plots (left) and medians with error bars (right).

by Wright and Klumpp (2004), collaborative inhibition may find an explanation in the finished product itself (in this case, the collaborative sketch maps), rather than in the collaboration process. However, we still observe that participants of Group 3 exhibit collaborative inhibition similar to that of Group 1, even though they also had access to a map during exploration. If the effect of the collaboration process in drawing the sketch maps is marginal – a position we strongly contest – it might be possible that collective in situ interactions have impacted *individual* spatial knowledge acquisition. It could be conjectured, for example, that the mandatory real-time display of routes within the same subgroup of walkers disrupted the individual memorisation of the mapped locations.

However, this latter point must be strongly nuanced, as participants in Group 3, like those in Group 2, created collaborative sketch maps that were significantly more precise – in terms of estimated distances – than those of Group 1. Two complementary readings can be offered to discuss this second main result. On the one hand, we can adhere to a strictly individual interpretation by suggesting that participants in the first group individually acquired a less precise configurational understanding of the environment (survey knowledge). This interpretation is somewhat consistent with the seminal study of Thorndyke and Hayes-Roth (1982), which shows that, compared to direct experiencers, people who explore an environment using a paper map present higher performances for distance evaluation. While their findings could be attributed to the fact that paper maps were commonplace in the early 1980s, ours could also be explained by the rise of digital mapping (Quesnot, 2021). Indeed, the younger generation – which characterises our sample (i.e., the under 30s) – is comfortable with web mapping platforms (Quesnot & Roche, 2020; Speake & Axon, 2012), such as the one we used for this experiment. However, it is important to clarify that unlike the map learners of the study by Thorndyke and Hayes-Roth, our participants did not familiarise themselves with the environment's configuration prior to the in situ phase, but rather, they did so during the exploration itself. In addition, this first reading (i.e., participants in Group 1 individually acquired less precise metric knowledge) is not in line with the work of Ishikawa et al. (2008), which reports no difference in distance estimation between these two categories of learners, and better sketch map accuracy for the direct experiencers. Nor does it agree with Montello's spatiogenesis framework (1998), which assumes that exposure to a new environment, even minimal, leads to the development of metric knowledge. From our perspective, it is therefore reasonable to think that, contrary to what is typically observed at the individual level, using a map during the exploration increases the precision of the collaborative sketch maps. A possible reason for this second reading could be the standardisation offered by the conventional map. Indeed, combining diverse cognitive maps onto one medium can be challenging (multiscalarity, unstable metrics, etc.). By providing common symbology and scales, along with identical place names, the map

potentially acts as a stabilising artifact that allows individuals within the same subgroup to better coordinate in transcribing onto paper a common spatial configuration.

Furthermore, there is a noticeable difference in distance estimations between Group 1 and Group 3, hinting at an underlying factor beyond just the map. On the surface, the group dynamics (or collaboration process) seemed to be consistent across groups. Or more precisely, the verbal exchanges observed within the three groups did not affect the rate at which global landmarks appeared. That said, it is important to emphasise that Indicator 3 is quite reductive, as it quantifies a process that remains qualitative *per se*. Unlike individual mental maps, collaborative sketches involve group discussions and negotiations about specific aspects, namely: (1) the orientation of the paper sheet; (2) agreement on what object to include (places, roads, etc.), (3) its name, if applicable, and (4) its relative location on the map, with the first one typically being the MSH. This group dynamics, taking more or less time depending on individual temperaments (leadership, shyness, extroversion, etc.), undeniably influences the collaborative sketch map and its design. To our knowledge, there is no reliable method to date for evaluating this group dynamics properly, essentially because of its complexity. If we agree with Sjolund et al. (2014) that there is little chance that the in situ collective interactions had an impact on the *individual* acquisition of spatial knowledge, we do think, on the other hand, that the interactions performed among members of the same subgroup (splitting up the area to explore before the navigation, as well as sharing photos and routes in real time) enhanced group cohesion. Unlike the participants from Groups 1 and 2 who explored the area individually, members of Group 3 knew each other before designing their collaborative sketch map. During the group drawing sessions, we observed smoother communication between the members of Group 3. Unlike what Wright and Klumpp (2004) observed for traditional recall tasks (e.g., retrieval of simple word lists), we argue that group dynamics have an effect on collaborative inhibition; at least for collaborative mapping sessions. Nevertheless, it seems that the better group cohesion we observed among the participants of Group 3 was not sufficient to reduce the discussion time required to add the global landmarks on the sketch maps. The mode of in situ interaction might be an explanatory factor. As a reminder, the explorations conducted by Group 3 were collective only on a virtual level, since a physical distance was imposed in the given instructions. A closer physical exploration might have yielded different results.

## Conclusion

Research into collaborative memory and shared spatial knowledge is still in its early stages. Our study remains therefore exploratory, *per se*. Rather than merging individual mental maps to produce a hypothetical collective mental

map of the Plaine Saint-Denis district, we opted for a more pragmatic approach; in this case – gathering individuals in the same room for producing a unique sketch map, sharing spatial knowledge acquired either individually (Groups 1 and 2) or as a group (Group 3). Following on from this, we investigated the impact of collective interactions on collaborative inhibition, sketch map accuracy, and group dynamics. Our experiment with 118 participants shows that the phenomenon of collaborative inhibition also applies to the recollection of spatial knowledge and its pooling in the form of a sketch map. Using a map while exploring the environment seemingly intensifies collaborative inhibition (Group 2), while the addition of collective in situ interactions seems to counterbalance this phenomenon and simultaneously increase the accuracy of the group-generated sketch maps (Group 3). Yet, the collaboration process governing the drawing of the global landmarks remains consistent throughout all three groups. From our preliminary findings, we derive three hypotheses set for validation in a broader experimental context: (1) there is a collaborative inhibition of spatial memory specific to the practice of mental mapping, because of (i) the constraints of the chosen medium, be it paper or digital (e.g., paper size, initial area delineation, placement of starting points from which other features are positioned, etc.), and (ii) the individual skills in map reading and drawing; (2) the map used during the in situ exploration serves as a cohesive structure, facilitating the sharing of individual spatial knowledge, which in turn leads to more accurate collaborative sketch maps (distance estimations, directions, etc.); (3) active group interactions during environmental exploration foster better team synergy and communication, which subsequently translates during group drawing sessions into a mitigation of collaborative inhibition, and an improvement of the accuracy of the resulting sketch maps.

## Notes

1. The original French instruction was the following one: “Une de vos connaissances souhaite s’installer dans le quartier de la Plaine Saint-Denis. Elle habite trop loin pour venir l’explorer. Elle vous demande de l’explorer à sa place et de dessiner une carte. Pouvez-vous lui indiquer des repères utiles à la découverte du quartier en vue d’en apprécier son environnement ?”
2. Here is the original instruction, which was also given in French: “Pour répondre à ces objectifs, vous réaliserez une exploration collective du quartier avec 4 autres participants — mais à distance les uns des autres – grâce à l’utilisation de l’application interactive du smartphone qui vous est fourni. La carte sur le mobile vous permet de partager vos trajectoires et vos photos pour interagir avec vos coéquipiers. Observer le quartier, repérez et photographiez les lieux intéressants en coordination avec vos coéquipiers.”
3. Please note that the different colours do not necessarily represent different individuals. As a reminder, participants were free to use the pen of their choice, and to change it as they wished.
4. We started from the centroid of the entity when it was an area symbol (rectangle, etc.).

5. To facilitate the reading of the paper, the results of the two other groups are shown in appendices A-B.
6. The results of the two other groups appear in appendices C-D.

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## Data availability statement

The data we used for the statistical analyses are available in Table 4, Table 7, and Table 9, as well as Appendices A, B, C, and D. However, the raw data collected as part of this research (individual and collective mental maps) are not yet accessible, but are expected to be by the end of the ANR research project CORES (April 2024).

## Disclosure statement

No potential conflict of interest was reported by the authors.

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## Appendices

### Appendix A

Deltas observed between the estimated Euclidean proportions within the subgroups of Group 2

Pair	Group 2-1	Group 2-2	Group 2-3	Group 2-4	Group 2-5	Group 2-6	Google
E-Q	-3.7048625	-1.2579346	-1.3877976	-5.0770093	-3.8968942	0.47931235	5.40530303
Q-F	-3.6921806	-1.1013158	-5.3399891	-2.6860151	-4.2068241	1.05288462	5.375
Q-M	-3.5617908	-1.3213317	-2.1992656	-5.052024	-3.5505753	1.49460956	5.33712121
Q-MSH	-3.6244994	-0.7211722	-1.631117	-2.8816758	-3.5079531	1.00524476	4.96590909
Q-S	-3.9400948	-1.0805423	-5.5616836	-2.2536979	-3.7823023	0.79268648	5.96212121
E-F	-3.8604158	-2.4322568	-5.5772412	-2.5899355	-4.7219756	1.80696387	5.89015152
E-M	-3.9998832	-6.036563	-3.1109094	-2.8556434	-4.8630728	1.64000583	6.41287879
E-MSH	-3.9930083	-2.4885566	-3.06698	-2.7476847	-4.8652877	1.62485431	5.4280303
E-S	-3.4123782	-2.2143142	-2.8227157	-2.3790579	-4.1554696	1.39044289	5.25378788
F-M	-0.1716059	-0.1179426	-0.152775	-0.3750245	-0.314242	-0.2517483	0.63636364
F-MSH	0.04829128	-0.0082935	0.19532856	0.18995026	0.05628406	0.0719697	0.5530303
F-S	-0.7020591	-0.332815	-0.2903239	0.1175715	-0.4359981	0.32983683	1.31439394
M-MSH	0	0	0	0	0	0	1
M-S	-0.908073	-0.417185	-0.9202888	-0.4518048	-0.8864469	-0.2000291	1.93560606
MSH-S	-0.5401315	-0.5801037	-0.56451	0.40495942	-0.5086391	0.08275058	1.25378788

### Appendix B

Deltas observed between the estimated Euclidean proportions within the subgroups of Group 3

Pair	Group 3-1	Group 3-2	Group 3-3	Group 3-4	Group 3-5	Group 3-6	Google
E-Q	-1.0033179	-1.0972222	-1.9480903	-2.725	0.13655743	-0.3237683	5.40530303
Q-F	-1.7645782	-2.1830808	-2.3970049	-3.3992424	-1.302907	-1.904976	5.375
Q-M	-2.3470468	-2.125	-2.5693951	-3.3962121	-1.4975863	-1.9030685	5.33712121
Q-MSH	-1.5713681	-1.9583333	-2.2299678	-3.3113636	-1.0961416	-1.5534391	4.96590909
Q-S	-1.393883	-1.0151515	-5.5758131	-3.4484848	-1.1365398	-2.1947351	5.96212121
E-F	-2.6420126	-5.8598485	-1.3351393	-5.6068182	-5.8645701	-1.2330772	5.89015152
E-M	-2.8967498	-2.9608586	-1.5986979	-3.3401515	-3.5872974	-1.2977709	6.41287879
E-MSH	-2.7803876	-2.9558081	-1.4158054	-3.3431818	-3.3257047	-1.2961358	5.4280303
E-S	-2.2810832	-2.3270202	-0.627871	-2.9280303	-3.3212297	-4.8341236	5.25378788
F-M	0.1179788	-0.2070707	-0.0764614	-0.3227273	-0.3433404	-0.1159799	0.63636364
F-MSH	0.05491014	0.03030303	-0.007798	0.20454545	0.4469697	-0.0398409	0.5530303
F-S	-0.1158828	0.67550505	-0.2092595	-0.3492424	-0.2911381	-0.6789023	1.31439394
M-MSH	0	0	0	0	0	0	1
M-S	-0.037343	0.14267677	-0.2803493	-0.6416667	-0.919327	-0.7941193	1.93560606
MSH-S	-0.0776092	0.70833333	-0.1462084	-0.3659091	-0.2444856	-0.8796872	1.25378788

### Appendix C

Occurrence time of global landmarks in Group 2 (seconds)

Landmark	Group 2-1	Group 2-2	Group 2-3	Group 2-4	Group 2-5	Group 2-6
Lucien Lefranc Quay	481	582	540	578	716	525
Saint-Paul de la Plaine Church	525	758	1140	1158	803	632
Franprix grocery shop	45	145	192	117	296	161
Front Populaire subway station	29	115	121	37	154	73
Human Sciences Institute (MSH) – Paris Nord	178	261	352	132	474	236
Diderot Square	254	283	485	518	543	381
End	1310	948	1380	1387	1295	1364

**Appendix D**

Occurrence time of global landmarks in Group 3 (seconds)

Landmark	Group 3-1	Group 3-2	Group 3-3	Group 3-4	Group 3-5	Group 3-6
Lucien Lefranc Quay	189	267	107	119	72	129
Saint-Paul de la Plaine Church	1380	1270	734	1010	957	1
Franprix grocery shop	201	477	223	169	89	198
Front Populaire subway station	301	428	284	213	405	205
Human Sciences Institute (MSH) – Paris Nord	145	150	54	70	62	14
Diderot Square	720	828	494	986	456	233
End	2280	1302	1065	1563	1428	868