Transit maps: do they shape our minds?

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***Abstract* — Transit maps are schematic representations designed to present a simplified version of a transport network to help travellers find their way. When asked to draw a map of Greater London, Londoners seem to comply to a transit map reference (Vertesi, 2008). This finding suggests that these maps may have an important impact on travellers' spatial mental representations of their region. Herein, using the Greater Paris region (France) as a case study, our objective was to experimentally show the impact of transit maps on travellers' representations of their region. Our results, based on a comparison between the participants' drawings and the schematic or geographic maps of the region, give new arguments toward the hypothesis of a link between transit maps and inhabitants' representations.**

Keywords—geographic space, mental representation, schematic map, transportation.

I. Introduction

In a 2008 study, Vertesi [1] asked Londoners familiar with the city's Tube Map to draw a sketch map of London. She showed that participants tended to structure their productions by relying heavily on the city's transit map, i.e., on a diagrammatic representation of underground metro lines and stations. Considering research in spatial cognition, this finding is of considerable significance: based on diagrammatic cognition, schematic transit maps propose simplified geometrical tools that help inhabitants create a representation of their city or of their regional surroundings. Since then, a larger body of work has studied the impact of schematic transit maps on route planning strategies, heuristics, and performances to better define and comprehend the effects on how to structure and design these maps [2-3]. However, to our knowledge, Vertesi's findings are yet to be replicated and experimentally strengthened. We therefore set out to fill this gap and propose a methodology designed to answer the following question: do inhabitants of big cities, who regularly use the transportation network, structure their representation relying on the transit map with which they are familiar? To answer this question, our methodology also questions the flip side of the coin: if exposure to the transit map does indeed influence inhabitants' representations of their city, then do those inhabitants whose primary mode of transport is a private vehicle still retain a representation of the city that is truer to actual landmarks' geographic positions as encountered during their travel using topography-based road maps and GPS- based car services?

II. Literature Review

Transit maps are diagrams [4] presenting the operational elements [5] of a public transit system [2]. In favouring topology over topography, transit maps comprise a category of cartographic representations distinct from that of geographic maps. Omitting, simplifying, and distorting certain elements of the topography of a city may prove helpful in reducing users' cognitive load and facilitating their decision-making process during travel [6].

Owing to the information that transit maps present, they heavily influence preferences of route choices, potentially leading individuals to choose routes that appear shorter but are in fact longer (spatially or temporally speaking) in comparison to alternative routes – all other factors being equal, the longer a route appears on the transit map, the less likely it is to be chosen [2], [6]. It then follows that exposure to a city's transit map may also influence individuals' perceptions of the city. In this respect, Vertesi's [1] investigation into Londoners' cognitive maps revealed that the Tube Map depicting the London Underground transit system has largely distorted their perception of the city, with inhabitants identifying the Tube Map as a standard representation of London despite recognising it to be a distortion of the city's topography. Such was reflected in their sketches of the city as well as in their ability to provide navigational directions.

III. Research Question

The exposed literature has shown that human representations of geographic spaces tend to be distorted. A possible explanation is that such representations are extremely dependent on maps. In large cities, transit maps may offer inhabitants a simplified diagrammatic representation of their living space. Vertesi's initial work led us to think that representations might have an impact on how inhabitants of bigger cities mentally represent these geographic spaces. The question addressed in this paper concerns the potential link between peoples' representations of geographic spaces and transit maps. More precisely, we hypothesized that, if inhabitants refer to a transit map to create a simplified representation of the geographic space, we should observe in their drawings the same distortions present in the transit map. Furthermore, this phenomenon would primarily concern the inhabitants who frequently use transit maps for operational purposes within the region's transit network; in other words, we tested how familiarity with the transit map may induce spatial distortions in inhabitants' representations of their city. Moreover, we predicted that inhabitants whose primary mode of transport is a private vehicle, may produce drawings that present a closer resemblance to a geographic map of the region given their less frequent use of the region's transit map and the topography-based structure of road maps and GPS-based car services.

IV. METHODOLOGY

A. *Participants*

Ninety-nine inhabitants of Greater Paris participated in this study for monetary compensation. We recruited participants aged between 18 and 50 years (mean age = 34.8±9.1; 50 men and 49 women) who were right-handed, presented no cognitive deficits and declared having resided in Greater Paris for a minimum of 5 years. To constitute our group of public transit users, we recruited 51 persons using the public transit network at least 5 out of 7 days each week and not using a private vehicle more than once per week. To constitute our group of private transport users, we recruited 48 persons using a private vehicle at least 5 out of 7 days each week and not using the public transit network more than once per week. Participants described their use of private vehicles to be limited to cars, bicycles, motorbikes, and scooters.

B. *Material*

1) Landmarks: Fifteen well known geographic landmarks in Greater Paris were selected via a preliminary study: 30 French inhabitants (mean age = 35.9 ± 10.3; 16 men and 14 women) were required to cite up to 50 well reputed landmarks situated in and known to represent the region of Greater Paris. The 10 most cited landmarks were retained (landmarks 1-10 in Table 1), and an additional 5 landmarks situated in the outskirts of Greater Paris (landmarks 11-15 in Table 1) were added to arrive at a total of 15 landmarks situated in Greater Paris.

TABLE 1. LIST OF CHOSEN LANDMARKS

Landmark no.	Landmark name
1	Château de Versailles
2	Tour Eiffel
3	Bois de Vincennes
4	La Défense
5	Aéroport Charles de Gaulle
6	Bois de Boulogne
7	Eurodisney
8	Aéroport d'Orly
9	Forêt de Fontainebleau
10	Stade de France
11	Forêt de Saint-Germain-en-Laye
12	Mantes-la-Jolie
13	Meaux
14	Évry
15	Rambouillet

2) Test layout: Participants were provided with a test layout on which they were to produce their sketch maps by plotting the fifteen landmarks (see Fig.1). This test layout was depicted on a A3-sized sheet of paper only displaying the geographic point of reference of a common central landmark - Notre Dame de Paris - to help participants orient and situate the plottable landmarks within the Greater Paris region. The Parisian cathedral was selected for its central position within, visible on both reference maps described below (see Fig.2)

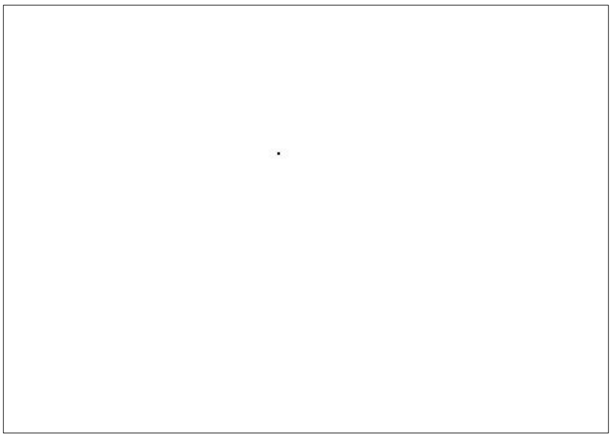

Fig. 1. Test layout given to participants, the single dot representing the geographic coordinates of Notre Dame de Paris

3) Reference maps: A layout of the geographic positions of the fifteen landmarks constituted a geographic reference map, and a layout of the positions of these points on the actual transit map of Greater Paris constituted a schematic reference map (Fig.2).

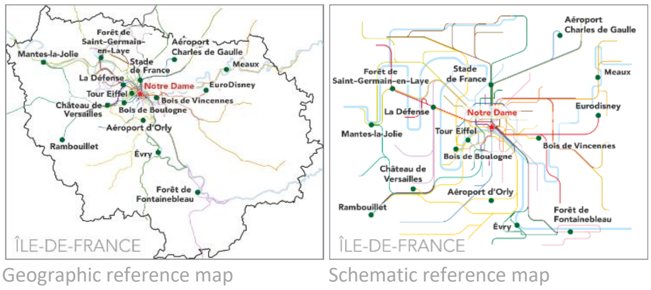

Fig. 2. Layout of plottable landmarks and Notre Dame de Paris as appearing on the geographic and schematic reference maps.

4) Post-experimental questionnaire: A questionnaire consisting of twelve questions explored participants' sociodemographic characteristics and their transportation habits, including their use (and frequency of use) of public and private means of transportation. These questions mainly served as an additional confirmation of the characteristics that distinguished the two recruited groups of participants.

C. *Procedure*

Participants were tested individually. First, they read and signed a consent form. Then, they were given written instructions on how to plot the fifteen landmarks on an A3-sized test layout. They were asked to plot these landmarks, in no specific order, in relation to the position of Notre Dame de Paris indicated on the test layout. They were informed that the task would take no longer than ten minutes and that they were to attempt to plot the greatest number of landmarks possible, however approximate their estimations may be. Upon completion of the task, they completed the questionnaire before being debriefed on the aims of the study.

D. *Data analyses*

1) Extraction of Euclidean coordinates: The Euclidean coordinates of the landmarks as found on participants' sketch maps and both reference maps were extracted using the Gardony Map Drawing Analyzer [7].

2) Sketch maps: Sketch maps missing more than two landmarks were eliminated, leaving the sample size at 84 (mean age = 34.6 ± 8.5; 45 men and 39 women). 41 were public transit users (mean age = 31.3 ± 8.5; 24 men and 17 women). and 43 were private transport users (mean age = 37.8 ± 7.4; 21 men and 22 women). For 21 sketch maps missing one or two landmarks, their comparison to the reference maps was realised after discarding the corresponding missing landmarks on the reference maps.

3) Preliminary comparison between reference maps: A bidimensional regression was performed on the two reference maps, with the geographic reference map serving as the independent variable and the schematic reference map as the dependent variable, on the R software 4.1.1. Measures of global configuration relative to scaling bias, rotational bias, and correlation coefficient of bidimensional regression were extracted via the function BiDimRegression which implements Euclidean and Affine transformations as outlined by Tobler in 1965 [8]. Additional precisions on the computation of these measures may be found in [9].

The scaling bias score reflects the compression or expansion of inter-landmark distances on the transit map in relation to the geographic map. Inter-landmark Euclidean distances on the transit map are compared to their corresponding references on the geographic map to calculate this score. Values above 1 indicate that inter-landmark distances on the transit map are generally expanded, and values below 1 indicate that they are generally compressed.

The rotational bias score reflects in degrees how inter-landmark angles on the transit map are rotated in relation to the geographic map. Inter-landmark angles on the transit map are compared to their corresponding references on the geographic map to calculate this score. Positive values indicate that inter-landmark angles on the transit map are generally rotated clockwise and negative values indicate that they are generally rotated anticlockwise.

The correlation coefficient, *r*, output from bi-dimensional regressions reflects the spatial fit between the transit and geographic maps while factoring out any scaling, translation and rotation imposed upon inter-landmark pairs on the transit map. Values closer to 1 indicate a closer spatial fit between the transit and geographic maps' landmark configurations.

4) Comparison between participants' sketch maps and reference maps: Bidimensional regressions were performed to compare participants' sketch maps to the reference maps, with the two reference maps serving as independent variables and the sketch maps as dependent variables. Measures of global configuration relative to scaling bias, rotational bias and correlation coefficient of bi-dimensional regression were extracted.

To test our hypotheses, we performed a multiple linear mixed-effects regression using the bidimensional regression output scores as dependent variables and the alpha level set to .05. Three linear mixed-effects models were thus built for the three measures, scaling bias, rotational bias, and correlation coefficient of bi-dimensional regression. Scale and rotation dependent variables were converted into z-scores to suppress the metric distortion inherent to the schematic reference map compared to the geographic reference map (see Table 2 presented in the following section). The fixed effects for each of the models consisted of the reference map, participants' transportation category and the pairwise interaction; autocorrelation within participants' responses was accounted for in each model by the addition of a random effects intercept parameter. Each model was tested for abnormally influential observations using the Cook's distance method [10]. We used the standard cut-off value of $D_i < 4/n$ to remove outlier observations before refitting the models.

Given the conversion of the scaling bias score into a z-score for participants' sketch maps, positive values of this measure indicate that inter-landmark distances on participants' sketch maps are generally expanded, and negative values indicate that they are generally compressed. Regarding the conversion of the rotation bias score into a z-score, positive values indicate that inter-landmark angles on the sketch maps are generally rotated clockwise and negative values that they are generally rotated anticlockwise.

V. RESULTS

A. *Preliminary comparison between reference maps*

TABLE 2. BIDIMENSIONAL REGRESSION MEASURES FOR THE COMPARISONS BETWEEN THE GEOGRAPHIC AND SCHEMATIC REFERENCE MAPS.

Bidimensional regression measure	**Score**
Scaling bias	1.49
Rotational bias	9.12
Correlation coefficient	0.95

As reported in Table 2, inter-landmark distances between the fifteen landmarks are globally expanded on the transit map, and inter-landmark angles are globally rotated clockwise on the transit map. A correlation coefficient of 0.95 signifies that a close spatial fit was observed between the geographic and schematic reference maps.

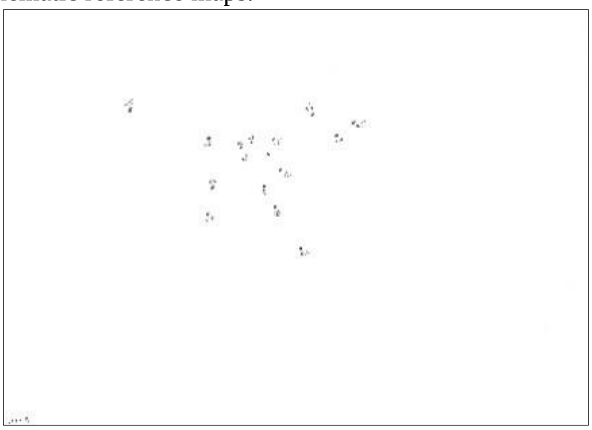

Fig. 3. Sketch map obtained from a participant from the public group.

TABLE 3. SCORES OF SCALING BIAS, ROTATIONAL BIAS AND CORRELATION COEFFICIENT OBTAINED BY ONE PARTICIPANT

AGAINST THE SCHEMATIC AND GEOGRAPHIC MAPS. Z-SCORES ARE REPORTED FOR SCALING AND ROTATIONAL BIASES

	Transit map	Geographic map
Scaling bias	-0.99	-0.44
Rotational bias	-0.1	0.21
Correlation coefficient	0.93	0.96

Figure 3 presents a sketch map produced by a participant from the public transit group. Table 3 reports the scores of scaling bias, rotational bias and correlation coefficient in comparison to the transit and geographic maps. Scaling and rotational bias scores are presented after conversion into z-scores. With regards to the transit map, we observe a compression of inter-landmark distances, an anticlockwise rotation of inter-landmark angles and a close spatial fit of 0.93. With regards to the geographic map, we observe a compression of inter-landmark distances, a clockwise rotation of inter-landmark angles and a close spatial fit of 0.96.

B. Comparison between participants' sketch maps and reference maps

1) Scaling bias: A significant effect was found for the reference map (β = -0.74, SE = 0.06, t = -12.36, *p.* < .001), indicating a global compression of inter-landmark distances on participants' sketch maps when compared against the transit map (*M* = -0.37, *SD* = ± 0.72) and a global expansion when compared against the geographic map (*M* = 0.31, *SD* = ± 1.03). Contrary to what was expected, no significant effect was found for the transport category (β = -0.05, SE = 0.20, t = -0.26, *p.* = .80). No interaction effect between the reference map and the transport category was revealed, (β = 0.06, SE = 0.09, t = 0.74, *p.* = .46). The model's marginal and conditional pseudo R^2 indices indicate that the model's fixed factors account for 1.4% of variation observed in participants' responses and the fixed and random factors together account for 92% of the variation observed.

2) Rotational bias: A significant effect was found for the reference map (β = -0.22, SE = 0.04, t = -5.41, *p.* < .001), indicating a global anticlockwise rotation of inter-landmark angles on participants' sketch maps when compared against the transit map (*M* = -0.1, *SD* = ± 0.89) whereas a global clockwise rotation of inter-landmark angles was observed when compared against the geographic map (*M* = 0.09, *SD* = ± 0.86). A significant effect was found for the transport category (β = 0.42, SE = 0.19, t = 2.22, *p.* = .03), indicating a global anticlockwise rotation of inter-landmark angles on private transport users' sketch maps (*M* = -0.21, *SD* = ± 0.9) and a global clockwise rotation of inter-landmark angles on public transit users' sketch maps (*M* = 0.2, *SD* = ± 0.81). Finally, no interaction effect between the reference map and the transport category was revealed, (β = 0.02, SE = 0.06, t = 0.42, *p.* = .68). The model's marginal and conditional pseudo R2 indices indicate that the model's fixed factors account for 0.7% of variation observed in participants' responses and the fixed and random factors together account for 96% of the variation observed.

3) Correlation coefficient: A significant effect was found for the reference map (β = 0.03, SE = 0.01, t = 4.74, *p.* < .001), indicating a better spatial fit between participants' sketch maps and the transit map (*M* = 0.68, *SD* = ± 0.22) than between the participants' sketch maps and the geographic map (*M* = 0.65, *SD* = ± 0.23). No significant effect was found for the transport category (β = -0.04, SE = 0.05, t = -0.76, *p.* = .45), and no interaction effect between the reference map and the transport category was revealed, (β = 0.01, SE = 0.01, t = 1.13, *p.* = .26). The model's marginal and conditional pseudo R2 indices indicate that the model's fixed factors account for 0.1% of variation observed in participants' responses and the fixed and random factors together account for 98% of the variation observed.

VI. DISCUSSION

Our findings indicate that participants' sketch maps were globally compressed in relation to the transit map, and globally expanded in relation to the geographic map. We found the scaling observed on participants' sketch maps to be situated between either reference maps, with a compression towards the geographic map when compared against the transit map and an expansion towards the transit map when compared against the geographic map.

Sketch maps were rotated clockwise compared to the geographic map and anticlockwise to the transit map. We found the rotational bias observed on participants' sketch maps to be situated between either reference maps, with a rotation towards the transit map when compared against the geographic map and a rotation towards the geographic map when compared against the transit map. Additionally, private transport users' sketch maps were rotated anticlockwise and public transit users' clockwise, albeit not specifically in relation to either reference map.

These findings, presenting a rapprochement of sketch maps' scaling and rotational bias scores towards the geographical reference map, are to be interpreted taking into consideration that the test layout held the geographic reference coordinates of Notre Dame de Paris. Indeed, participants were, from the start, led to structure their productions towards the geographic reference map.

Finally, the correlation coefficient measure, which discards any scaling and rotational biases, suggests that the sketch maps more closely resembled the transit map than the geographic one. Surprisingly, this was the case for both groups of participants, users as well as non-users of public transportation and its transit map, and is, therefore, seemingly in contrast to our initial hypothesis elaborated in accordance with Vertesi's findings that it is the exposure to the transit map which leads to a cognitive representation of the geographic space which reflects the distortions present in the transit map [1].

While Vertesi's work employed a qualitative approach to interview around 20 Londoners who were familiar with the London Underground Tube Map and collect verbal accounts and sketch maps, we integrated her approach with an experimental and inferential statistical method to obtain a more fine-tuned view of inhabitants' representations of the Greater Paris region. To do so, we studied two groups of inhabitants, supposedly distinct because of their respective exposures to the region's transit map – a group of inhabitants primarily using the region's public transportation network and its schematised transit map, and a group of inhabitants primarily using private means of transportation and topography-based road maps or GPS-based car services. Nevertheless, if we consider that habitual use of schematic tools inside transit spaces and for transit uses isn't enough to justify a difference between the two studied groups, this raises further questions regarding the origins of the effect observed whereby both private and public transport users of the Greater Paris region retain representations of the region that more closely resemble its transit map than the geographic map.

Our findings therefore require additional research to help determine why private transport users sketch a representation of the region more closely resembling a transit map than a geographic one despite using more topography-based tools than schematic transit maps. Using a similar experimental approach, the authors work on a complementary experiment to test inhabitants' representations of three large European cities – Greater London, Greater Paris, and Greater Berlin. Participants will be required to produce a sketch map of their respective residential city and, following a brief learning phase, a sketch map of one of the two other unknown cities. New findings will help comprehend whether long lasting exposure to Parisian transit map (either due to its widespread presence in public space or due to a more frequent use in the past), or other general cognitive processes may have led private transport users in the present study to retain a mental representation of Greater Paris that is truer to its transit map than its topography.

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