On the Sense of Direction in Urban Navigation

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Abstract— **This study investigates how passengers perceive and process directional information from horizontal transit maps displayed on railway platforms, specifically examining the RER A line in Paris, a west-east line. Through three experiments (N=1,881) using video stimuli of actual platform displays, we tested preferences for map orientations aligned with train direction, cardinal directions, or left-to-right cultural reading pattern. Contrary to our hypothesis that alignment with train movement would dominate orientation preferences, results revealed that left-to-right reading direction emerged as the primary factor influencing map orientation preference. This finding held true across different platform configurations and remained independent of individual spatial abilities. Additionally, we observed a strong preference for conventional north-up orientation of branch lines, even when this conflicted with geographical accuracy. These results suggest that the sense of spatial direction during urban navigation, especially underground rail transit lines, may be underpinned by unarticulated frames of reference that operate independently rather than in integration, allowing for successful navigation despite disorientation.**

Keywords—spatial cognition, wayfinding, rapid transit, public transportation, disorientation, map design

I. Introduction

Do map orientations impact transit riders' spatial awareness in railway networks? Transit maps inherently influence spatial awareness of metropolises (1,2), and certain navigation contexts, such as car riding, tend to favor oriented maps—for instance, to communicate upcoming congestion (3). In line with this idea, goal-directed map viewing has been found to not only influence attention patterns but also constrain memory formation to perspective-congruent representations (4). Yet these findings have not been extensively applied to map orientation preferences in railway networks.

We examine this issue for one-dimensional rail line maps that represent sequential stops along a transit route. When represented on horizontal displays positioned parallel to train tracks on platforms, map orientations can create visual conflicts - such as when a map shows the next station to the left, but the train arrives from the left heading right. Some might consider these as diagrams rather than maps—not merely due to spatial accuracy, but because their design prioritizes conceptual relationships over strict geographic fidelity (5). This suggests that, in practice, reading conventions (e.g., left to right) may shape map interpretation just as much as geographic consistency. Further, on west-east transit lines, riders may prefer map orientations aligned with the cardinal directions used in static maps, reinforcing a more stable mental representation. Supporting this hypothesis, pointing tasks in virtual models of participants' hometowns show that spatial memory favors a north-oriented frame, likely shaped by conventional map use rather than direct navigation (6). This raises a crucial question for transit map designers: Which map orientation do passengers perceive as most intuitive?

Orientation A: Aligned with train direction, where the leftward or rightward direction corresponds to the train's heading in physical space.

Orientation B: Based on cardinal directions, with west consistently on the left.

Orientation C: Following western cultural reading patterns, with origin always on the left and destination on the right.

We address this question through three experiments on Paris's RER A line, which we selected for three key reasons. Firstly, RER A is Europe's busiest transit line (7), and is the first in Paris to implement horizontal displays parallel to the tracks, so our results could have a direct real-world application. Second, its east-west configuration offers an ideal test case for cardinal orientation, while findings regarding reading direction versus train-heading apply to all orientations. Third and most importantly, RER A platforms create a naturally occurring experimental setting where different reference frames can be tested against each other. Some RER A stations feature platforms with a central deck and tracks on the outer edges, while others have peripheral decks with centrally located tracks. Consequently, depending on the station layout, the relative direction of trains from a passenger's perspective may vary: in other words, there are stations in which orientations C and A align vs. B, while others in which C and B align vs. A. This methodological approach allows us to determine which orientation (A, B, or C) most influences travelers' cognitive preferences for any horizontal display of a transit line parallel to the track. Using controlled video stimuli originating from two RER A stations, we tested whether passenger preferences align with train direction, cardinal orientation, or reading conventions. We also included a third, image-based, experiment to investigate up-down preferences of north/south outer branches (Figure 1).

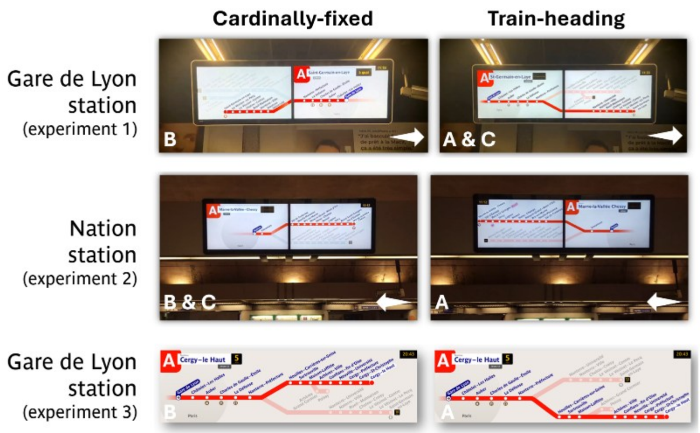

Figure 1: Stills from six stimuli (four video excerpts and two images) used across the three experiments in the study. Line management agreed to invert map orientations for

experiments 1 and 2 to produce the alternate stimuli. The two stations instantiate opposite relative orientations of the traveller relative to the train heading. A white arrow indicates train-heading direction. Letters indicate which of the above-mentioned orientations each map stimulus aligns with.

This research is grounded in theories of how individuals maintain their sense of direction in complex environments (8). This requires subjects to coordinate egocentric directions (left/right relative to self) with allocentric directions (cardinal directions), a process crucial for navigation (9), and supported by multiple types of cells in the brain (10). While extensive research exists on spatial navigation and directional sense (11), less is known about directional orientation in urban public transport settings, especially underground metro systems such as the one studied here. Commuting can be accomplished through following directional signage and the learning associated with repeated trips, relying on procedural memory and familiarity rather than on survey knowledge (12,13). Because of a lesser reliance on survey knowledge in metro systems, and because other forms of navigation such as car riding usually favour egocentrically oriented maps (3), we hypothesize that passengers prefer transit maps aligned with train direction, as this orientation provides maximum visual consistency with the immediate environment. We further hypothesize that the visual inconsistency of a train arriving in the opposite direction as represented in the map, which is captured in the videos, makes travellers prefer the train-heading map orientation.

In the remainder of this paper, we detail methods for the three experiments, alongside pre-registered hypotheses. We then validate the psychometric scale, report results for the main hypotheses, and discuss our findings. Contrary to our initial hypotheses, we underestimate the importance of the reading direction heuristic, which is the single factor providing a coherent explanation of our findings across the three experiments.

II. METHODDS AND HYPOTHESES

Study designs and hypotheses were pre-registered for experiments 2 and 3 following analysis of experiment 1's data (14). While the three experiments share core methodological elements, each addresses distinct research questions with specific methodological adaptations. We first detail the commonalities across all three experiments, then describe each experiment's unique design features, and finally validate the psychometric scale employed throughout the study.

A. *General methods*

Participants were recruited through Prolific and completed surveys hosted on Qualtrics. The experiments employed a mixed design: orientation evaluation was within-subjects (all participants viewed both orientations A and B), while orientation order and priming were between-subjects factors (participants were randomly assigned to either receive priming or not, and to see either order A→B or B→A). This design structure was replicated across all experiments.

Participants viewed video recordings of information screens showing train arrivals at platforms, evaluating the same screen in both possible orientations (Figure 1). After a minimum 40-second viewing period, participants rated seven aspects of the screen (ease of understanding, orientation aid, intuitiveness, usefulness, satisfaction, relevance, and readability) on 0-100 visual analog scales with Likert-type anchors.

The research was conducted in accordance with the Declaration of Helsinki, with ethical approval requirements waived by the Pôle Éthique of the Institut des Sciences Biologiques for anonymous questionnaires. All participants provided informed consent, with speed running as the sole exclusion criterion.

B. *Experiment 1*

Six hundred and thirty-six French-speaking participants in France were recruited through Prolific. This exploratory study examined configurations where map orientation aligned with train direction coincided with left-to-right reading experience. Its findings informed the pre-registered hypotheses for Experiments 2 and 3 (14), particularly regarding the relationship between alignment and reading direction. The experiment also raised questions about map representation of north-south branches on an east-west line, which became the focus of Experiment 3.

C. *Experiment 2*

Five hundred and ninety-five French-speaking participants after exclusion and located in France were recruited through Prolific. Experiment 2 incorporated two additional measures beyond those used in Experiment 1. First, participants completed the Santa Barbara Sense of Direction (SBSOD) questionnaire to assess individual differences in spatial reasoning abilities (15). Second, participants completed a spatial reference frame task adapted from the Man and Tree test (16). In this task, after viewing the video stimulus, participants chose between four randomly ordered descriptors ("to the right," "to the left," "to the east," or "to the west") to describe the relative position of adjacent stations, allowing assessment of egocentric versus allocentric reference frame preferences depending on map orientation. We pre-registered the following hypotheses:

- H1: Participants will prefer maps oriented in the direction of trains despite the resulting right-to-left reading experience, compared to maps-oriented opposite to train direction but maintaining left-to-right reading experience.
- H2: The preference for direction-aligned maps will be stronger when alignment coincides with left-to-right reading experience (Experiment 1) compared to when it creates right-to-left reading experience (Experiment 2).
- H3: Participants scoring higher on spatial reasoning ability (SBSOD) will show reduced preference for egocentric alignment and increased preference for allocentric (north-up) orientation.
- H4: Map orientation will influence spatial language choice, with increased use of allocentric descriptors when map orientation conflicts with left-to-right reading direction (i.e. in context of experiment 2, when the east is to the left of the map instead of the right).

D. *Experiment 3*

Six hundred and fifty French-speaking participants after exclusion and located in France were recruited through Prolific. Experiment 3 investigates preferences for the orientation of north-south branches following east-west inversion of the map. Unlike previous experiments which used video recordings, experiment 3 employs a static image of the map produced by the display designers and showing potential top-down inversions of north-south branches. The same psychometric scale as in Experiments 1 and 2 was used to evaluate both map orientations. Experiment 3 retained the Santa Barbara Sense of Direction questionnaire from Experiment 2 but replaced the spatial language task with a novel masking procedure. Prior to viewing the main stimulus, participants were shown a display with east-west inversion and asked to locate the north branch on a partially masked section of the display, either at the top or bottom. This task assessed participants' intuitive geographical expectations for branch placement. We pre-registered the following hypotheses:

- H5: Participants exposed to maps with non-standard cardinal alignment (east oriented left) will misplace branches relative to their true geographical positions, with reduced errors among participants who completed the prior orientation task.
- H6: Participants with higher spatial reasoning abilities (SBSOD scores) will demonstrate stronger preferences for geographically consistent map orientations.

E. Scale validation and hypothesis testing

To ensure the validity of the custom scale used throughout the three experiments, we detail a Confirmatory Factor Analysis (CFA) with a single-factor solution, loading the 7 observed variables onto a single factor. The analysis was conducted using the Sequential Least Squares Programming (SLSQP) optimizer implemented in semopy. The aim is not to ground the validity of the scale for future studies, but rather to assess fit indices and reliability metrics before computing a factor score for hypothesis testing in the results section.

The same factor analysis was conducted across all six stimuli (two per experiment) to validate the psychometric scale by showing replicability across samples (17). Data suitability was strongly supported: Bartlett's test of sphericity was highly significant for all samples ($p < .001$), with substantial chi-square values (mean $\chi^2 = 185.346$, range: 112.477-285.637). The Kaiser-Meyer-Olkin measure indicated excellent sampling adequacy (mean KMO = 0.910, range: 0.906-0.916, recommendation: $\geqslant .60$).

The single-factor solution demonstrated robust psychometric properties. The factor explained a substantial portion of variance (mean = 68.9%, range: 63.0-72.7%), well above the recommended 50% threshold. The scale showed excellent internal consistency (mean Cronbach's $\alpha = 0.917$, range: 0.893-0.936), with strong item-total correlations (mean $r = 0.756$, range: 0.539-0.879).

Fit indices showed varying levels of adequacy:

- CFI reached the recommended threshold (mean = 0.950, range: 0.935-0.968, recommendation: $\geqslant .95$)
- TLI fell slightly below recommendations (mean = 0.925, range: 0.903-0.952, recommendation: $\geqslant .95$)
- χ^2/df exceeded recommendations (mean = 10.369, range: 5.427-16.515, recommendation: $\leqslant 3$), likely due to large sample sizes
- RMSEA exceeded recommended values (mean = 0.134, range: 0.097-0.167, recommendation: $\leqslant .06$)
- SRMR showed excellent fit (mean = 0.066, range: 0.055-0.080, recommendation: $\leqslant .08$)

The elevated RMSEA values can be attributed to the model's low degrees of freedom (df = 14). Following Kenny et al. (18), when df is low, good SRMR and CFI values may be more meaningful indicators of model fit than RMSEA. In our case, both CFI and SRMR demonstrated excellent fit. The strong reliability coefficients, substantial variance explained, and robust item-total correlations, combined with adequate fit indices, support the scale's validity for the current experiments, though some fit indices suggest potential for refinement in future applications.

To provide conservative estimates during hypothesis testing, we employed non-parametric tests throughout: Wilcoxon signed-rank tests for within-groups comparisons (H1); Vandekar's S as a robust effect size metric for differential comparison (H2) (19) with a low effect with $S \approx 0.1$, medium effect with $S \approx 0.25$ and a large effect with $S \approx 0.40$); Spearman correlation coefficients for SBSOD influence on orientation preferences (H3, H6); McNemar's test for comparing within-subject changes in descriptor use across stimuli (H4); Fisher's exact tests for between-subjects group proportions (H5). All p-values were Holm-Bonferroni corrected to control for family-wise error rate.

III. Results and Discussion

A. Experiment 1

In Experiment 1, none of the groups preferred the cardinally aligned orientation over the train-heading orientation. In groups without orientation priming, participants who viewed stimuli in different orders both showed strong preferences for train-heading orientation: those who saw train-heading first showed a large preference (factor score $Mean_1 = 88.27$, $Mean_2 = 65.47$, $W = 765$, $p < .001$, $S = 0.67$, large effect), while those who saw cardinally-coherent first also showed a medium preference for train-heading orientation (factor score $Mean_1 = 88.99$, $Mean_2 = 82.44$, $W = 1894$, $p < .001$, $S = 0.24$, medium effect).

In groups with prior orientation priming on cardinally-coherent maps, this preference persisted but was weaker: participants who saw train-heading first showed a small but significant preference for it (factor score $Mean_1 = 85.82$, $Mean_2 = 79.93$, $W = 4285$, $p = .007$, $S = 0.19$, small effect), while those who saw cardinally-coherent first showed a negligible difference (factor score $Mean_1 = 83.47$, $Mean_2 = 82.42$, $W = 4476$, $p = .01$, $S = 0.03$).

B. Experiment 2

In Experiment 2, none of the groups preferred the train-heading orientation over the cardinally aligned orientation, invalidating our first hypothesis (H1). Instead, strong preferences for cardinally-coherent orientation emerged in specific conditions.

For groups with orientation priming, those who viewed the cardinally-coherent orientation first showed a medium preference for it (factor score $Mean_2 = 88.11$, $Mean_1 = 77.40$, $W = 2289$, $p < .001$, $S = 0.34$, medium effect), while those who viewed train-heading first showed no significant preference (factor score $Mean_1 = 85.32$, $Mean_2 = 84.99$, $W = 4549$, $p = .538$, $S = 0.01$).

Similarly, in groups without orientation priming, those who viewed cardinally-coherent first demonstrated a medium preference for it (factor score $Mean_2 = 87.74$, $Mean_1 = 78.12$, W = 2862.5, $p < .001$, S = 0.29, medium effect), while those who viewed train-heading first showed no significant preference (factor score $Mean_1 = 87.17$, $Mean_2 = 84.89$, W = 4709, p = .638, S = 0.08).

Our second hypothesis (H2) predicted stronger preferences for train-heading orientation when aligned with left-to-right reading (Experiment 1) versus creating right-to-left reading (Experiment 2). This hypothesis was invalidated, as Experiment 2 showed no preference for train-heading orientation. Instead, both experiments revealed a consistent pattern favoring orientations that provided left-to-right reading - train-heading in Experiment 1 and cardinally-coherent in Experiment 2. Effect sizes varied notably between experiments, with stronger preferences when left-to-right reading aligned with train-heading (S up to 0.67) compared to cardinal orientation (S up to 0.34), suggesting that certain orientation combinations might be more intuitive than others.

Our third hypothesis (H3) predicted that participants with higher spatial reasoning abilities would show stronger preferences for cardinally-coherent orientation (north-up). However, SBSOD scores showed no meaningful relationship with orientation preferences (Spearman's $\rho = 0.055$, p = .538). This suggests that the preference for different map orientations in transit settings might be independent of individual differences in spatial ability, at least as measured by the Santa Barbara Sense of Direction scale.

Results strongly supported our fourth hypothesis (H4) regarding the influence of map orientation on spatial language choice. Participants used cardinal descriptors more frequently with cardinally-coherent maps (19.8%, 95% CI [16.8%, 23.2%]) compared to train-heading maps (14.6%, 95% CI [12.0%, 17.7%]; McNemar's test, $p < .001$). More revealing was the pattern of spatial misattribution: when east was positioned on the left in train-heading maps, 10.8% of participants (95% CI [8.5%, 13.5%]) incorrectly equated left-positioned stations with westward location, compared to only 1.7% (95% CI [0.9%, 3.1%]) with cardinally-coherent maps (McNemar's test, $p < .001$). This systematic confusion between spatial and cardinal references demonstrates how map orientation can create cognitive conflicts between different spatial reference frames, i.e. spatial disorientation.

C. *Experiment 3*

In Experiment 3, where the only difference between stimuli was the top-bottom placement of the northern branch on an east-west reversed map, participants consistently preferred or showed no aversion to placing north at the top, even when this conflicted with geographical accuracy. For groups with orientation priming, those who viewed north-top first showed no significant preference (factor score $Mean_1 = 79.06$, $Mean_2 = 79.37$, W = 6472, p = .935, S = 0.01), while those who viewed north-bottom first had a medium preference for north-top placement ($Mean_2 = 85.02$, $Mean_1 = 75.23$, W = 1227, $p < .001$, S = 0.34, medium effect).

The pattern was similar in groups without orientation priming: those who viewed north-top first showed a small preference for it (factor score $Mean_2 = 82.35$, $Mean_1 = 78.91$, W = 4644.5, p = .025, S = 0.11, small effect), while those who viewed north-bottom first showed a medium preference for north-top placement (factor score $Mean_2 = 86.04$, $Mean_1 = 75.49$, W = 1408, $p < .001$, S = 0.33, medium effect).

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Our fifth hypothesis (H5) was fully supported. When exposed to maps with east oriented left, the vast majority of participants (86.2%, 95% CI [83.5%, 88.8%]) incorrectly placed branches relative to their true geographical positions, significantly exceeding chance levels ($p < .001$). Moreover, while prior exposure to cardinally-coherent maps reduced these errors (82.5% errors with priming vs 89.7% without, Fisher's exact test, p = .027), the error rate remained remarkably high in both conditions. These results, combined with our previous findings about north-top preferences regardless of geographical accuracy, demonstrate that both our intuitions and preferences during public transport navigation tend to favor conventional orientations (e.g., north-up even on a west-east transit line) even when these conflict with geographical reality.

Our sixth hypothesis (H6) was not supported: SBSOD scores showed no significant correlation with preferences for geographically consistent map orientations (Spearman's $\rho = -0.050$, p = .399). Notably, both SBSOD-related hypotheses (H3 and H6) yielded non-significant results, suggesting that individual differences in spatial reasoning abilities play a relatively minor role in map orientation preferences compared to the systematic patterns we observed across conditions. While further analysis of sociodemographic variables might reveal other individual-level effects, our results indicate that cognitive preferences for map orientation are driven more by shared cultural conventions, such as reading direction in Western contexts, than by individual spatial abilities.

IV. Conclusion

Our findings reveal that left-to-right reading direction emerges as the dominant factor in map orientation preferences in the context of the displays we studied, superseding both alignment with train movement and cardinal directions. This conclusion stems from abductive reasoning: left-to-right preference provides the only coherent explanation for effects observed across all situations.

Several limitations warrant consideration. While we employed ecologically valid video stimuli captured in actual transit stations, the digital administration of our study may have amplified directional bias compared to potential in-situ testing. Furthermore, our exclusively French sample raises questions about generalizability across cultures with different reading directions (20).

These methodological considerations notwithstanding, our results point to a fundamental insight: so-called transit maps may function more as non-oriented diagrams than traditional maps. To the extent that they are oriented at all, this orientation appears to be temporal rather than spatial: the sequential nature of travel, where left-to-right direction coincides with both reading direction and the progression of upcoming stops, aligns with intuitive cognitive representations of mental time on a left-to-right timeline (21). Yet simultaneously, the systematic preference for northern branches to be situated at the top of inverted east-west maps suggests that certain spatial cardinal intuitions exert substantial influence on map reading. Perhaps, then, the most distinctive feature of directional sense in urban public transport navigation lies in its peculiar flexibility: various spatial frames of reference—egocentric, allocentric—need not be integrated for successful navigation. This cognitive independence of reference frames may itself be an artifact of the topologically constrained nature of public transport networks, where successful navigation depends more on sequential decision-making than on continuous spatial orientation.

V. References

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