Emerging Research on Design and
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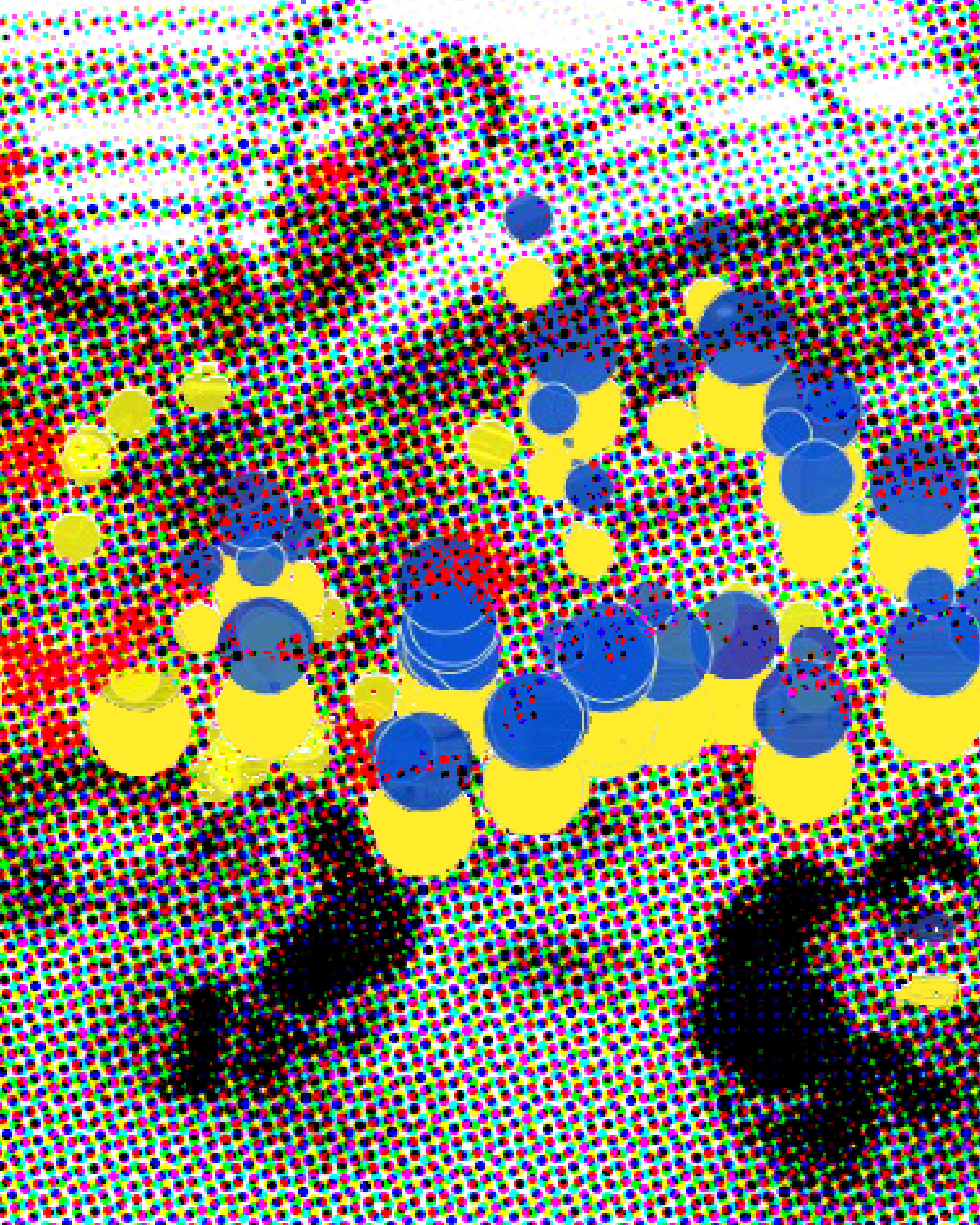

Emerging Research for Informing the Design and Use of Wayfinding Systems

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Well-designed signage and wayfinding systems are essential components of contemporary life. They can save time as well as reduce the stress (and potential for accidents when driving) associated with navigating through unfamiliar environments to new destinations. Well-designed systems are especially important in complex environments, both within buildings and on outdoor pedestrian routes and as part of roadways, as they have important health, social, economic, and environmental consequences for individuals, organizations and communities (Iftikhar et al., 2021; Robinson, 2021; Iftikhar and Luximon, 2022). Factors associated with difficulty in wayfinding include ineffectively designed and placed signs or the lack of other conspicuous environmental clues for inflection points. While using navigational aids such as analog maps or digital electronics (i.e. smartphones or navigation systems) can provide substantial assistance, their use in some environments and circumstance may be limited, and there is an ongoing need for legible and appropriately informational signage able to capture the visual attention of those unfamiliar with navigating a particular space. Traffic control devices are important parts of roadway signage systems and especially critical for regulating the safe flow of traffic around highway construction.

This issue of the *Interdisciplinary Journal of Signage and Wayfinding* provides findings from emerging research informing the design and use of technology and traditional signage for enhanced wayfinding in a diverse array of complex visual environments. Some of the results reported here will likely have important implications for the design and use of wayfinding systems in interior, as well as outdoors environments. In their article, "Landmarks on Mobile Maps: Roles of Visual Variables in the Acquisition of Spatial

Knowledge," Andrew Kim and Rui Li evaluate a new mobile map design to address limitations imposed by the small screens of handheld devices by visualizing landmarks located beyond the displayed map extent. Their results showing visualization of distant landmarks facilitates spatial learning has important implication for the design of mobile mapping systems.

In the article, "Towards Linguistic Inclusivity: An Exploration of the Wayfinding System at Stellenbosch University, South Africa," Gera de Villiers et al. explore important considerations of linguistic landscaping and spatial justice as part of wayfinding systems. Their findings of a system that is "lacking in effective and efficient accessibility" suggests important implications for wayfinding design far beyond South Africa. Indeed, the lessons should resonate in much of the world as countries deal with their own acknowledged histories of racial and social injustice.

In their article "A Comparison of the Serial Order Strategy and the Associative Cue Strategy for Decision Making in Wayfinding Tasks," Otmar Bock and Steliana Borisova assess how cue strategies are used to decide which direction to take at intersections. They find that based on their research design that a serial order strategy was more efficient than the associative cue strategy, though this may depend on task demand. Based on their results, they call for additional research that will allow control of task demand. The implications for the design of interior and outdoor wayfinding systems for pedestrian, as well as motorized wayfinding are significant, as the elevated importance of task demand will have crucial implications.

The article by Ming Tang and Adekunle Adebisi, "Using Eye-Tracking for Traffic Control Signage Design at Highway Work Zone," describes their development and testing of an innovative application of dynamic eye-tracking technology in conjunction with screen-based video and a driving simulator. The application was tested in an evaluation of the design of the traffic control devices (TCD) used with highway construction and repairs. Ultimately, they put forward the utilization of data for "total fixation time" and "time to first fixation" as metrics for TCD design, and effectively established a baseline against which other approaches might be used to assess the effectiveness of TCDs and other highway safety signage systems.

Given its focus, it is especially appropriate that this issue of the *Interdisciplinary Journal of Signage and Wayfinding* also includes Craig Berger's review of Mark Polger's recent book, *Library Signage and Wayfinding Design: Communicating Effectively with Your Users.* Berger notes the importance of library signage and wayfinding, and applauds the books articulation of best practices. Certainly, librarians have long been experts in effectively directing both new and long-time users to very specific locations for the materials they are seeking. All of us in academia have likely experienced a wide range of libraries over the course of our lifetimes and can appreciate the benefits of a well-designed one. Arguably, the best characteristic of a well-designed library is one where a user can intuitively find the materials they seek. As Berger notes, for library and other planners and designers the recommendations from best practices are important. That insight can be equally applied to all the articles in this issue of *IJSW*.

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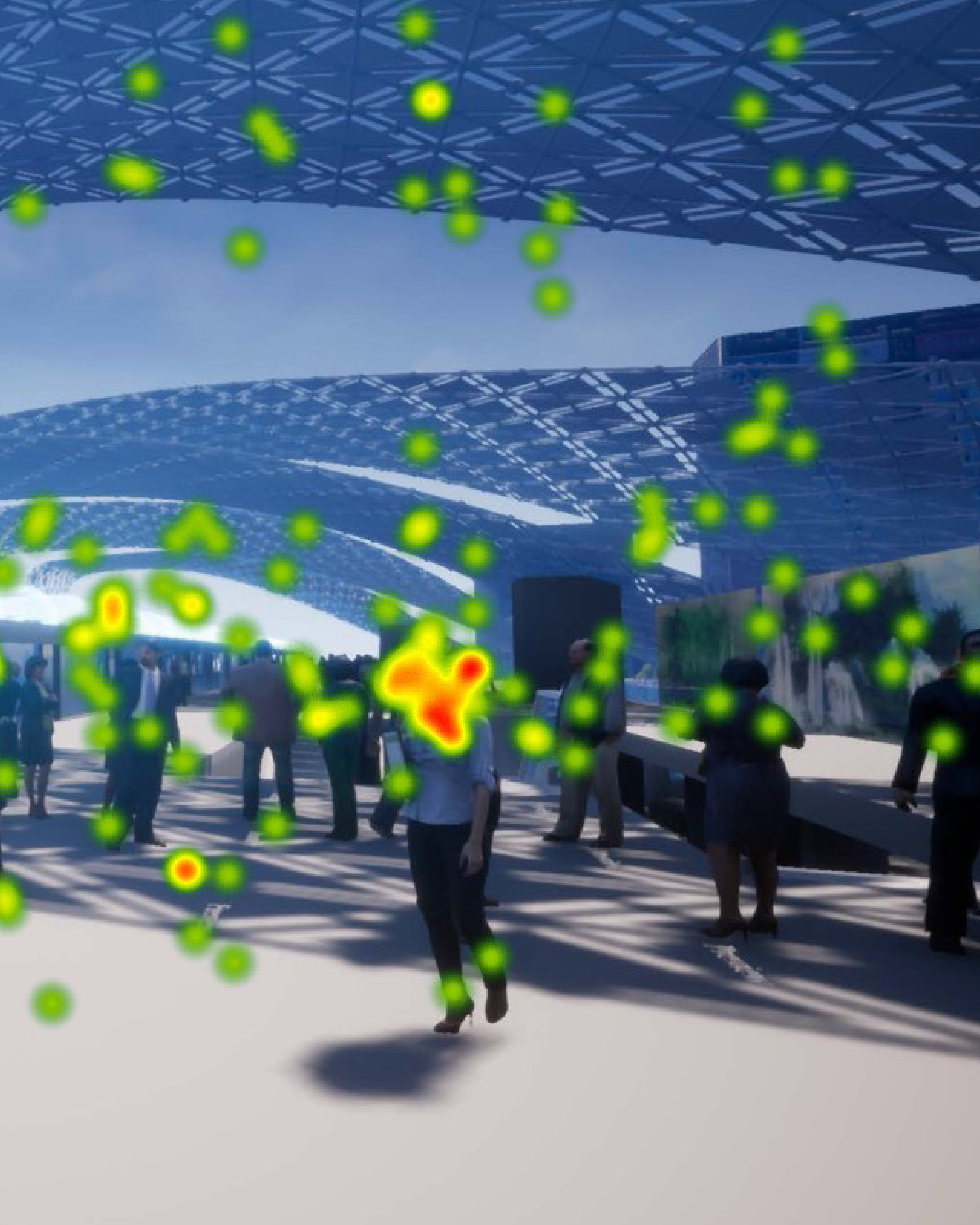

A Comparison of the Serial Order Strategy and the Associative Cue Strategy for Decision Making in Wayfinding Tasks

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Abstract /

It has been proposed that in wayfinding, humans can use multiple strategies to decide which direction to take at intersections. One of them is the serial order strategy, where travelers memorize the order in which those directions should be taken. Another is the associative cue strategy, where travelers memorize associations between conspicuous objects along the way, and the directions to take. We designed tasks in which participants had to base their decisions on the serial order strategy (task S), on the associative cue strategy (task A), or were free to use either of those strategies (task SA). We found that performance errors decreased with practice in all three tasks but were higher in A than in S and SA. We conclude that in our study, the serial order strategy was more efficient than the paired associate strategy. We further conclude that this outcome is likely to depend on task demand, which calls for additional research that varies not only the available strategies, but also the task demand.

Keywords /

wayfinding; navigation; route knowledge; spatial cognition; spatial learning

INTRODUCTION

Finding our way through a city or building is a formidable cognitive skill. It includes the integration of spatial information from different sensory modalities, the maintenance of spatial representations in multiple reference frames, decision making, action planning, movement execution and executive control (Wolbers & Hegarty, 2010). These processes can be deployed in a flexible fashion, depending on the environmental layout, the purpose of the way-finding task, available information, prior knowledge and individual preferences (Ekstrom et al., 2018; Hölscher et al., 2009; Wiener et al., 2009).

The present work deals with one specific component of wayfinding, namely, with decision-making at intersections. It has been proposed in the past that humans can use a range of strategies to determine which way to proceed at intersections. With the *serial order strategy*, they recall a series of directions to take (Tlauka and Wilson, 1994; Iglói et al., 2009), such as "turn right at the first intersection, then left at the next." With the *associative cue strategy*, they recall the directions associated with distinctive objects along the way (Tlauka & Wilson, 1994; Waller & Lippa, 2007), such as "turn right at the gas station, then left at the cathedral"; this strategy is a form of paired associate learning (Arndt, 2012). With the *beacon strategy*, they chose directions which incrementally reduce their distance to a widely visible distinctive object (Waller and Lippa, 2007), such as "walk towards the TV tower, the destination is next to it." With the *relative location strategy*, they incrementally reduce their distance to a point defined by several widely visible objects (Morris, 1984; Jacobs et al., 1997), such as "walk towards a point midway between the TV tower and the cathedral." Lastly, with the *cognitive map strategy*, they decide on the direction to take by referring to an internal representation of the environment (Tolman, 1948; O'Keefe and Nadel, 1978), such as "to get from Buckingham Palace to the Cavalry Museum, walk north-east down The Mall, and then turn south into Whitehall." Travelers can switch between strategies on repeated trips (Iaria et al., 2003), and even in the course of a single trip (Hamburger, 2020, Wolbers & Hegarty, 2010). Indeed, the ability to flexibly switch between strategies was found to be a characteristic of good wayfinders (Liben et al., 2010).

To investigate human wayfinding skills, a number of studies asked participants to follow a prescribed route through a virtual maze with four-way intersections. The maze was displayed on a computer monitor in first-person perspective, and participants had to indicate at each intersection which way to proceed. Participants learned the required directions even if all corridors and intersections of the maze looked exactly the same, but they learned them more efficiently if a distinctive visual cue was provided near each intersection (Jansen-Osmann, 2002; Jansen-Osmann & Fuchs, 2006; Waller & Lippa, 2007). These findings suggest that directions can be learned by the serial order strategy, but they are learned more efficiently when both the serial order strategy and the associative cue strategy is available.

In contrast to the above work, other studies found that learning of a prescribed route does not benefit from visual cues near intersections (Lingwood et al., 2015; Tlauka and Wilson, 1994). One possible interpretation for this discrepancy is that visual cues are only beneficial if the 'task demand' is sufficiently high (Hamburger, 2020). This is a conceivable hypothesis if the concept of 'task demand' is not strictly limited to the number of intersections along the route, since available studies reveal no relationship between the number of intersections and the effectiveness of visual cues, as performance improved in the presence of visual cues in studies where the route had eight, nine or twenty intersections (Jansen-Osmann, 2002; Jansen-Osmann & Fuchs, 2006; Waller & Lippa, 2007), but not in studies where the route had six or fifteen intersections (Lingwood et al., 2015; Tlauka and Wilson, 1994). The above discrepancy might therefore be related not only to the number of intersections, but also to other aspects of task demand, such as the cognitive load imposed by concurrent distracting activities (Tlauka & Wilson, 1994), or the familiarity and discriminability of the visual cues.

The above research compared decision making at intersections when only the serial order strategy could be used, or when both the serial order strategy and the associative cue strategy could be used. Decision making has not yet been investigated when only the associative cue strategy could be used. To explore the latter, it would be necessary to disambiguate associative cues from serial order by presenting the same cue-direction associations in a different order on successive trials. On the first trial, for example, participants may encounter a gas station at the first intersection and have to turn left, and they may encounter a school building on the second intersection and have to turn right. On the second trial, they may encounter the school building rather than the gas station at the first intersection and therefore have to turn right rather than left, and they may encounter the gas station at the fifth intersection and therefore have to turn left there. Thus, the direction to proceed would depend only on the identity of the visual cue, not on the serial position of that cue. Such a dissociation between cue identity and cue serial order does not exist in everyday life, but it is a necessary experimental manipulation for evaluating the associative cue strategy separately from the serial order strategy.

In two earlier studies, participants learned a prescribed route while both the serial order strategy and the associative cue strategy was available, and they subsequently were asked to recall the direction associated with each visual cue. Participants recalled the directions with comparable accuracy when the visual cues were presented in the previously encountered order, and when they were presented in a reshuffled order (Hamburger & Röser, 2014; Karimpur et al., 2016). This indicates that participants had learned the cue-direction associations; however, it leaves open whether they learned them incidentally (Brügger et al., 2019; Münzer et al., 2006), or rather used them to decide which direction to proceed across intersections. It also leaves open whether the associative cue strategy is more or less efficient than the serial order strategy. The present study was designed as a first step towards closing this gap in our knowledge. We describe a method for the study of decision making by either strategy, either alone or in combination, and we present a first set of results that compare the performance of the strategies, either alone or in combination.

Human wayfinding skills have been previously investigated in actual buildings and cities, as well as in virtual environments through which participants proceed by walking on a treadmill, by stepping in place, or by operating keys or joysticks. The disadvantage of virtual environments are their lower fidelity: fields of view are smaller, screen resolution limited, and vestibular, proprioceptive and outflow signals about one's movement are degraded or missing. The advantage of virtual environments is their better control of confounding variables such as light and sounds, pedestrian and vehicular traffic, weather conditions, and other subtle details that might serve as orientation cues. The confounders can be placed under the experimenter's full control and precisely replicated across trials and participants (Coutrot et al., 2019; Ruddle et al., 1997).

Human spatial orientation and wayfinding has been found to be more accurate in real-world rather than in virtual environments (Grant & Magee, 1998; Richardson et al., 1999; Waller et al., 1998), although the differences were reduced with increasing difficulty of the wayfinding task (Coutrot et al., 2019), and were eliminated after prolonged exposure to the virtual environment (Waller et al., 1998).

An intriguingly simple virtual environment has been implemented by Cohen and Schuepfer (1980). Participants saw a series of slides, each showing an intersection, and had to indicate for each slide in which direction the route continued. If their response was correct, the next slide was shown, otherwise they had to try again. The authors' main findings were later replicated by a study where seated participants were passively transported through a virtual environment from one intersection to the next (Jansen-Osmann & Wiedenbauer, 2004). The similarity of findings suggests that the optic flow generated by passive transport through the environment may not play a major role for route learning. This might seem surprising at a first glance, given that optic flow is a powerful cue for the monitoring of one's own movement (Wolbers et al., 2007); however, such monitoring may not be essential if the task is to choose the correct direction at intersections. Since this research is about the choice of directions at intersections, it was decided to adopt the Cohen and Schuepfer (1980) paradigm. To enhance task realism, still slides were not presented but instead a simulation of the optic flow that would occur during the approach to an intersection was used.

METHODS

Participants

To determine the number of participants needed, we registered data from six persons per group, and used their scores to calculate Cohen's f for the effect of primary interest, which is the effect of the factor task on the number of errors in the learning phase in a 3(tasks) x 2(trials) analysis of variance. We thus yielded $f = 0.5324$. Entering $\alpha = 0.05$, $1\text{-}ß = 0.81$, correlation among repetitions = 0.5 and $f = 0.5324$ into G*Power (Faul et al., 2007) yielded a total sample size of 30. We therefore decided to test a total of 36 participants.

Participants were recruited by word of mouth and by written postings. We did not pre-select them with regard to gender, age, profession or social status. They were 35 to 49 years old (mean ±SD: 40.25 ±3.95), and 21 were female. Thirty-three held a university degree, and the remaining three a secondary school degree. All were healthy by self-report, and exhibited no overt sensorimotor or cognitive deficits. All participants signed an Informed Consent Statement before testing began. The research protocol was pre-approved by the Commission for Bioethics of the Institute of Neurobiology of the Bulgarian Academy of Sciences (1–41, 12. July 2019), and was performed in accordance with the ethical standards as laid down in the Declaration of Helsinki.

Participants were evaluated during a single visit to our laboratory, which took about 30 minutes. They engaged first in a learning phase that consisted of three trials, and directly thereafter in a test phase that consisted of three different tests.

Learning Phase - Materials

Participants were seated in front of a 15.6-inch computer monitor, at a viewing distance of about 50 cm. If they wore eyeglasses in everyday life, they continued to wear them during testing. The monitor displayed the color image of a four-way intersection, which participants viewed in first person perspective (Fig. 1). The intersection was created with Unreal Engine® 4.16.2 (Epic Games), a software for the design of virtual environments.

Each experimental trial consisted of a sequence of nine intersections, all looking exactly the same except for a photograph that served as a visual cue. Thus, walls, floors, and ceilings always had the same structure, size, shape, color, and brightness, the photograph always hung from the ceiling at the same location, and it always had the same size and shape. However, a different photograph was displayed at each of the nine intersections. All photographs showed a distinctive building and were photo-edited for mirror symmetry (left portion of Fig. 1), to ensure that they served as visual cues because of their characteristic architectural features, and not because of their asymmetry. This was to avoid, for example, that a turret on the left but not right side of a building signaled participants to turn left. The displayed buildings types ranged from modern to medieval, were prototypical rather than unique, and none of them could be considered as "famous." As such, semantic influence (Hamburger & Röser, 2014) should not influence the study results.

The nine intersections of a trial were presented as PowerPoint® slides. We used the 'animation' function of PowerPoint® to simulate optic flow during the approach to an intersection: after its appearance, each intersection expanded radially by 50% within one second. Once a decision was made to turn left or right at a given intersection (see below), the next intersection appeared and expanded, etc. Thus, we simulated optic flow during the approach to the intersections, but not during the exit from the intersections.

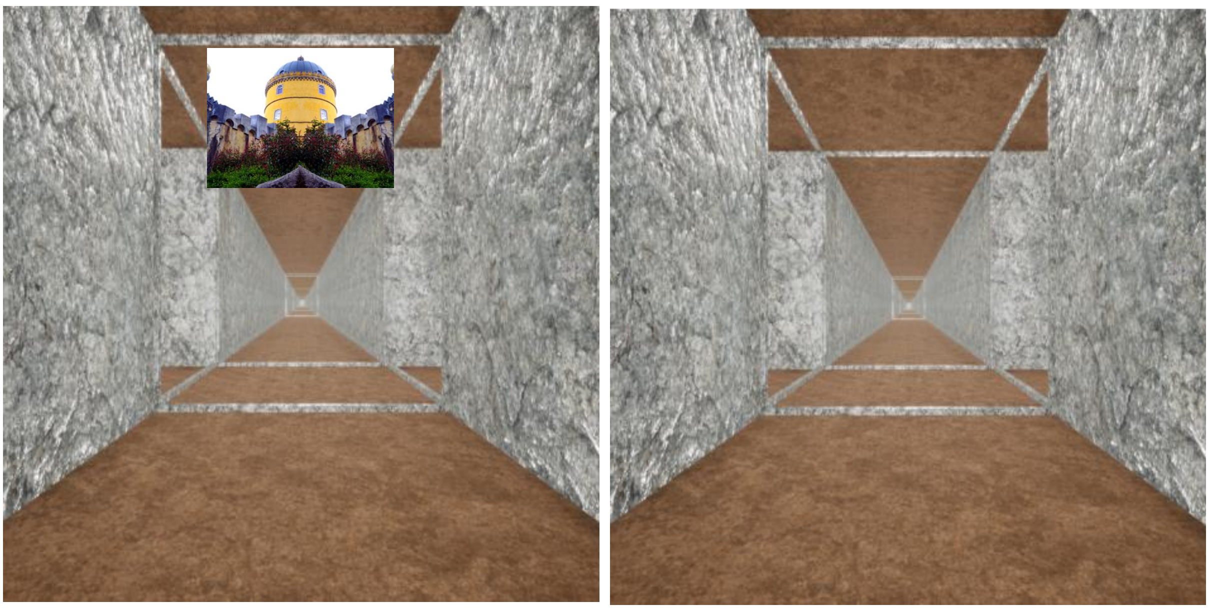

Figure 1 /

Example of an Intersection in the Learning Phase (Left) and in the Serial Order Test (Right)

Note / Participants saw the intersection in first person perspective, as shown. All nine intersections looked the same except for the visual cues, which showed a different distinctive building at each intersection. Visual cues were displayed during the learning phase (left), but not during the serial order test (right).

the approach to the intersections, but not during the exit from the intersections.

Learning Phase - Procedures

The first trial of the learning phase was experimenter-guided. At each intersection, the experimenter said "here you must turn left" or "here you must turn right", and then presented the next slide. The second and third trials of the learning phase were self-guided. At each intersection, participants decided on their own which way to turn by saying "leftwards" or "rightwards." If the decision was correct, the experimenter said "o.k." or "correct." If the decision was wrong, the experimenter said "no, the correct direction is rightwards" or "no, the correct direction is leftwards." In either case, the experimenter then triggered the presentation of the next slide.

Each trial was concluded by a virtual reward: after the ninth intersection participants were shown yet another intersection which displayed a golden trophy in place of a visual cue. They were then told the next trial would now begin or, after the third trial, that the test phase would now begin.

The exact instructions given at the onset of the learning phase were "I will walk with you through a maze with four-way intersections. At each intersection, you will have to turn left or right. In a first walk, I will tell you at each intersection which way to turn. In a second and third walk, you will tell me which way to turn, and I will correct you if necessary." This was followed by a last sentence, which differed between tasks (see below). Note that we instructed participants to "walk" even though they did not actually walk as they were seated. We did so to enhance task realism by facilitating the participants' mental imagery of walking through a maze. Throughout this article we use the term "walk" when directly describing our instructions, but we use the term "trial" otherwise.

Learning Phase - Tasks

Participants were assigned alternately to three tasks. In task SA (Serial order strategy and Associative cue strategy), visual cues were presented in the same order on each trial and each visual cue was associated with the same direction in all trials. For example, the tower depicted in Fig. 1 was displayed at the fifth intersection on all trials, and participants had to turn right at that intersection on all trials. To respond correctly, therefore, participants could use the serial order strategy ("turn right at the fifth intersection"), and/or they could use the associative cue strategy ("turn right at the yellow tower"). The last sentence of instructions for this task was "You will see the photo of a different building at each intersection, which will help you to find the way". The serial order of required directions for task SA is illustrated in Fig. 2.

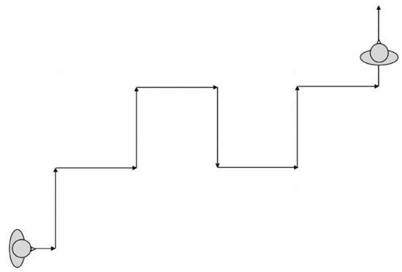

Figure 2 /

Serial Order of Required Directions for Task SA, Task S, and Trial 1 of Task A.

Note / Human body schemes illustrate the participants' orientation before entering the first intersection (bottom left), and after leaving the ninth intersection (top right). Note that participants were not shown this figure, and that they did not physically walk along the displayed route; rather they were seated, saw a sequence of intersections, and only imagined walking across intersections.

In task S (Serial order strategy), visual cues were presented in a different order on each trial but the order of required directions remained fixed across trials. For example, the tower in Fig. 1 was displayed at the fifth intersection on trial 1, and participants had to turn right; another visual cue was displayed at the fifth intersection of trial 2, and yet another at the fifth intersection of trial 3, but participants still had to turn right at the fifth intersection. To respond correctly, therefore, participants had to use the serial order strategy ("turn right at the fifth intersection"). Visual cues were non-informative, and were only displayed to keep visual stimulation comparable across tasks. The serial order of required directions for task S was the same as for task SA. The last sentence of instructions for task S was "You will see the photo of a different building at each intersection, but the photos will not help you to find the way."

In task A (Associative cue strategy), visual cues were presented in a different order on each trial but the association of visual cues with required directions remained fixed across trials. For example, the tower in Fig. 1 was displayed at the fifth intersection on trial 1, at the seventh intersection on trial 2, and at the second intersection on trial 3, and participants had to turn right at the tower irrespective of its serial order. To respond correctly, therefore, participants had to use the associative cue strategy ("turn right at the yellow tower"). The last sentence of instructions for this task was "You will see the photo of a different building at each intersection, and these photos determine which way to turn; if the same photo is encountered on one walk earlier or later than on another walk, it still requires the same turn as before."

Performance in the learning phase was quantified as the number of errors committed on each trial, which is identical to the number of experimenter-provided corrections on each trial. Random performance on the nine two-choice intersections would therefore yield an error score of 4.5.

Test Phase

The *serial order test* was similar to a learning phase trial, except that visual cues were absent, as shown on the right part of Fig. 1. Thus, to respond correctly, participants had to rely on serial order knowledge. Instructions were "In the next test, you walk through the maze once again, but there will be no photos. At each intersection, tell me again which way to turn." No feedback about response correctness was provided. Performance was quantified as the number of errors committed. It was quantified following task SA and task S, but not following task A, since the order of turns varied from trial to trial in the latter task.

In the *cue association test*, all nine visual cues were presented concurrently on the screen. Participants were instructed "In the next test, I will show you a slide with buildings. I will point at each building, tell me the direction related to it, left or right." The experimenter then pointed at each visual cue, in an order that differed from the order(s) in the learning phase. No feedback about response correctness was provided. Performance was quantified as the number of errors committed. It was quantified following task SA and task A, but not following task S, since the cue-direction association varied from trial to trial in the latter task.

In the *direction test*, participants were shown a schematic top view of a human body (shoulders, head, and nose), facing a trophy like the one displayed after the ninth intersection. They were instructed "I will now test your sense of direction. Assume this [experimenter points at the body scheme] is you at the end of the walk. You stand there and look at the trophy. In which direction is the start of the maze? Draw an arrow in that direction." No feedback about response correctness was provided. Performance was quantified as response angle, with 0° representing an arrow that points exactly to the left, and -90° representing an arrow that points exactly forwards. In this reference frame, the true direction to the start of the maze was +31° (broken line in Fig. 4). This test assessed participants' survey knowledge, that is, their knowledge about the spatial layout of the imagined route across nine intersections. We implemented this particular test rather than the judgment of relative directions test (JRD test: Rieser, 1989) since it is more sensitive to small gains in spatial knowledge during route learning (Zhang et al., 2014), and we indeed expected only small gains in our participants' knowledge about the spatial layout of their route. Performance was quantified following task SA and task S, but not following task A, since the spatial layout of the imagined route varied from trial to trial in the latter task.

Data Analysis

Error scores from the learning phase were submitted to an analysis of variance (ANOVA) with the between-factor Task (SA, S, A), and with repeated measures on the factor Trial (2, 3). Levene's tests confirmed that the ANOVA met the prerequisite of homoscedasticity ($p > 0.05$). We checked for an influence of the participants' gender by adding the factor "Gender" to the ANOVA. However, the main effect of Gender and its interaction(s) were non-significant, and the other effects remained virtually unchanged. We therefore report only the outcome without the factor "Gender".

Error scores from the serial order test and from the cue association test were tested against chance (i.e., 4.5 errors) by t-tests of one mean. Response angles from the direction test were analyzed with the circular statistics package CircStats of the software R. The mean angle of responses was calculated with the function circ.mean, and the dispersion of angles with the function circ.disp (dispersion R is a measure of variability for circular data, where R = 0 indicates that angles are uniformly distributed within the full 360° range, and R = 1 indicates that all angles are identical). The distribution of response angles was tested against uniformity with the function rao.spacing (i.e. Rao's Spacing Test, Rao, 1976), and confidence intervals were calculated with the function vm.bootstrap.ci.

RESULTS

Task * Trial ANOVA of the learning phase yielded significance for Task ($F(2,33) = 5.72$; $p = 0.007$; $\eta^2 = 0.26$) and Trial ($F(1,33) = 12.6846$; $p = 0.002$; $\eta^2 = 0.26$), but not for the interaction term ($F(2,33) = 0.35$; $p = 0.710$; $\eta^2 = 0.02$). Post-hoc decomposition by Tukey's HSD tests revealed no significant difference between tasks SA and S ($p = 0.989$), but significant differences emerged between SA and A ($p = 0.020$), as well as between S and A ($p = 0.014$). As Fig. 3 shows, wayfinding errors were smaller in SA and S compared to A, and they were smaller on trial 3 compared to trial 2. Although performance of task A on trial 3 was quite poor, it was better than chance (t-test against a fixed value of 4.5 errors: $t(11) = 3.39$; $p = 0.007$; Cohen's $d = 0.70$).

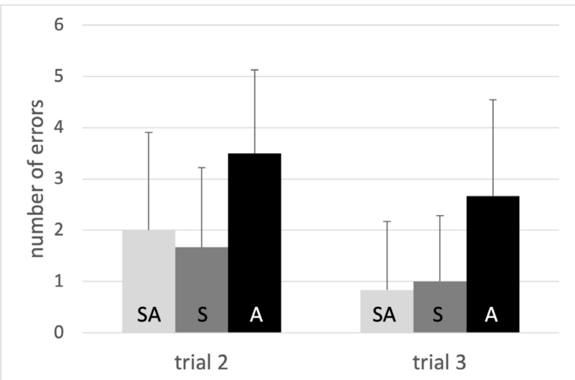

Figure 3 /

Number of Wayfinding Errors on the two Self-Guided Trials of the Learning Phase

Note / Bars show across participant means and whiskers show between-participant standard deviations. The three tasks are coded by different bar shadings.

The mean standard deviation of error scores in the serial order test was 1.75 ±2.01 following task SA, and 0.92 ±1.51 following task S. The corresponding outcome in the cue association test was 2.33 ±1.56 following task SA, and 2.50 ±2.15 following task A. All four outcomes were significantly lower than the chance score of 4.5 ($t(11) = 4.75$; $p < 0.001$, $t(11) = 8.25$; $p < 0.001$, $t(11) = 4.82$; $p < 0.001$, and $t(11) = 3.22$; $p = 0.008$, respectively).

The outcome of the direction test is illustrated in Fig. 4. Response angles were scattered throughout much of the full 360° range, with more responses in the left rather than the right hemispace. Accordingly, Rao's test yielded a significant deviation from a uniform distribution (U (N = 24) = 162.82; $p < 0.05$). The mean angle was +13.19° (cf. solid arrow in Fig. 4), and the angular dispersion was R = 0.54. The 95% confidence interval for the mean ranged from -14.15° to +43.66°; it therefore included both the true direction towards the start of the imagined maze (+31°) and the direction due left (0°). The difference between responses following task SA and those following task S was not significant ($t(22) = 0.41$; $p = 0.688$).

DISCUSSION

Several previous studies evaluated decision making in wayfinding tasks where only the serial order strategy can be used, or when both the serial order strategy and the associative cue strategy can be used. The present study is the first to also evaluate decision making when only the associative cue strategy can be used. To this end, we modified an available experimental paradigm (Cohen and Schuepfer, 1980; Wiener et al., 2012) which isolates decision-making at intersections from other cognitive processes that normally take place during wayfinding (see Introduction).

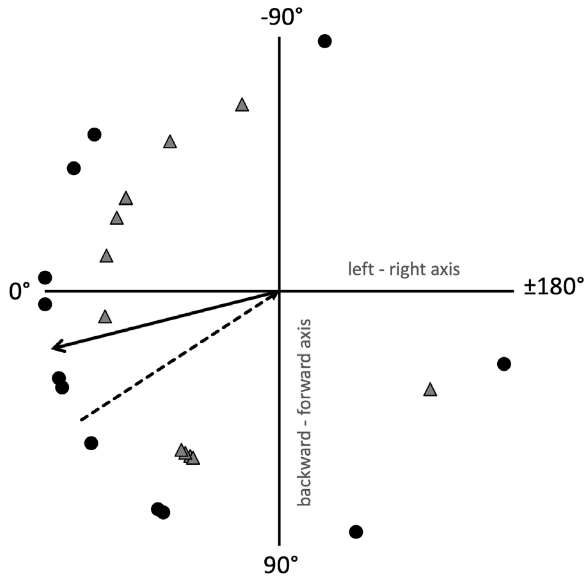

Figure 4

Distribution of Response Angles in the Direction Test

Note / 0° corresponds to responses directed towards the participants' left shoulder, -90° to responses directed towards the participants' nose, etc. The broken line indicates the correct direction towards the start of the imagined maze, and the solid arrow indicates participants' mean response direction, 13.19°. Each symbol represents the response of one person. For clarity, responses following task SA are plotted along a larger perimeter (black circles) than those following task S (grey triangles).

It was found that the number of errors decreased significantly from trial 2 to trial 3 of the learning phase, and that it was comparable in task SA and in task S. Thus, performance was not appreciably better when both the serial order strategy and the associative cue strategy were available, compared to when only the serial order strategy was available. This outcome is in accordance with some (Lingwood et al., 2015; Tlauka & Wilson, 1994), but not with other earlier studies (Jansen-Osmann, 2002; Jansen-Osmann & Fuchs, 2006; Waller & Lippa, 2007). As pointed out in the Introduction section, the discrepancy between studies might well be related to different task demands (Hamburger, 2020), in that availability of the associative cue strategy only becomes beneficial for performance if the task is demanding enough.

Further, it was found that the number of errors was significantly higher in task A than in task SA and in task S. Thus, performance was poorer when only the associative cue strategy was available, compared to when only the serial order strategy was available or when both strategies were available. Again, this apparent disadvantage of the associative cue strategy might well depend on task demand; the associative cue strategy might yield better rather than poorer performance than the serial order strategy when the task is demanding enough (Hamburger, 2020).

In task A, visual cues were presented in a different order on each trial. This was necessary to deconfound route learning by the associative cue strategy from route learning by the serial order strategy, but it deviates from our experience in everyday life, which possibly had a negative impact on the participants' performance on task A. A related argument can be made regarding task S. There, all intersections looked exactly alike, which served to deconfound the serial order strategy from the associative cue strategy, but it again deviates from our experience in everyday life and thus might impact performance on task S. One possible approach for scrutinizing such an impact in future research would be to compare performance on task A to that on a control task where participants also form associations between nine stimulus items and two response items, but those associations have no everyday-life connotation. Similarly, one could compare performance on task S to that on a control task where participants also learn a sequence of nine binary items, but that sequence has no everyday-life connotation.

In sum, the present study introduced a new methodological approach, and presented a first set of data collected with this approach. Like most earlier studies, however, it did not explore the role of task demand. To overcome this limitation, our current research expands the same methodological approach by varying the task demand in multiple ways: we vary the number of intersections, the number of potential directions at each intersection, the presence or absence of concurrent distracting tasks, as well as the familiarity (Hamburger & Röser, 2014), ambiguity (Strickrodt et al., 2015), and salience (Dong et al., 2020) of visual cues.

The spatial knowledge that participants acquired during the learning phase was assessed during the subsequent test phase. Following task SA, performance on the serial order test and on the cue association test was significantly better than chance, which confirms the outcome of earlier work (Cohen & Schuepfer, 1980; Hamburger & Röser, 2014; Jansen-Osmann & Wiedenbauer, 2004; Karimpur et al., 2016; O'Malley et al., 2018; Wang et al., 2014). Following task S, performance on the serial order test was significantly better than chance, and following task A, performance on the cue association test was significantly better than chance. Thus, all participants had acquired substantial spatial knowledge of the types that were available to them.

The direction test was included to find out whether participants acquired the spatial layout of an imagined route in tasks SA and S, i.e., in those tasks where that route would be consistent across trials (Fig. 2). We found that responses angles were not randomly distributed throughout the full 360° range, but rather varied within a wide range; the confidence interval included the true direction towards the start of the maze. It therefore appears that participants had acquired a vague knowledge about the spatial layout of the maze. This is not trivial, since participants did not physically walk along a route, but rather were seated and only *imagined* walking along that route.

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Data Availability Statement: Stimulus materials and raw data are available from the corresponding author on reasonable request

Authors' Contributions: Otmar Bock conceived the experiment, performed statistical analyses, and wrote the first draft of the manu script. Steliana Borisova collected the data, performed preliminary analyses, and critically commented on the manuscript.

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Landmarks on Mobile Maps: Roles of Visual Variables in the Acquisition of Spatial Knowledge

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Abstract /

This study presents the evaluation of a new design of mobile maps to overcome the limit of the small screen by visualizing landmarks which are normally invisible as located beyond the displayed map extent. The visualization of distant landmarks adapts a specific cartographic visual variable: size, fuzziness, or transparency, respectively, to conceptualize distances in three ranges: nearby, intermediate, and far. To evaluate the effectiveness of each design on acquisition of spatial knowledge, this study carries out an online experiment and then a field experiment in the actual environment. In the online experiment, participants see the static default screen of the mobile maps with landmarks. In the field experiment, participants can interact with the mobile map App which allows them to tap, pan, or zoom the map. Results show that both online and field experiments yield similar findings, although the results from field experiment with allowed interaction are better. In general, the visualization of distant landmarks contributes to the spatial learning. Individual visual variables such as fuzziness and transparency, however, facilitate the acquisition of spatial knowledge better than size.

Keywords /

mobile map; distant landmarks; visual variables, spatial knowledge; orientation

INTRODUCTION

Using maps is an essential means of acquiring spatial knowledge for wayfinding. With the increasing usage of mobile devices in one's daily lives, mobile maps have become a major source, compared to traditional paper maps. Many researchers suggest that the small screen size on mobile devices limits the acquisition of spatial knowledge. In particular, user's acquired spatial knowledge and accuracy from mobile maps decrease as screen size shrinks (Dillemuth, 2009). In the specific case of using mobile devices for navigation, the passive following mode together with mobile maps lead to spatial disorientation (Gardony et al., 2013; Ishikawa et al., 2008). Although many factors lead to the degradation of acquired spatial knowledge and orientation, this study focuses on the small map display and evaluates a new design of visualizing spatial information on the small screen to facilitate the acquisition of spatial knowledge.

Small screen size limits the amount of spatial information that can be displayed at once. If a method can imply information of locations beyond the mapped extent on the screen, one can acquire more spatial knowledge of the surroundings. Researchers in the field of human-computer interaction suggest possible ways to visualize distance to locations beyond the mapped extent. For example, methods such as Halo approach (Baudisch & Rosenholtz, 2003) and Wedge approach (Gustafson et al., 2008) can convey distance to locations at the edge of the mobile screen using the geometry of partial arc or triangle, respectively. Users need to mentally complete the arc or triangle to imply the distant location. These methods overcome the limit of small screen size by visualizing distance to a location beyond the displaced map extent. The identity of the visualized distant location, however, remains generic in these methods. Building on previous approaches, we introduce the visualization of landmarks at distant locations. The knowledge of landmarks, which refer to visually salient objects due to their characteristics of colors, sign, and visibility (Sorrows & Hirtle, 1999), can serve as nodes to organize spatial knowledge, which is important to developing mental representations (Siegel & White, 1975) and wayfinding success (Couclelis et al., 1987). People not only memorize landmarks easily but also integrate them with path information when they are building mental representations. Locations in the environment and paths of connecting them work as anchors and vectors of developing spatial knowledge (Allen et al., 2014; Mittelstaedt & Mittelstaedt, 1980). Therefore, providing information of landmarks, especially those beyond the mapped extent, may effectively enhance the acquisition of spatial knowledge of the larger surroundings. We term the landmarks located beyond the mapped extent *distant landmarks* in this study.

This new design starts with evaluating the effectiveness of visualized distant landmarks without the consideration of their distance (Li et al., 2014). After testifying the roles of landmark identity, the authors explore ways to visualize the distance to distant landmarks. As a way of symbolizing distance, which is metric information, the authors then select visual variables of cartography (MacEachren et al., 2012) suitable for representing distance (metric) information (Li, 2017). Theoretically, effective visual variables for visualizing distant landmarks are *size*, *fuzziness*, and *transparency*. However, the effectiveness of these visual variables on facilitating the acquisition of spatial knowledge is unknown, which motivates the design of this study.

This study creates three designs for visualizing distant landmarks, each of which adapts one of the three visual variables. This study investigates the effectiveness of selected visual variables to provide empirical evidence of the new design for enhancing acquiring spatial knowledge through mobile devices. Using the same design, this study first carries out an online experiment and then a field experiment in the actual environment. The difference is that participants in the online experiment can only see a static screenshot of the design, while participants in the field experiment can interact with the design by zooming, panning, and clicking on the mobile phone screen. On the one hand, the purpose is to investigate if the added interaction with the small screen can influence the acquisition of spatial knowledge. On the other hand, another purpose is to test the reliability of the online experiment, which might be a cost-efficient solution for evaluating future designs of distant landmarks.

DESIGN

The study adapts the conceptualization of distance carried out in a previous study (Li & Zhao, 2017). As a result, the representation of distance to landmarks is at the ordinal level. The three levels are nearby, intermediate, and far distant landmarks. Eleven were landmarks selected from a survey of residents who were familiar with the environment. Based on their distance to default user location, distance within 2,000m from the user's location is considered nearby; distance between 2,000m and 3,000m is considered intermediate, and distance over 3000m is considered far. This design results in three distant landmarks and eight local landmarks on the default map, in addition to the indicator of user's location. Each distant landmark is bounded in a bold square to imply the nature of being distant. When a landmark does not have a bold square, it indicates a local landmark at its actual location on map. Using the visual variable *size*, 90 x 90 pixels icons are for nearby distant or local locations, 60 x 60 pixels icons are for intermediate distant locations, and 30 x 30 pixels icons are for far distant locations, respectively. Using the visual variable *fuzziness*, icons in the intermediate group and in the far group are blurred by 3% and 6% respectively, both horizontally and vertically. Icons in the nearby and local categories are not blurred. Using the visual variable *transparency*, 75% and 50% opacity is applied respectively, to the icons for middle and far distant landmarks. Icons in the nearby and local categories retain 100% opacity. All icons are created using the tool Inkscape (inkscape.org) with open-source elements from Flaticon (flaticon.com). Figure 1 illustrates the concept of visualizing distant landmarks and three scenarios of using a specific visual variable transparency and Google Maps as the base map.

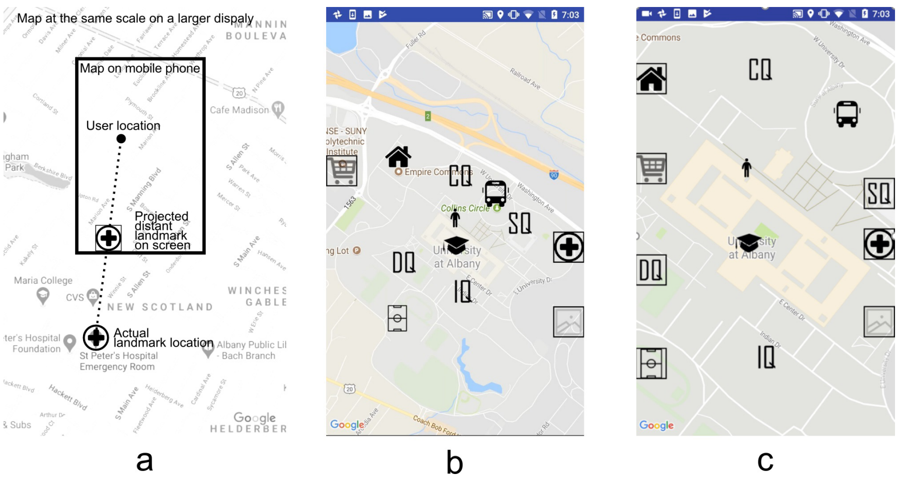

Figure 1 /

Illustration of visualizing a distant landmark on mobile map and screenshot of the designed mobile map with the visual variable *transparency*. Based on the distance, a distant landmark is projected to the edge of mobile map with a bounding square (a). On the default map scale, there are three distant landmarks representing three different level of distance (b). When the map scale increases to include a smaller area, many local landmarks become distant landmarks, which are projected at the edge of the screen (c).

ONLINE EXPERIMENT

To evaluate the acquisition of spatial knowledge using a distant landmark design, this study carried out an online experiment first. The online experiment only used a static screenshot of the default map (e.g., Figure 1.b) of each scenario on the platform of Amazon Mechanical Turk (MTurk).

Participants were from all over the world, which represented a very diverse group that could shed light on the effectiveness of designs in each scenario. In total 164 individuals participated in the online experiment. Each participant could only sign up for one scenario. After excluding the incomplete and invalid responses (6 in the size scenario, 6 in the fuzziness group, and 1 in the transparency scenario), the final dataset consisted of complete responses from 50 participants in the size scenario, 51 participants in the fuzziness scenario, and 50 participants in the transparency scenario.

Methods

Each participant was required to answer 10 questions by typing their answers. This was done to avoid participant's random guessing as they needed to understand the design. If a participant's typed answer was not relevant to any of the icons or part of the App, the participant's answer was considered invalid and excluded from data analysis. Instructions oriented each participant that he or she was in an environment with a mobile device as shown on their screen. The human symbol at the center indicated his or her location in an unfamiliar environment (Figure 1.b). Other icons showed important landmarks in the surroundings. The instructions informed each participant of the name of each icon, the design of distant landmarks in each scenario, and how distant landmarks varied. To complete the tasks, participants in the size scenario needed to compare the relative sizes of icon to determine the relative distances symbolized in distant landmarks. Participants in the fuzziness scenario needed to compare the fuzziness of symbol to determine the relative distance in distant landmarks. Participants in the transparency scenario needed to compare the opacity of symbol to determine relative distances symbolized in distant landmarks.

The ten questions consisted of four categories: 1) one question to name the closest and one questions to name the furthest landmark; 2) two questions to name the closer landmark between two local landmarks (*e.g., Between the bus stop and classroom, which is the closer location to you?*); 3) three questions to name the closer landmark between one local and one distant landmark (e.g., *Between supermarket and classroom, which is the closer location to you?*); and 4) three questions to name the closer landmark between two distant landmarks (e.g., *Between supermarket and museum, which is the closer location to you?*).

The first category of questions verified if participants understood the icons in the design. The other questions investigated if participants could distinguish the relative distance information symbolized in local and distant landmarks. A correct answer to each question resulted in 10 points for calculating their performance (rate of correct points in each category of questions). The presentation of results was also based on the four categoies of tasks.

Results

Participants in all three groups took similar time (in seconds) to complete the experiment without significant differences among all three scenarios (Size: M = 293.86, SD = 240.51; Fuzziness: M = 284.22, SD = 453.75; Transparency: M = 252.04, SD = 337.35, p = .83). The performance in each category of tasks is the dependent variables in a one-way ANOVA using scenario (visual variable) as the independent variable. This statistical analysis is to compare the roles of each visual variable on acquiring distance knowledge from the designed interface. In the tasks of selecting the closest and furthest landmarks, participants needed to identify the shortest and longest distance from their location to a specific landmark. They had no difficulty finding the closest land-mark regardless of their scenarios. The performance of selecting the furthest landmark represented by the distant landmarks using a particular visual variable, however, was different.

In general, participants had very poor performance finding the most distant landmark in all three scenarios (Size: M = 0.22, SD = 0.42; Fuzziness: M = 0.61, SD = 0.49; Transparency: M = 0.44, SD = 0.50). However, size scenario results had the lowest accuracy. One-way ANOVA shows significant differences among three scenarios (F (2, 148) = 8.55, $p < .001$, partial η^2= .10). Post-hoc comparison using Tukey-HSD indicates that the participant's performance in size scenario is significantly lower than that in fuzziness scenario ($p < .001$). The difference between size and transparency is marginal (p = .055). This suggests that size is the least effective visual variable for representing distance to distant locations beyond the mapped area. Figure 2 shows the participants' performance in this category of tasks.

In the tasks of comparing distance between two local landmarks, participant's performance was similar (Figure 3). All participants in both size and transparency scenarios made no error (M = 1.00, SD = .00) while participants in the fuzziness scenario made very few errors (M = 0.94, SD = 0.24). All three types of visual variables show no different effects for Text Boxlocal landmarks.

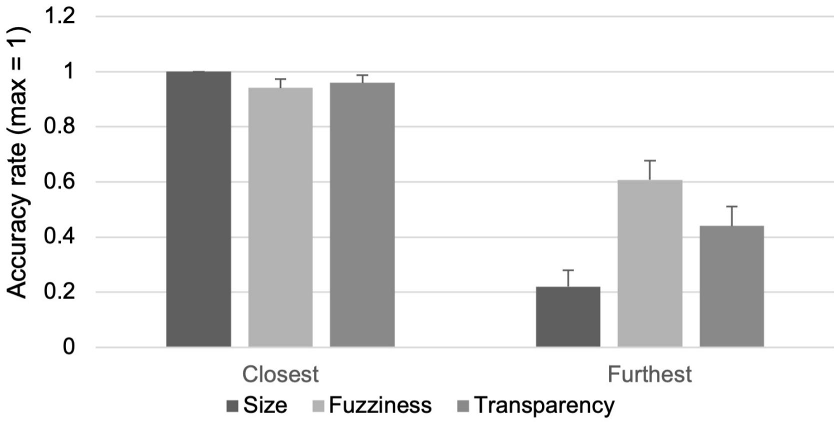

Figure 2 /

Participants' performance of selecting the closest and the furthest landmark in the online experiment.

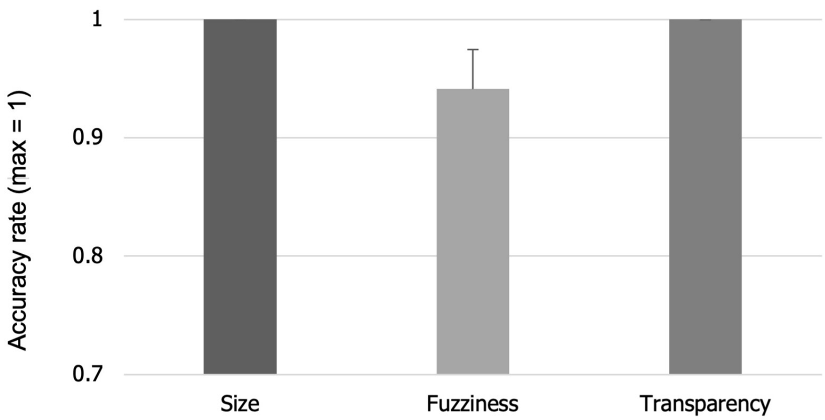

Figure 3 /

Participants' accuracy in the task of comparing two local landmarks.

In the tasks of comparing, one local landmark and one distant landmark, difference exists across scenarios (*F* (2, 148) = 3.90, *p* = .022, partial η^2= .05). Post hoc comparison using Tukey-HSD indicates that participant's performance in size scenario (*M* = 1.00, *SD* = .00) is not significantly different than that in fuzziness scenario (*M* = 0.97, *SD* = 0.16), but different from that in transparency scenario (*M* = 0.92, *SD* = 0.20), (*p* = .018). There is no difference in performance between the fuzziness and the transparency scenario. This is to imply that when both local landmark for a location on screen and distant landmark for a location off screen are involved, visual variable size seems more important. But considering its ineffectiveness for indicating the location of longest distance, it may not be the best option for actual use.

In the tasks of comparing two distant landmarks, significant difference exists among the three scenarios (*F* (2, 148) = 44.53, *p* < .001, partial *η2*= .38). As shown in Figure 5, post-hoc comparison using Tukey-HSD shows that participants in the fuzziness group have the lowest accuracy (*M* = 0.55, *SD* = 0.22) compared to that in the size scenario (*M* = 0.64, *SD* = 0.21 and transparency scenario (*M* = 0.91, *SD* = 0.17). Accuracy from both size and fuzziness scenarios does not show difference. When all involved landmarks are distant landmarks, visual transparency has the greatest effect while size has the least effect.

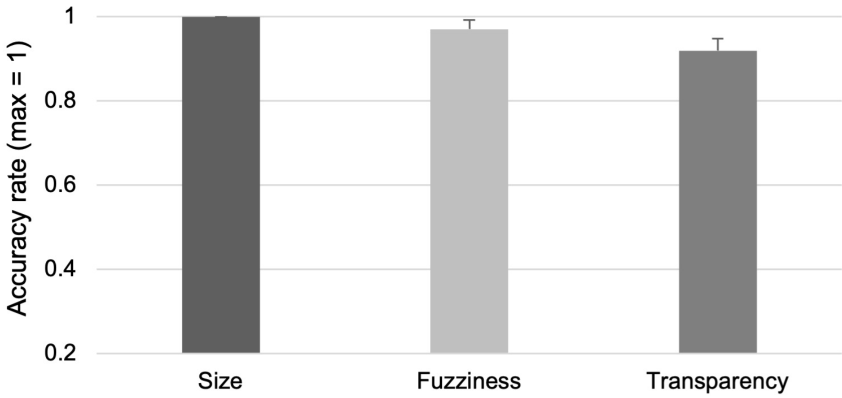

Figure 4 /

Participants' performance in tasks of comparing one local and one distant landmark.

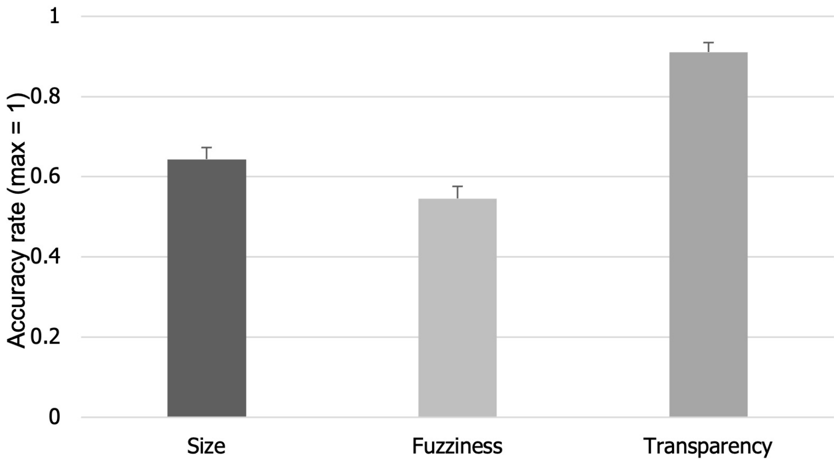

Figure 5 /

Participants' accuracy in comparing two distant landmarks.

Discussion

It is not surprising to find that almost all participants had no problem finding the closest landmark to them as well as comparing distances of local landmarks. These local landmarks simulated the existing mobile map display in everyone's daily experiences. The distance between a landmark symbol and user's symbol was intuitively visualized on screen. Participant's performance in both tasks also shows similar results indicating that they have little problem understanding local landmarks.

In the tasks of comparing one local landmark and one distant landmark, participant's performance was also good with slight differences among scenarios. Transparency seemed slightly more difficult for comparing landmarks in two qualitatively different categories (i.e., a local landmark vs. a distant landmark). One likely reason is that these participants still treat symbols of distant locations as indicating their positions on screen. Therefore, participants still employed the distance on the display as the only criterion for comparing distance instead of comparing the transparency or fuzziness of icons. When there was a distant landmark at the edge of screen whose position was closer to the center than the position of a local landmark, some participants may have assumed that the distant landmark's symbol indicated a closer location.

In summary, this experiment compared three visual variables in terms of their effects on acquiring distance knowledge based on visualized local and distant landmarks. Each visual variable had different effects on acquiring distance knowledge. In particular, the visual variable size does not seem to effectively help users identify the furthest location. The other two visual variables, fuzziness and transparency, had a stronger overall effect on understanding distances when comparing locations on screen and off screen.

There are two main reasons leading to these results. The first is that participants in each scenario may not have fully understood how the change of size, fuzziness, or transparency indicates relative distance off screen. Instead of choosing an icon of the smallest size or the most transparent for the furthest landmark, participants may have used the distance between the icon's positions on screen as their criterion. The second reason is related to the use of online environment. The static screenshot used of the online environment may have made it harder for participants to distinguish the change of size, fuzziness, and transparency in symbols, as it prohibits any interaction with the design. A follow-up question is whether a user can perform better in terms of acquiring spatial knowledge if he or she can interact with the map interface such as tap, pan, or zoom using their own mobile phone.

FIELD EXPERIMENT

To answer the follow-up question, this study carried out a field experiment in a real-world environment. As mentioned earlier, one objective is to investigate if the interaction with the map in a real environment would lead to different performance. Another objective is to verify if the online experiment, a cost-efficient setup, can lead to reliable results.

Methods

For this field experiment, the design of local and distant landmarks is implemented as a prototype. This prototype is installed on an Android phone (Google Nexus 5X) with a 5-inch screen. The interface of the mobile map is the same as that used in the online experiment. The only difference is the enabled interaction on the mobile phone, as a user can tap an icon to know its name, can pan the map to see other areas, or can zoom the map to a larger or smaller scale. When a user pans or zooms the map, the distance between each landmark and the user is recalculated and visualized on the map. As Figure 1b and 1c show, when a user zooms the map to a larger scale, many local landmarks fall out of the mapped extent, and hence are visualized as distant landmarks at the edge of the screen.

In addition to the same 10 tasks used in the online experiment, the field experiment employed additional tasks to investigate if participants could establish spatial orientation in the real-world environment: Participants were asked to give directions from their actual location to an unseen distant location (e.g., Science Library Entrance), that is not visualized on the App. One task was carried out at the beginning of this experiment to verify participants' unfamiliarity with the environment. Another one was carried out after using this App to investigate if participants establish spatial orientation in the physical environment. In addition, three psychometric tests measured participants' spatial ability.

A self-rated measure was not employed in this experiment as the test had promising correlation with participant's acquisition of spatial knowledge and performance in the environment without the interaction with additional sources such maps. Since this experiment still involves the use of mobile maps while in the environment, we adapted the tests from studies which have a similar involvement of environment, map, and spatial performance. For example, previous studies investigating spatial learning using maps between online and field experiments validate these tests (see Liben et al., 2010). Three tests collected scores of participants from a 0 to 10 scale in Paper Folding Test (PFT), Mental Rotation Test (MRT), and Water Level Test (WLT). The PFT was used for testing visuospatial memory (Linn & Petersen, 1985). MRT is based on the adapted version research for testing mental rotation ability (Vandenberg & Kuse, 1978). WLT measures spatial perception based on objects' orientation and configuration.

Environment

The underground tunnel system on one of the authors' university campus was the site for this field experiment. The tunnels are constantly reported to be places for students to easily get lost due to their highly symmetric structure, limited visual cues to the outdoors,

Figure 6 /

Three testing locations in the underground tunnels: i) tunnel underneath Arts and Science Building, ii) lower level in the tunnel underneath the Lecture Center, iii) tunnel underneath Fine Art Building (Base map source: Open Street Map).

and lack of appropriate signage. Three locations were selected in the tunnels. Test locations were separated from each other by about a two- to three-minute walk (see Figure 6).

Participants and Procedure

In total, 20 participants from two nearby university campuses, who were unfamiliar with the tunnel system took part in the experiment. Their ages ranged from 18 to 28 years-old (*M* = 21.45, *SD* = 2.48). The field experiment began in a laboratory with close access to the tunnel system. The lab was also used for a participant to store their personal belongings and give their consent. The experimenter then lead each participant to the tunnel system to perform tasks using the App. The order of locations and visual variable scenarios were randomized for each participant. At the first test location, the participant was asked to give an initial estimation of direction to an unseen distant location, which was not visualized in the App. This was to check if a participant was familiar with the environment. At a testing location, participants answered the same ten questions, the same as those in the online experiment, while using the App. Participants could tap, pan, or zoom in the App to help them answer the questions. The App recorded the frequency of tapping, panning, and zooming as a measure of interaction. At the last testing location, participants estimated the direction to the unseen distant location again. After all tasks, the participant and the experimenter came back to the lab and completed the three psychometric tests with a three-minute timer for each task.

Results

Similar to the analyses of the online experiment, each performance and interaction measured with the App was entered as a dependent variable in a repeated measures ANOVA. The purpose of using the analysis is to compare if specific visual variables have different effects on the acquisition of spatial knowledge and the development of spatial orientation in the actual environment. The within-subject variable is the scenario of three designs while spatial ability is the between-subject variable in each repeated measure. To code the spatial ability, the authors used the combined scores of PFT and MRT, as participants show no difference in the WLT. If the combined score of both tests was above 50% of the maximum combined score, corresponding participants were placed in the high spatial ability group. Likewise, participants whose combined score were lower than the

50% of the maximum combined score, were placed in the low spatial ability group. All participants completed the experiment with an average duration of 43 minutes. The range of time was between a maximum of 57 minutes and a minimum of 30 minutes.

Interaction with App

The repeated measures ANOVA with Greenhouse-Geisser correction shows that the number of panning in the App differ significantly among three scenarios (F (1.08, 19.41) = 8.75, p = .001, partial η^2= .33) (Figure 7). Participants in the size scenario panned 11.85 times more than those in the fuzziness scenario and 12.15 times more than those in the transparency scenario. The effect of spatial ability on the panning frequency was marginal (F (1, 18) = 24.20, p =.057, partial η^2= .57). Participants with higher spatial ability (M = 9.50, SD = 10.90) panned fewer times than those with lower spatial ability (M = 22.90, SD = 21.88). There was no interaction effect of visual variable and spatial ability on panning. Neither the visual variable nor spatial ability had significant effect on tapping or zooming. Regarding usability, size seemed least effective as it required more interaction with the App in order to understand the design, especially if a user's spatial ability was not high.

Acquisition of Spatial Knowledge

Performing the same tasks as in the online experiment, participants in the field experiment performed accurately in selecting the closest landmark (Size: M = 0.90, SD = 0.31; Fuzziness: M= 0.85, SD = 0.37; Transparency: M = 0.95, SD = 0.22). This shows how the interaction enabled in the field experiment contributed to participant's performance. Participants in the field experiment, however, differed in their accuracy of selecting the furthest landmark among three scenarios, as shown in Figure 8. The repeated measures ANOVA with Greenhouse-Geisser correction showed that the participant's accuracy of selecting the furthest landmark differed significantly among three scenarios (F (1.49, 26.78) = 5.23, p = .019, partial η^2= .23). Participants in the size scenario had the lowest accuracy (M = 0.65, SD = 0.49) while they had very high accuracy in the fuzziness (M = 0.95, SD = 0.32) and transparency scenarios (M = 0.95, SD = 0.23). Similar to the findings in the online experiment, the visual variable size seemed least effective for supporting the acquisition of distance knowledge of locations beyond the mapped area.

Spatial ability had a significant effect on the performance of comparing the distance between two local landmarks (F (1, 18) = 6.79, p = .018, partial η^2= .27). As shown in Figure 9, participants with lower spatial ability with regard to a scenario had poorer performance (M = 0.85, SD = 0.17) compared to those with higher spatial ability (M = 0.93, SD = 0.13). This significant effect of spatial ability also existed in the performance of comparing one local landmark with one distant landmark (F (1, 18) = 10.97, p = .004, partial η^2 = .38). Regardless of the visual variable, participants with lower

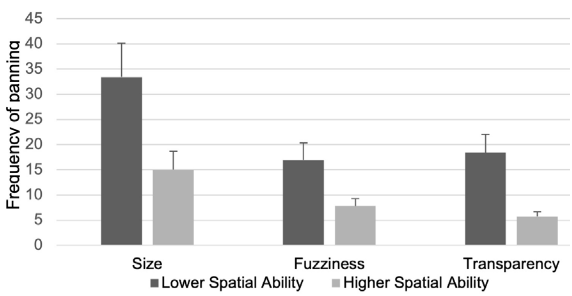

Figure 7 /

Participant's mean frequency of panning by visual variables and spatial ability.

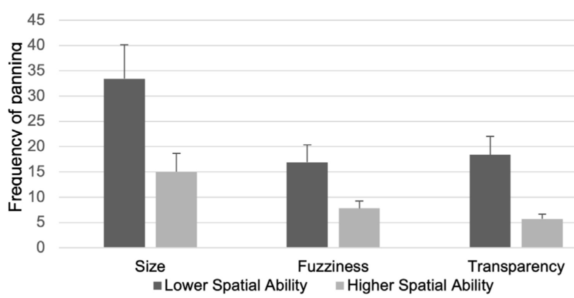

Figure 8 /

Participant's performance of selecting the furthest landmark by scenario and spatial ability.

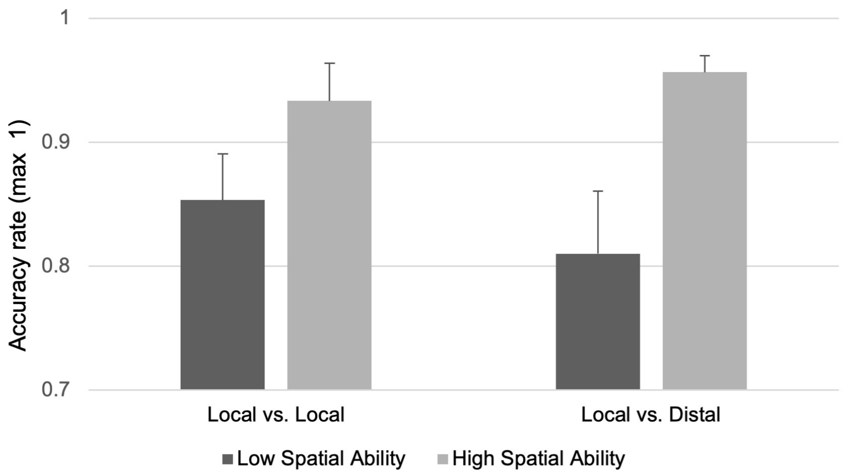

Figure 9 /

Participant's performance of comparing the distance between two local landmarks (local vs. local) and between one local landmark and one distant landmark (local vs. distant).

spatial ability had lower accuracy (*M* = 0.81, *SD*= 0.23) compared to those with higher spatial ability (*M* = 0.96, *SD* = 0.06). No main effect of spatial ability nor visual variable was significant in the accuracy of comparing the distance between two distant landmarks. The field experiment further clarifies that a user's spatial ability can impact the acquisition of spatial knowledge, regardless of visual variables.

In the field experiment, participants estimated the direction to a distant location which was not visualized in the App. This was to investigate if users could establish spatial orientation through establishing directions to locations in the environment. As shown in Figure 10, the pointing errors to the unseen object were impacted by spatial ability in both before- and after- App performance (Pre: F (1, 18) = 4.68, p = .044, partial η^2 = .21; Post: F (1, 18) = 14.73, p = .004, partial η^2 = .46). The pointing errors decreased after using the App but did not differ among the three scenarios. With very brief usage of the App, the spatial ability of participants differently impacted their acquisition of spatial knowledge at the survey

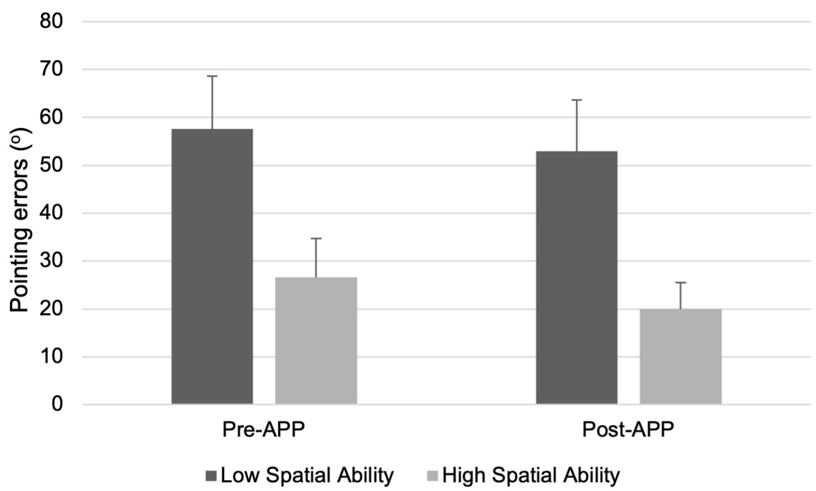

Figure 10 /

Pointing errors of participants before and after using the App.

level. In general, the App using different visual variables contributes to the development of spatial orientation, but spatial ability is a critical factor that determines the accuracy of one's spatial orientation.

Discussion

The results of the statistical analyses reported in previous section compare differences among individual's visual variables that have implication for their effectiveness. This section discusses the effects of these visual variables in relation to the findings of the online experiment, and on the usability of the results, acquisition of spatial knowledge and development of spatial orientation, as well as the implication of these results for future studies.

Usability

Results clearly show that icon size is not effective for visualizing distant landmarks, as it requires a user to pan more on the screen to understand the symbolized landmarks and acquire spatial knowledge. Participants in both fuzziness and transparency scenarios pan significantly fewer times to learn about all visualized landmarks and the surroundings. Results also show that the participant's spatial ability influences the frequency of panning in this experiment. If a user's spatial ability is relatively higher, he or she pans fewer times than those with lower spatial ability. In short, the visual variables of fuzziness and transparency seem more important than size for providing better usability. This suggestion is further supported by the effects of visual variables on acquiring spatial knowledge.

Acquisition of spatial knowledge

When a participant was asked to compare the distance between two landmarks, he or she needed to acquire the distance knowledge symbolized in the landmarks. The result of comparing the closest distance in the field experiment was consistent to the online experiment. The participant's performance in naming the closer location between a pair of visualized landmarks, which can be both local, both distant, or one local and one distant, showed all three visual variables effectively represented both local and distant landmarks, with the lowest accuracy above 85%. In addition, spatial ability has some impact on the performance. When comparing two local landmarks or one local vs. one distant landmark, higher spatial ability leads to better performance. In short, with the visualized distant landmarks, participants using the App can acquire spatial knowledge to distinguish their relative distance correctly.

The performance for judging the longest distance, however, is worth noting. The results of the online experiment show very low accuracy across all scenarios. In the field experiment, the interaction with the actual App benefits participants understanding the design and using it for acquiring distance knowledge through designed landmarks. Although the size visual variable yields much higher accuracy than that in the online experiment, it leads to the lowest accuracy of 65%. In the field study, it is still much higher than in the online experiment. In addition to usability, size also seems not an ideal visual variable to visualize distant landmarks, compared to fuzziness or transparency, due to its small effect on the acquisition of spatial knowledge.

Spatial orientation in the environment

One additional goal of the field study was to investigate if using the App can facilitate one's spatial orientation in the environment. In the field experiment, participants needed to align their mental representation of the tunnel with the campus to estimate direction to the unseen distant location. The scenario and spatial ability did not influence the performance pre- and post-using the App. Participant's larger errors before using this App confirmed their unfamiliarity with the tunnel. The unfamiliarity with the tunnel made it harder for them to align it with their mental representation of the campus. There is no clear difference among all three visual variables regarding their effects on spatial orientation, as their effects seem similar in this aspect. Spatial ability, however, seems a more influential factor that differentiates participants regarding spatial orientation. Participants with higher spatial ability consistently had higher accuracy of spatial orientation than those with lower spatial ability, regardless pre- or post-using the App.

Although the chosen locations in the tunnel were not familiar to participants, once participants could correctly align their quickly learned tunnel space with the outdoor environment, they could use what they knew about the outdoor environment to help with their spatial orientation. This may explain the significant effect of spatial ability in the estimation tasks. Spatial ability is categorized based on the combined score of the paper folding tasks (PFT) and mental rotation tasks (MRT) which reflect the visuospatial memory and mental rotation ability of a person. Therefore, if a participant is good at mental rotation, he or she can easily rotate their mental map of the learned tunnel space and align it with the campus environment, which contributes to the higher accuracy of the pointing task. In future studies, instead of using spatial ability test, self-ratings such sense of direction, spatial strategies can also be included and used to correlate participant's performance to further clarify the roles of spatial ability and the visual variables on spatial orientation.

CONCLUSION

Through the two experiments, one online and one in the field, this study has assessed the potential of using an online environment in assessing the effects of design. An online environment can be a cost-efficient solution for assessing the acquisition of spatial knowledge, even though limited user information is collected. In the meantime, it is important to note that the performance online is slightly poorer than in field experiment, but the difference of performance among designed scenarios are consistent with that in field experiment. The performance of participants online is likely impacted by the use of static screenshots. The results, however, can shed light on user's performance in a real-world environment. For comparing various scenarios, the online experiment is a cost-effective choice, although it cannot provide all necessary data for a more comprehensive understating as in a field experiment. For example, due to the protection of participants identity on the online platform, personal information such as spatial ability was not collected. Although the online experiment implemented mechanism such as qualifying questions for excluding invalid answers and requiring participants to type all their answers instead of simply clicking, participant's responses could still include ones that were guessed. To overcome these limitations, future research can adapt the use of virtual applications to simulate the actual design on mobile phones. Users can interact with the application by using a mouse or the touchpad of a computer. This can be a suitable improvement for carrying out online experiments, which enables user's interaction with the App while acquiring spatial knowledge from the map.

The field experiment confirms the finding in the online experiment with more details and enhanced performance. The design of distant landmarks using chosen visual variables can serve as reference points for users to acquire spatial knowledge of a larger extent of an environment. Due to the actual interaction with the App, participant's performance is more accurate than that in the online experiment. Using this design in an actual environment that is challenging to community members, this study shows the efficiency of using symbolized landmarks to help users orient in an environment and acquire spatial knowledge, especially distance knowledge. In particular, this study compares the differences using three visual variables including size, fuzziness, and transparency to indicate the distance to distant locations. Based on the results in both experiments, size seems the least effective visual variable for designing distant landmarks based on the results of both usability and acquired spatial knowledge. Instead, fuzziness and particularly transparency are more efficient. They lead to higher efficiency as they do not require more interaction and lead to better acquisition of spatial knowledge. Both these visual variables seem to intuitively indicate on the screen that the further the location is, the harder it is to see the location clearly.

The limitations of this study should be noted and further addressed in future studies. First, it is important to note that the sample size in the field experiment is relatively small, as it has been challenging to recruit participants who are not familiar with the site. Second, only one visual variable is used in one design. It is not clear if combined visual variables lead to better performance. In future studies, it is necessary to apply both fuzziness and transparency to one distant landmark and evaluate their effectiveness on spatial learning. Third, future studies should consider additional factors such as a person's familiarity and self-rated sense of direction. After the initial evaluation of the effectiveness of visualized distant landmarks on acquiring spatial knowledge, it is necessary to investigate their roles on actual navigation tasks.

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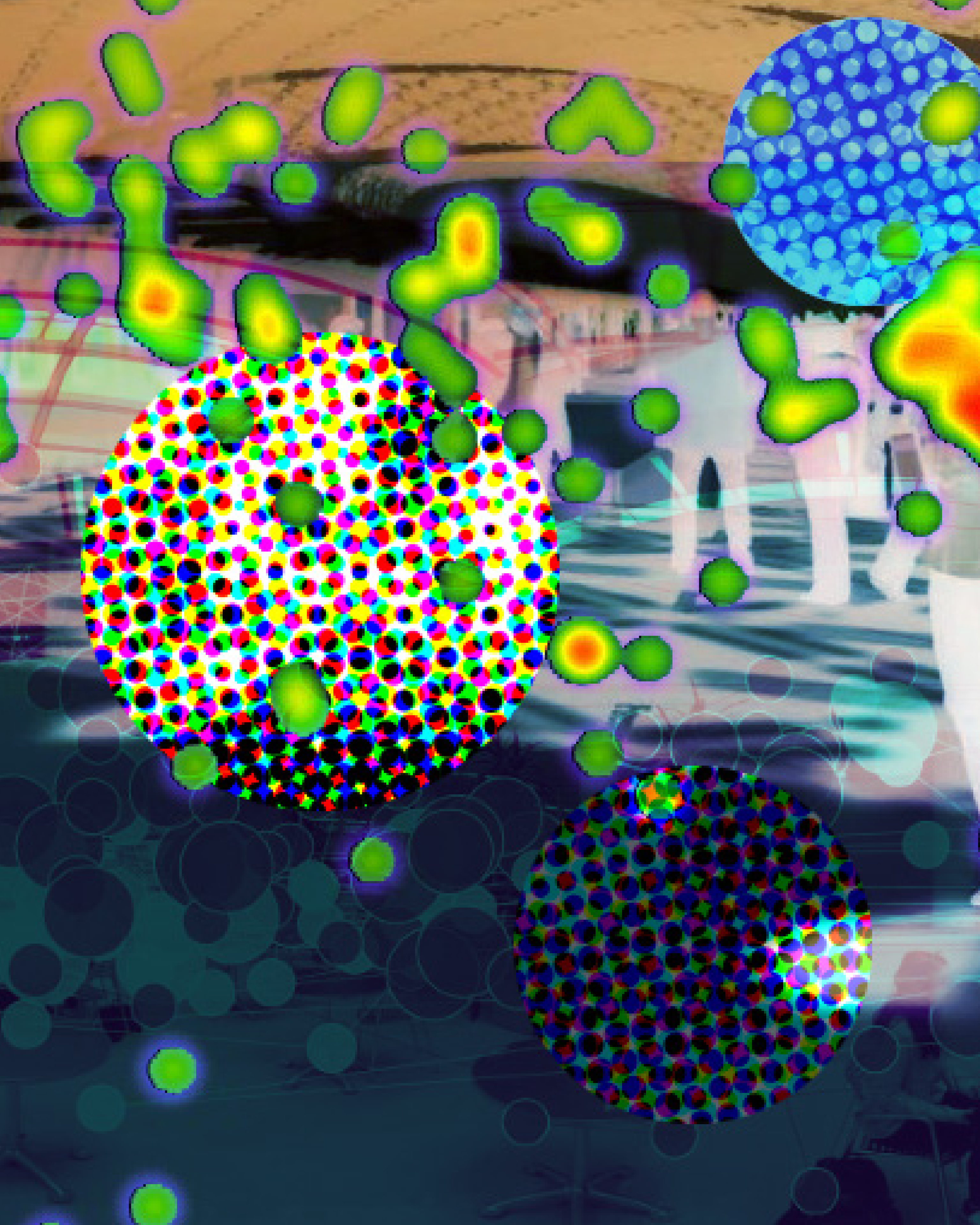

Towards Linguistic Inclusivity: An Exploration of the Wayfinding System at Stellenbosch University, South Africa

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Abstract /

Effective wayfinding design should efficiently and accessibly provide navigational tools to its user. These tools are multidimensional and engage a complex network of socio-political, cultural, economic, and linguistic issues. This paper interrogates the wayfinding system on Stellenbosch University's campus – a space where issues regarding linguistic injustice have been prevalent due to the university's long history with Afrikaans language and culture. The research considers the theoretical perspectives of wayfinding, linguistic landscaping, and spatial justice. These theories were utilised alongside qualitative data collected through interviews with and questionnaires completed by relevant participants on campus. The results revealed that the user experience of the wayfinding system was lacking in effective and efficient accessibility. It was suggested that an amended wayfinding design – one that took into account the balancing of power relations in the campus space – could contribute towards spatial justice and a more welcoming environment for all.

Keywords /

spatial justice; wayfinding; semiotic landscapes; linguistic landscaping

INTRODUCTION

Wayfinding is intended to facilitate a person's movement through space by "the process of using spatial and environmental information to navigate to a destination" (Lidwell, Holden and Butler, 2010, p. 260). However, the reading of wayfinding is not only influenced by the tangible but also the intangible, which together create a multidimensional experience operating at the complex intersections of socio-political, cultural, economic, and linguistic issues. Therefore, the aim of an inclusive wayfinding system should be both equitable and accessible to accommodate users with diverse preferences, backgrounds, and abilities (Arthur and Passini, 1992).

This paper investigates the wayfinding system on the main campus of Stellenbosch University in Stellenbosch, South Africa. In 2016, this historically white, Afrikaans university adopted a new language policy that elevated the use of English and isiXhosa alongside Afrikaans within the university's academic and social sphere (Stellenbosch University, 2016). The research aimed to gain insight into how users experienced and negotiated the campus using the directional and informational wayfinding systems available. In addition to an analysis of these wayfinding systems on campus, data were collected through interviews with, and questionnaires completed by participants on Stellenbosch University's campus.

This article begins by providing the context of South Africa's divided history, the Afrikaans language, and Stellenbosch University's relationship with language on campus. This is followed by an explanation of this study's methodology, unpacking of the theoretical perspectives including wayfinding, linguistic landscaping, and spatial justice, and concludes with a presentation and discussion of findings. The intent is to contribute to an understanding of the role of wayfinding systems in providing equitable, and inclusive public spaces.

CONTEXT

South Africa's long history with oppression and exclusion spans back to 1652, when the Dutch East India Company created the Cape Colony. The settlers stole ancestral land from the Khoikhoi and San peoples and imported slaves from the East Indies and other parts of Africa. Although slaves were "freed" in 1834, a racist, segregated system was still in place. This became formalized in 1948, when the National Party came to power on the platform of apartheid in accordance with Afrikaner nationalism. Apartheid separated people into four racial categories – black, colored, Indian, and white – and passed laws that denied rights to people of color to privilege the white minority.

Stellenbosch, founded in 1679, lies approximately 50 kilometers inland from Cape Town and is known for its wine production and university. Due to segregationist policies, black and colored communities were established on the outskirts of the town, leaving the center for white people. This was enforced during apartheid when, in 1964, a colored community was violently removed from the center of town (an area called Die Vlakte) and relocated further away. Stellenbosch University received some of this land for its campus. This is an event that has repercussions today, as the university works to address the fractured relationship between it and the previous residents of Die Vlakte.[1]

In 1994, apartheid was officially dismantled and a democratic South Africa was ushered in with Nelson Mandela at its helm; a former lawyer and anti-apartheid activist who had recently become a free man after being imprisoned for 27 years for his activism. This event also allowed for nine African languages to be recognized as equal official languages of South Africa (along with English and Afrikaans).[2] While there has been great progress since the end of apartheid, the country is still struggling to rectify the wrongs of its past and there is also great disappointment and unease in the slow process.

Some of this disappointment and unease came to a head in 2015 and 2016, when students across the country were galvanized in protests against the injustices of the past and the systemic racism still prevalent in universities. These protests began with the #Rhodesmustfall movement at the University of Cape Town in 2015 with calls to remove the statue of Cecil John Rhodes, the British imperialist who bequeathed "his" land to South Africa, a portion of which the university is built upon.[3] However, the movement brought about much larger issues inherent within higher education across the country such as the necessity for the decolonization of university space and curriculum (for Stellenbosch University this specifically included a look at language use), addressing of university fees with the outcome of affordable and accessible education, and more student housing.

Afrikaans

Afrikaans developed in South Africa from three main language sources: Dutch colonizers, indigenous peoples, and slaves (Roberge, 2002, p. 79). The late 19th Century gave rise to Afrikaner nationalism to uphold Afrikaans language and culture – as spurred on by the Anglo Boer/South African Wars (Kriel, 2010). During apartheid, Afrikaans was the language of the ruling party – and, thus, was seen as the language of the oppressor. In 1953, the government passed the Bantu Education act, which amongst many things, enforced racially separated schools. In 1974, the *Afrikaans Medium Decree* was enacted, which forced the teaching of subjects in Afrikaans within black schools. One fallout of this decree was the 16 June 1976 Soweto Uprising; a protest by black school children in Soweto, a township outside of Johannesburg, against being taught in Afrikaans. The protestors were met with violence from police that left many dead or wounded. The use of Afrikaans by the ruling party during apartheid has superseded its history within other cultural groups – it is also the linguistic and cultural identity of many people of color. As Hein Willemse (2015, p. 1) states "While our recent sociopolitical history often casts Afrikaans as the language of racists, oppressors and unreconstructed nationalists, the language also bears the imprint of a fierce tradition of anti-imperialism, anti-colonialism, of an all-embracing humanism and anti-apartheid activism." The history of Afrikaans is richly multifaceted.

Stellenbosch University and Language

Stellenbosch University was formally established in 1918 as an Afrikaans university – in both language and culture. This foundation tied it (and the town that it sits in the heart of) to the rise of Afrikaner Nationalism and apartheid. As an institution that was historically white, Afrikaans, and exclusionary, the university has officially acknowledged and apologized for its "role in the injustices of our country's past" (De Villiers, 2018) and has taken many strides towards institutional transformation since 1994 (Stellenbosch University, 2022b). However, it is still a space that is grappling with issues of inclusivity.

In recent years the demographics have changed to welcome people from more diverse linguistic and cultural backgrounds and this necessitated a renegotiation of the linguistic landscape of the university. In 2022, 32,535 students were enrolled at the university with the following home language (first language) statistics: 48% English, 32.8% Afrikaans, 5.46% Xhosa, 8.82% other official South African languages, and 4.84% other (international) languages (Stellenbosch University, 2022a).[4] The university further reports that in 2021, 80.8% of undergraduate students preferred English as their language of learning and teaching. This includes 49.5% with Afrikaans as their home language along with almost 100% of students with other home languages. In terms of race, almost 100% of black African and Indian/Asian, 80.7% of colored, and 73.8% of white undergraduates preferred English as their language of teaching and learning (Stellenbosch University, 2021c). The university's physical landscape encompasses five campuses and 10 faculties. The main campus – the one central to this article – holds eight of these faculties and sits in the center of the town of Stellenbosch.[5]

It is important to note that there has been a long, emotional, and tumultuous debate regarding language at Stellenbosch University. A very superficial explanation of the complexities of the debate is that one side (mostly outside Afrikaans interest groups) are adamant that the language of instruction at the university should be Afrikaans and the other side (namely, many staff, students, and the leadership of the university) believe that it needs to be multilingual. While this debate began long before the 2015 student protests, these protests catalyzed a critical look at the university's then language policy, which the student organization Open Stellenbosch suggested "safeguards Afrikaner culture and excludes black students" (Phakathi, 2016).

A new language policy was established in 2016 – and updated in 2022 – that

> *aims to increase equitable access to SU for all students and staff, promote multilingualism and the appreciation thereof, and facilitate pedagogically sound teaching and learning. Without losing sight of the fact that SU also serves continental and global communities, we commit ourselves to multilingualism by using the three official languages of the Western Cape, namely Afrikaans, English and isiXhosa* (Stellenbosch University, 2021b, p. 3).

The policy supports the use of multilingualism institutionally and in social settings. Prior to this, the language policy of the university made provisions for Afrikaans and English as academic languages (Stellenbosch University, 2014).

In 2015, the Department of Visual Arts at the university initiated a preliminary survey in which students indicated the need for multilingual signage on campus. Various respondents discussed their inability to navigate around campus because much of the signage was in Afrikaans, which they could not read, and this led to them feeling confused and unwelcome (Costandius & de Villiers 2015, p.1). The department then motivated the Facilities Management to include three languages (Afrikaans, English, and isiXhosa) on signage boards, and this was approved in late 2015. Unfortunately, however, the wayfinding system on campus was slow to be updated according to this new procedure.[6]

As mentioned, modifications to the language policy have not been welcomed or supported by everyone. Specifically, the 2016 language policy was challenged by

Afrikaans rights activists but was upheld by the Western Cape High Court in 2017 (see *Gelyke Kanse and Others v Chairperson of the Senate of the University of Stellenbosch and Others* [2017] 17501/2016) and the Constitutional Court in 2019 (see *Gelyke Kanse and Others v Chairperson of the Senate of the University of Stellenbosch and Others* [2019] ZACC 38). There is an ongoing investigation (started in 2021) by the South African Human Rights Commission into an alleged "ban on Afrikaans in residences during the welcoming period at the beginning of the academic year at Stellenbosch University" (Stellenbosch University, 2021a, n.p.). These are just a few of the legal issues involved with language at the university. A simple Google search will reveal even more threats of legal action and public debates regarding the merits or implementation of the language policy. It is clearly a contentious and emotional topic for many.

METHODOLOGY

The methodology for this research was an explanatory qualitative case study within an interpretative paradigm, which aimed "to discover the social dynamics operating within [a] population" (Babbie, 2007, p. 96). For the purpose of this study, "social dynamics" refers to the linguistic landscape at Stellenbosch University and how it affects wayfinding. An interpretative paradigm suggests that an individual's reality is created "through social constructions such a[s] language, consciousness, shared meanings, documents, tools, and other artifacts" (Klein & Myers, 1999, p. 69). It also understands that these social constructs can be conflicting and biased (Klein & Myers, 1999).

Semi-structured interviews were conducted with three individuals involved in the reform of the wayfinding system at the university on an institutional level, as well as through questionnaires completed by a small, random sample of linguistically diverse university students and staff – three Afrikaans-speaking, four English-speaking, three Xhosa-speaking individuals (this reflects the first language of the individuals). This collected data were supplemented by analysis of the directional and informational signage on campus (both the old signage in Afrikaans or Afrikaans and English and the new signage in all three languages) and document analysis of official university documents concerning the language policy and signage/building name changes. This also incorporated university statistics and the preliminary survey on the proposed signage changes conducted by the Department of Visual Arts in 2015.

THEORETICAL PERSPECTIVES

This research considers the theoretical perspectives of wayfinding, linguistic landscape, and spatial justice. These three perspectives work together to provide an understanding for the necessity of a linguistically inclusive signage system on Stellenbosch University's campus that abides by the institution's new language policy. This type of signage system could assist in creating an equitable and just navigational tool for staff, students, and visitors to campus.

Romedi Passini (1981, p. 17) describes wayfinding as "[people's] ability to reach spatial destinations in novel as well as in familiar settings." Kevin Lynch (1960, p. 4), who coined the term "wayfinding," defines it as being "a product both of immediate sensation and of the memory of past experience, and it is used to interpret information and to guide action." Wayfinding, then, relies on a user's reading of the duality of the physical/visual and experiential environment to successfully navigate through a space.

A wayfinding system can contribute to manipulating the network of relationships already present in a space, and, in the process, it "can enable or disable people" (Clarkson and Coleman, 2015, p. 236). An inclusive/enabling approach aims to negotiate uneven power relations in a space by providing equitable, effective, and accessible wayfinding information, thereby allowing the majority of users to actively participate in the space. Such an approach should produce a system that is able to communicate effectively to a diversity of people with different intellectual, linguistic, physical, and sensory abilities, as well as varying social stratifications and cultural backgrounds (Arthur and Passini, 1992, p. 85). This could facilitate an environment that enables navigational independence to the greatest extent possible (Salmi, 2005, p. 6). For Stellenbosch University, an enabling approach to wayfinding is to include all three languages on the university's signage boards.

The understanding of communication within the environment is also considered in the theory of linguistic landscape. This semiotically based theory was first defined by Landry and Bourhis (1997, p. 25) as encompassing "[t]he language of public road signs, advertising billboards, street names, place names, commercial shop signs, and public signs on government buildings combines to form the linguistic landscape of a given territory, region, or urban agglomeration." Updated definitions have been offered such as "any sign or announcement located outside or inside a public institution or a private business in a given geographical location" (Ben-Rafael, Shohamy, Amara, and Trumper-Hecht, 2006, p 14) or "any piece of written text within a spatially definable frame" (Backhaus, 2007, p. 66).

Linguistic landscaping considers the process and intent behind a sign. It asks the questions: "who puts up what sign(s) where, in what language(s) and last but not least why (or why not)?" (Marten, Van Mensel, and Gorter, 2012, p. 5) – and also, for whom? It is about the sign and how people interact with the sign. It investigates the complexities of language use on signs – especially in multilingual contexts – as an "outcome of different power struggles over space, of ownership and legitimacy, of policy and ideology…" (van Mensel, Blackwood, and Vandenbroucke, 2016, p. 8). Particularly, for Stellenbosch University, it assists in understanding the "aspects of linguistic diversity that typify the multilayered, superdiverse multilingual contexts" (van Mensel et al, 2016, p. 3) of the university sphere and of the power dynamics within this linguistic diversity.

Linguistic landscaping encompasses many themes; one aspect it considers is the impact of official language policies on the landscape.[7] This is of particular interest to this paper as it considers the multilingual language policy of Stellenbosch University and how it has been implemented in directional and informational signage across the main campus. As mentioned, South Africa has 11 official languages, and is thus ripe for research regarding language policies in linguistic landscapes. A number of scholars have provided research on this topic throughout the country; Theodorus du Plessis (2012) looks at language policies in the linguistic landscape of three towns within a rural area in the Free State Province; Philadelphia Mokwena (2017) analyses the linguistic landscape of two rural municipalities in the Northern Cape Province; Temitope Adekunle, Gift Mheta, and Maleshoane Rapeane-Mathonsi (2019) investigate the linguistic landscapes of the University of Cape Town and the University of the Western Cape; and Michael Kretzer and Russell Kaschula (2021) consider language policy in regards to linguistic landscapes at 300 schools in three provinces in South Africa. Additionally, Sibongile Philibane (2014) provides us with an overview of the linguistic landscapes at three Western Cape Province Universities – including Stellenbosch University – with the discovery of an unequal promotion of multilingual signage (between Afrikaans, English, and isiXhosa) at these institutions; also finding that Stellenbosch University's signage favored Afrikaans.

Linguistic landscaping goes hand in hand with the semiotic landscape. Such a landscape is understood through human intervention of meaning making in a space and, specifically in the sense of language use, contributes to "power relations and identity formation through the lens of place-naming, multilingualism, linguistic vitality, and language policy" (Jaworski and Thurlow, 2009, p. 9). These landscapes are a "reflection of socio-cultural symbols and meanings that define what it means to be a human being in a particular culture" (Greider and Garkovich, 1994, p. 3). They are a combination of the physical and linguistic signs that contribute to the identity of a place – and, reflexively, to the identity of a person or group of people.

In order to effectively negotiate an inclusive approach to wayfinding, one needs to gain insight into the context within which it functions; most often, public social spaces. Social space, according to Henri Lefebvre (1991, p. 77), "contains a great diversity of objects, both natural and social, including the networks and pathways, which facilitate the exchange of material things and information." As spaces are "an active force shaping human life" (Soja 2009, p. 2), linguistic landscaping, then, must be created with the understanding of the "situated social dynamics of multivocality in local spaces, manifest in the contesting lives of multiple publics" (Stroud and Jegels, 2014, p. 2). Therefore, the wayfinding of a space must cater to the language of the public that it serves – it should not enable or disable one group over another but, rather, work to empower all.

For this to occur, wayfinding needs to incorporate spatial justice practices to confront a range of unequal power relations within a space; as Edward Soja (2010, p. 28) rightly asserts, "[s]pace – like justice – is socially produced, experienced, and contested on constantly shifting social, political, economic, and geographical terrains, which means that justice must be engaged on spatial as well as social terms." For Soja (2009, p. 1), spatial justice considers how inequality and injustice is created by, manifested in, and maintained through public social space and how justice in these spaces is an "active negotiation of multiple publics, in search of productive ways to build solidarity across difference" (Soja, 2010, p. 28). David Harvey (1988) argues that to amplify the prospects for social engagement for all, one should attempt to create social spaces in a way that would make it accessible to the majority of those who move through these spaces. Nancy Fraser (1990, p. 57), a seminal theorist in the field of social justice, suggests that the public social space acts as an "arena of public discourse" within which social justice functions. She views the concept of social justice through the lens of what she terms "participatory parity" (Fraser, 2008, p. 278), which she describes as involving social policies and arrangements that make it possible for all inhabitants of a space to participate in that space in an equal capacity (Fraser, 2008, p. 280) – spatial justice.

Doreen Massey (2013, p. 3) speaks to this when she explains that everyone relates differently to spaces and has distinct relations to the social interconnections in these spaces: "you're not traveling across a dead flat surface that is space, you're cutting across a myriad of stories." It is the spatial relations between these stories that are integral to an understanding of politics and power (Massey, 2013, p. 2). The wayfinding system is just one of the avenues in which these linguistic power relations are established; they create the social justices and injustices that manifest in the space and are both informed by and create the semiotic landscape in which they exist. Massey (2013, pp. 3-4) furthers this idea by explaining that "…what we have is a geography, which is in a sense the geography of power. The distribution of these relations, mirrors the power relations within the society we have."

PRESENTATION AND DISCUSSION OF FINDINGS

This research was an investigation into the linguistic landscaping present in the wayfinding system on Stellenbosch University's campus – through signage – and the experiences of staff and students regarding the system. Interviews were conducted with three people who were involved in the updating of the wayfinding system at the university on an institutional level. Additionally, questionnaires were completed by three Afrikaans first language, four English first language, and three isiXhosa first language university students and staff. For anonymity, a coding system has been used to refer to each respondent. Those who were interviewed are referred to as Respondent 1 through 3 and for questionnaires they are referred to as Participants 1 through 10. Analysis of the data revealed that there were two main aspects of incorporating Afrikaans, English, and isiXhosa equally into the wayfinding on campus: the first is the use of language for accessibility and the second is the use of language as symbolic.

As mentioned, the university's language policy prior to 2016 made concessions for Afrikaans and English. Therefore, much of the directional and informational signage on campus was either in Afrikaans or Afrikaans and English. At the end of 2015, the proposal to incorporate three languages on signage was accepted and rolled out. The name of the university appears on both old and new signs in Afrikaans, English, and isiXhosa. Locational or informational signs outside of specific buildings include the name of the building in all three languages, as seen in Figure 1. Figure 2 demonstrates existing directional signs in Afrikaans and English and

Figure 1 /

Visual Arts Building signage in all three languages.

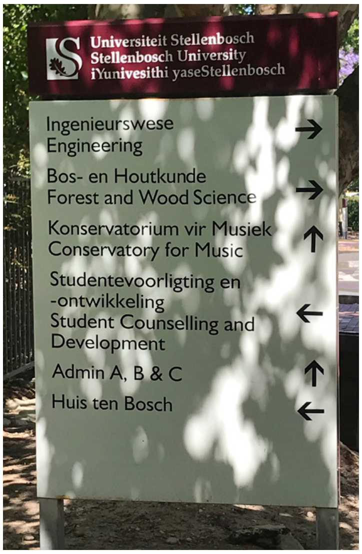

Figure 2 /

Directional signage in English and Afrikaans.

Figure 3 /

Directional signage in all three languages.

Figure 3 shows a new sign with all three languages. It has been standardized so that all new signage on campus is in the following language order: Afrikaans, English, isiXhosa.[8]

Reactions to Stellenbosch University's Wayfinding System

When asked to rate different navigational activities on campus on a scale from easy to difficult, all participants who completed the questionnaire indicated that they found it relatively difficult to find any building on campus. It was mentioned that the "campus is not very clearly marked overall and is confusing to outsiders and first-years" (Participant 5). One participant stated that "the wayfinding system is hidden, uninteresting, and sometimes inaccurate" (Participant 6). It was also mentioned that much of the wayfinding system has been the same for many years and that some of the signs have been broken, damaged, and vandalized (Participant 10). Such signs can be seen in Figures 4 and 5 below. Lidwell, Holden and Butler suggest that "navigational choices are complex and so destinations should be clearly marked by signage" (2010, p. 261) and the above demonstrates the need for clear signage on Stellenbosch University's campus — not only in regard to language.

Reactions to Stellenbosch University's Wayfinding System: Language for accessibility

Only one participant in the questionnaire answered that they use the wayfinding system, and this participant also indicated that their home language is Afrikaans. One isiXhosa participant explained that they do not use the signage because it is impractical as it is in Afrikaans, which echoed the sentiments of many of the other opinions expressed in the questionnaire. When asked what they would do if they had an opportunity to change something about the system, half of the participants (all of whom were either English- or isiXhosa-speaking) stated that they would modify the languages found on the signage. They mentioned that the signs should be revised to "ensure that the languages represented would be indicative of those who are a part of the university staff and student body" (Participant 3) and "make sure that it would be understood by more than just those who understand Afrikaans" (Participant 5).

When the participants of the questionnaire were asked if they understand written Afrikaans, half replied that they did, but also stated that "Afrikaans

(L)Figure 4 /

Vandalized Parking Signage.

(R)Figure 5 /

Damaged Directional Signage.

signs do not help, they were actually more confusing," that they "do not understand the technical terms in Afrikaans, like the environmental sciences building" and that "some of the Afrikaans names are long and confusing, hard to pronounce and hard to remember." This shows that the signs cannot just be in Afrikaans, it must be linguistically accessible to the majority of those who interact with them – to the "multilayered, superdiverse multilingual contexts" (van Mensel, Blackwood, and Vandenbroucke, 2016, p. 3) inherent in Stellenbosch University.

Reactions to Stellenbosch University's Wayfinding System: Language as symbolic

The majority of the participants of the questionnaire stated that they had either noticed that the new signage changes included Afrikaans, English, and isiXhosa, or had heard about them. While most participants supported the new signage, as it widened accessibility to diverse linguistic groups and demonstrated the university's commitment to multilingualism, one participant added that the new signs "had even more writing on them and were too busy" (Participant 9). This reveals that there is a chance that the inclusion of all three languages detracts from their practicality because if signage fails to present information in a simple and uncomplicated manner, it could contribute to making those who interact with it feel unwelcome in the space in which it operates. Conversely, perhaps a more powerful argument is that, in line with semiotics, language is such an integral part of an individual's identity that the benefit of the inclusion of "your" language greatly outweighs this issue of practicality. As Respondent 3 said, "the fact of the matter is that all three languages are there and it includes everyone. To me, I do not see it being something difficult if all the languages are there, if I can access my language and read it. Whether I read it on a third line or whether I read it on a first line, I do not really mind." Multilingual signage enables equitable access for multiple publics in the space (Stroud and Jegels, 2014; Soja, 2010). It amplifies the prospect of accessibility and spatial justice (Fraser, 2008). Additionally, as mentioned, the order of language has been standardized to facilitate a less confusing presentation of information.

Further, Respondent 1 argued that the "main target group [of the new wayfinding system] is not those that have been here for years and years but is mainly newcomers." This is because they will experience the new wayfinding system on campus without prior knowledge of or previous interaction with the old, existing wayfinding system. It is, however, acknowledged that the new signage will also affect those who have interacted with the university space for many years as it demonstrates that the university is working towards a more inclusive future. In line with Lefebvre, negotiating the update of the wayfinding system contributes to the production of the social space within which it functions. It engages the workings of its own production as well as encompasses the interrelationships between the "things" or "objects" that form the space (Lefebvre, 1991, p. 73). In order to move towards spatial justice and create a more inclusive environment for all, a balance needs to be "engaged on spatial as well as social terms" (Soja, 2010, p. 28).

On the questionnaire, participants were asked if they felt welcome on campus with regard to language. Interestingly, an Afrikaans-speaking respondent indicated that the campus space was not welcoming. This response was not based on their own experiences, but on the behalf of fellow isiXhosa and English students' attitudes and perceptions of what Afrikaans means on campus (Participant 9). The use of Afrikaans throughout the university environment "sends a message of exclusion to those who do not understand Afrikaans" (Respondent 3). An inclusive approach to wayfinding, with the understanding of the spatial injustices at play in a space, is important when attempting to address the invisible variables and power relations within the Stellenbosch University landscape.

The university "can't become too precious and show how things can never be changed" (Respondent 1). It should rather be adaptable to the constantly changing social contexts in which it finds itself because "true inclusivity is about understanding all the invisible variables and also making action institutionally sustainable" (Respondent 1). This shows how vital the move towards an inclusive wayfinding system is and the impact that it could have on social and institutional cohesion. This forms part of a "new spatial consciousness, making us aware that the geographies in which we live support oppressive forms of cultural and political domination and aggravate all forms of discrimination and injustice" (Soja, 2010, p. 19).

The roll out of the new signage has not been without issues, however. When some of the new signs were installed on campus there were complaints that there were spelling and translation mistakes in all languages. Criticism followed: "From a university where you have an Afrikaans department, the English department, and the African Languages department, which specializes in isiXhosa, [this] is unacceptable" (Respondent 3). The mistranslation of a minority language within the linguistic landscape that promotes equitable use of three languages could lead to frustrations and symbolize a lack of care on the part of the university as "language use on official inscriptions can carry highly symbolic value and provoke controversy" (van Mensel, Blackwood, Vandenbroucke, 2016, pp. 11-12).

In light of the above-mentioned issues that surfaced, it was suggested that the university create a wayfinding, naming, and signage committee comprising of permanent staff who can open dialogue with both students and the various offices and departments – such as the Transformation Office, the Department of Visual Arts, or Facilities Management – that are involved in the creation and implementation of the wayfinding system (Respondent 1; Respondent 3). In 2017, the visual redress committee was formed and this issue fell under their management and it has been formalized in the adoption of the visual redress policy (2021) that was in draft since 2017.[9] The policy "will proactively guide visual changes on SU campuses […] This will assist SU in its drive for transformation in and through visual redress" (Stellenbosch University, 2021d, p. 2), which is inclusive of campus signage.[10]

For Stellenbosch University, an updated wayfinding system is about both the straightforward aspect of providing information in languages that people understand and about the symbolic aspect of including three languages as a way to provide "participatory parity" (Fraser, 2008, p. 278). It is also "about negotiating social and political issues" (Respondent 2). As Respondent 1 indicated,

> *It seems like the most simple thing to take a sign down and to put another one in its place but it is governed by so many other variables, invisible*

variables […] If we could have done things with the experience of the end user in mind, then it would be simple […] This is not just about the end user; it is about underlying power battles […]

These battles create obstacles to inclusivity because of the web of power relations inherent in the linguistic landscaping of the university. Massey speaks to this when she suggests that everyone relates differently to spaces, with distinct relations to the social interconnections in these spaces (1994, p. 1). These "spatial relations between, for example, people, cities, jobs, is, however, key to an understanding of politics and power" (Massey, 2013, n.p.). Wayfinding as a system is just one of the avenues by which these power relations are established and so the issue of "signage and building names have come up on multiple university and non-university platforms, both being about the climate on campus and about accessibility" (Respondent 1). This is endorsed by Massey's (2013, n.p.) idea that the "geography of power, the distribution of these relations, mirrors the power relations within the society we have."

CONCLUSION

Reflecting on Stellenbosch University's transformation vision – i.e. "a welcoming campus culture, accessibility, and a multi-lingual academic offering" (Stellenbosch University, 2015) – in relation to its wayfinding system, the possibility of change through inclusive wayfinding is evident. Updating the wayfinding system of Stellenbosch University in such a manner necessitates an approach that is open to the dynamic, social nature of the environment (Stroud and Jegels, 2014). This reinforces the notion that the meaning and value of wayfinding do not merely lie in the signage itself, but also in the effects of the signage on the greater social consciousness of those who interact with it. Through continuous open dialogue with those who use the space, potential strategies for overcoming spatial injustices (Soja, 2009 and 2010; Fraser, 1990 and 2008) with inclusive wayfinding – i.e. new signage systems – could be negotiated and developed and, in the process, the semiotic landscape of the space can become more inclusive.

Stellenbosch University is still associated with Afrikaans. However, as the demographic statistics show, English is the predominant language and the preferred language of instruction. The adoption of the new language policy in 2016 – and update in 2022 – signified the university's commitment to linguistic inclusivity, which, ideally, can foster other types of inclusivity on campus – racial, social, cultural. To appease a diverse campus population, the wayfinding system has to function in a multifaceted and multilingual environment that understands the challenges of navigation, accessibility, language, and power inherent in a complex country such as South Africa.

These national complexities, which are echoed in the linguistic power relations found on campus, create the framework for the production of space at Stellenbosch University; they influence the semiotic landscape. Wayfinding as a system has the power to simultaneously include and/or exclude and can, therefore, be an obstacle to inclusivity as well as a powerful tool for curbing injustices. To overcome the challenges of functioning in such an intricate environment, the wayfinding system should act as a mediator between the various linguistic power relations. The research suggests that wayfinding could contribute to spatial justice by utilizing linguistic landscaping to create a space that is more accommodating, functional, and accessible to all users regardless of their linguistic ability. This goal could be achieved by providing signs that are clearly understood by a diverse, multi-cultural, and multi-linguistic population. The accessibility and equitability of wayfinding in shared public spaces – such as on Stellenbosch University's campus – could enable and empower users to feel welcome, confident, and knowledgeable.

Notes/

[1] Amongst numerous initiatives: In 2006, the University collaborated with the community and published a book on the people of Die Vlakte called In ons bloed ("In our blood"); A large map of Die Vlakte has been installed at the entrance of the Arts and Social Sciences building, which is built on land previously inhabited by the community. A scholarship fund has been established for descendants of Die Vlakte to study at Stellenbosch University.

[2] isiZulu, isiXhosa, Ndebele, Swazi, Northern Sotho, Sotho, Tswana, Venda, and Tsonga.

[3] The statue was removed a month after protests began. This issue of controversial statues is being grappled with worldwide.

[4] The university's statistical profile of enrolled students in June 2022 was 51.6% white, 23.3% black African, 17.3% coloured, 3.4% Indian, and 0.37% Asian (Stellenbosch University, 2022a). Addititionally, The university's statistical profile of permanent personelle in 2018 was 51.9% white, 36.6% coloured, 9.3% black African, 1.7% Indian, and 0.5% "unknown" (Stellenbosch University, 2018).

[5] The other campuses are all in the Western Cape Province, but not in Stellenbosch. They are in Bellville, Tygerberg, Saldanha, and Worcester.

[6] See Philibane, 2014, pp. 61 and 64 for a breakdown of language use on signage at Stellenbosch University prior to the updated signage policy (and University of the Western Cape and University of Cape Town).

[7] See these early studies on language policy: Rosenbaum, Nadel, Cooper, and Fishman, 1977; Tulp, 1978; Wenzel, 1998; and Monnier, 1989. Later studies include: Ben-Rafael et al., 2006; Backhaus, 2009; Barni and Vedovelli, 2012; and Shohamy, 2015.

[8] The order at the time represented the order that the university adopted each language: it was first an Afrikaans university, then English was included, then isiXhosa.

[9] See point 5.3 of the policy (Stellenbosch University, 2021d).

[10] The policy defines visual redress as: "An attempt to right the wrongs of former and current powers by removing hurtful symbols (e.g. of apartheid), social injustice and misrecognition and by remedying the harm that has been caused by these visual symbols through compensation with new visual symbols that allow for the inclusion of a variety of expressions, stories, identities and histories aligned with the restorative processes of healing at SU" (Stellenbosch University, 2021d, p. 7)

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Using Eye-Tracking for Traffic Control Signage Design at Highway Work Zone

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Abstract /

This paper discusses the application of Eye Tracking (ET) technologies for researchers to understand a driver's perception of signage at the highway work zone. Combining ET within a screen-based motion pictures and a driving simulator, the team developed an analytical method that allowed designers to evaluate signage design. Two experiments were set up to investigate how signage design might affect a driver's visual attention and interaction under various environmental complexities and glare conditions. The study explores the visual perception related to several spatial features, including signage modality, scene complexity, and color schemes. The ET method utilizes total fixation time and time to first fixation data to evaluate the effectiveness of signage presented through screen-based video and a driving simulator.

Keywords /

Eye-tracking; Signage design; Work zone safety

INTRODUCTION

According to the World Health Organization, road traffic crashes claim the lives of 1.25 million people yearly, with about 50 million others sustaining injuries resulting in permanent disabilities (Lee et al., 2018). Recent projections have indicated that by the year 2030, if not addressed, roadway crashes will be the seventh leading cause of death worldwide (Lee et al., 2018). The majority of these crashes, going up to 90%, are a result of human errors (Sharath & Mehran, 2021). Hence, one of the ways to alleviate crashes due to human errors is by providing travel advisory information early and adequately. Conventionally, traffic control devices (TCDs) serve as the interfaces through which travel information, including navigation, guidance, and control, can be provided to drivers on the roadway. These provides warnings to drivers about downstream roadway and traffic conditions, thereby supporting early decision making. The Manual of Uniform Traffic and Control Devices (MUTCD) provides the guidelines and recommendations on the designs and placement of roadway signs. Design characteristics such as colors, shapes, materials, and contrast have been identified to affect the effectiveness of TCDs and are provided as standards for engineers. For example, Speed Limit signs on straight roadway segments are often provided as black ink on white background rectangular signs, Curve Ahead signs are often provided with black ink on orange background diamond-shaped signs, and Work Zone signs are often provided with black inks on red background diamond-shaped signs. These three cases fall under the regulatory, cautionary, and warning categories of TCDs, respectively. Also often encountered are navigation signs positioned overhead to guide approaching drivers and are usually provided as white ink on green background rectangular signs. While these standards are often followed, some cases deviate from the norm, such as the warning signs with many variations in terms of color and shape. These characteristics may affect the effectiveness of TCDs in providing required information to drivers and potentially compromise safety.

Existing studies have shown the impacts of TCDs on driver behavior under various conditions. Zhao et al. (2015) developed a TCD selection model and investigated various alternatives to school zone TCDs and their effectiveness on driver acceleration and speed. The results indicated that the effectiveness of TCDs is different under various roadway and traffic conditions. In some cases, speed limit signs are effective in improving driver safety performance, while School Crossing Ahead Pavement markings are effective in others. Similarly, Zhao et al. (2016) evaluated the effects of school zone signs and markings on speed reduction using a driving simulator study. Their results showed that certain TCDs, such as the flashing beacons and school crossing warning assemblies were more effective in school zones adjacent to a major multilane highway characterized by high traffic volume, high speed, and pedestrian crossing signs. TCDs such as school crossing ahead pavement markings were more effective for school zones on minor two-lane roadways having low traffic volume, low speed, and no pedestrian crossing signs. Brimley et al. (2016) investigated driver behavior with TCDs at roadway curves using crash, roadway, and traffic information. The results showed that drivers unfamiliar with a specific roadway tend to drive more conservatively when the roadway horizontal alignment is treated with TCDs, thereby reducing crashes. Using eye-tracking and brain activity sensors, Yang et al. (2020) evaluated the impacts of highway directional signs on mental workload and behavior. They showed that using multiple boards for directional signs increases mental workload, especially when there are less than eight words needed to pass the information across to drivers. Another study (Lyu et al., 2017) also found a relationship between the amount of information on a traffic sign directly proportional to the amount of cognitive workload experienced by drivers.

Relative to the increasing population in the United States (U.S.), traffic demand on most roadways has also increased significantly, with construction and maintenance work being executed continuously. However, the safety of road users (including motor-vehicle drivers, bikers, and cyclists) and the workers at roadway work zones have attracted attention in recent years. The safety concern has led various Departments of Transportation (DOTs) to investigate the factors responsible for work zone crashes and evaluate measures for improving workers' and road users' safety. The existing safety measures are being reviewed, and new safety-enhancing technologies are being introduced. While a vast majority of crashes occur due to human errors (Diels & Bos, 2016), these errors can arise as a result of the inability to identify, interpret, or respond (early) to the traffic control devices meant to inform road users of upcoming work zones either due to human factors (Adebisi et al., 2019), information over load (Yang et al., 2020), or traffic scene complexity (Lyu et al., 2017).

Arrow panels, trailers, channeling devices, flaggers, flag trees, temporary barriers, attenuators, barricades, warning lights, and work vehicles are some of the TCDs usually seen in work zones. These elements provide the road users with the guidance needed to identify the equipment and the workers early to facilitate safe maneuvers. For example, arrow panels can be used to alert drivers of upcoming lane drops, traffic barriers and cones can be used to separate the work area from the traffic area, warning lights can signal workers ahead, trailers can have reflective materials to serve as visual cues for oncoming road users, and flaggers can complement these TCDs to direct the traffic. Individually, past studies (Qing et al., 2019; Rahman et al., 2017; Rea et al., 2018) have verified the effectiveness of some of these devices in improving safety. However, the design of these devices, has important implications for road users' visual attention and ultimately, workers' safety.

Eye-tracking (ET) is a research technology that helps researchers study visual attention by analyzing the gaze and fixation captured by sensors. The research team has previously applied ET in pilot studies for assessing spatial memory and visual attention toward architectural features (Tang, 2021). Through ET analysis of the signage design within a build environment, the team explored the method to assist designers and architects working on space planning and wayfinding (Tang, 2021). These early projects used Tobii Pro glasses, a wearable eye-tracker for conducting human subject visual experiments. With ET glasses and analytical software, visual data can be captured and evaluated to study how humans perceive visual elements while navigating virtual space. Simpson et al. (2019) provided insights into how pedestrians visually engage with urban street edges using mobile ET technologies under real world conditions. They evaluated how pedestrians visually engaged with urban street edges while performing their daily tasks and the factors that may affect this engagement, including variations in the nature of the social task being performed and the necessity (or optionality) of the task. Their results showed that pedestrians visually engaged more with street edges than other areas of interest (AOIs) such as the ground, sky, other people, objects, and adjacent realms. They also found that the nature and necessity of the task being performed significantly affected visual engagement with street edges.

Similarly, Batool (2021) conducted indoor experiments to investigate view preference in urban environments using ET technologies. The study found that the presence of people, color, and built elements moderates higher visual preference. Also, green, and naturalistic elements were found to have higher preference ratings and low number of longer fixations.

ET has also been used to study the impacts of lighting intensity on gaze fixation and pupil responses under various roadway types (Winter et al., 2017), suggesting that viewing behavior differed between main roads and residential streets. More specifically, eye movements tend to be clustered within a circle of ten degrees diameter centered at the lane horizon compared to residential streets with eye movements clustered within a circle of four degrees towards the near side. This suggests that drivers are more likely to focus on locations of anticipated hazards for specific roadway types when driving after dark.

In a similar context, lighting intensity (measured by luminance) has been found to affect pupil responses and diameter (Tyukhova & Waters, 2019), with findings showing that when background luminance decreases, pupil size increases. This was also correlated with discomfort to glare conditions experienced under exposure to lighting sources. This means that if drivers are exposed to glare conditions, there is a possibility of decreased pupil size and fixation on the area of the lighting source, which could potentially result in crashes on roadways. With discomfort arising from glare conditions and the possibility of pupil size decreases, it is possible to infer safety risks, especially under active driving tasks.

Goldhagen explained in her book, “Cognition is a product of a three-way collaboration of mind, body, and environment” (Goldhagen, 2017). Since the emergence of ET technologies for visual engagement evaluation, attempts have been made to reinforce the validity of ET experiments in both laboratory and real-world conditions, and how it contributes to cognitive evaluation. While there are potential points (in terms of the discrepancies between the natural environment and the controlled laboratory conditions) that need improvement (Ladouce et al., 2017), there exists a number of studies providing methods to improve the applicability of ET data for research under natural conditions (Simpson, 2021).

In the present study, the aim is to investigate the readability of TCDs under varying work zone conditions. With the driver’s body sitting physically in a driving simulator and engaging with the virtual environment through large screens and visual attention measured with eye-tracking (ET) sensors, the research team developed a process to study the cognition of mind, body, and environment. Specifically, the augmented driving simulator offered a promising platform to study human cognition developed through visual reactions in an interactive environment. The researchers analyzed the human visual attention and perception of TCDs. Three factors were considered: (a) signage design, (b) complexity of the work zone environment, and (c) effect of glare conditions on the drivers’ visual behavior. Two research questions were investigated: (1) are the existing signage design modalities effective under all lighting conditions and (2) does glare affect drivers’ focus so it impacts drivers’ visual attention to TCDs?

METHODOLOGY

Two experiments were conducted toward the objectives of this study: (1) the ET experiment and (2) the driving simulation experiment. The former is to obtain objective data to evaluate and quantify visual attention toward the TCDs, and the latter is to reinforce the findings subjectively using questionnaires. In the ET experiment, participants were instructed to sit behind a desktop computer (see Figure 1), and a series of virtual environments containing various combinations of work zone TCDs were displayed on the monitor as motion pictures. Participants’ gaze behavior under each displayed work zone setup was then measured using eye-tracking technologies. The driving simulator experiment involves the participants driving through a virtual work zone utilizing a driving simulator (see Figure 1), after which they are asked a set of questions to measure their perception of the TCDs encountered under each driving scenario. To ensure the accurate modeling of the visual properties of the work zone elements in the virtual environment, we conducted laboratory lighting experiments to obtain optical and photometric properties of standard work zone elements, including cones, pylons, vests, light devices, signs, and other TCDs under real-world settings. These elements were developed in Unreal Engine 4 (UE4), a game-development software that provides a photo-realistic representation of real-world elements and light environments. The UE4 engine has highly realistic graphics rendering and visualization capabilities, which are essential to this study. Also, the UE4 marketplace provides already-designed assets, allowing researchers to purchase other simulation elements used in this study, such as trailers and actor animations, without developing them from scratch, further adding to the realism of the virtual environment.

Experiment Design and Setup

Experiment 1: ET Experiment

In the ET experiment, pre-recorded videos of work zone elements positioned in a virtual world were displayed to participants. Based on the three factors considered in this study, we designed virtual environments in UE4 and placed simulated elements in the virtual world. Each virtual environment represents a combination of TCD modality (words only, symbol only, and hybrid), scene complexity (low, medium, and high), and color combinations for the signage devices (orange-green, red-white, and yellow-black). Figure 2 shows the TCD modalities considered in this study, representing the yellow-black color combinations. Figure 3 shows three virtual worlds representing three different variations of

Figure 1 /

Data Collection Setup: (left) Screen-based sit-down experiments with Tobii-ET glasses, (right) Driving Simulation Experiment

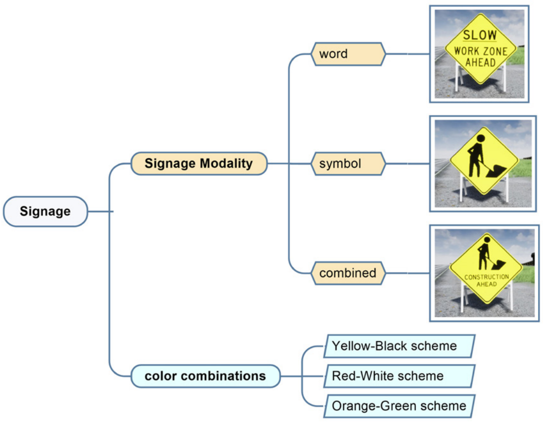

Figure 2 /

TCD modalities and color schemes used in the study.

Figure 3 /

Three levels of scene clutter intensity with TCD color schemes. Top to bottom: Low, Medium, and High

scene complexity. It should be noted that the virtual elements in these scenes are animated, including the lighting fixtures and the workers. All the fixtures behave as they would in a typical real-world setting. The animated videos were recorded and trimmed to meet the clip duration requirements. The videos were then embedded into slides with one blank slide between each video as a gaze reset time for the participants. Each video, as well as the gaze reset time, lasted for five seconds. There were 27 clips representing the 3 x 3 x 3 combinations of TCD modality, scene complexity, and color combinations. The TCD devices were placed randomly in the virtual environment on either the left or right side to reduce learning effects and decrease possible bias that may arise from putting them in the direct focus of the participants. The experiment was conducted on a desktop computer with an 11 x 22-inch screen size, and each participant was allowed to adjust the height of the monitor relative to their eye level before starting the experiment. Participants sat behind the computer with calibrated eye-tracking glasses and focused on the virtual environments as they were automatically displayed on the monitor (Figure 1, left). The clips were shown in the same sequence and took the same duration for all participants.

Experiment 2 – Driving Simulation Experiment

After the first experiment, participants were given a 5-minute break to regain energy, walk around, or attend to other personal activities as they liked. This also reduces the likelihood of early simulation (motion) sickness during the second experiment involving driving simulation. A freeway segment with a 60-mph speed limit and three lanes in each direction was designed for the driving simulation experiment. The lane markings, lane widths, and roadway signs were designed to match the U.S. standards. Like real-world roadway segments, traffic on the leftmost lane was modeled to have speeds closer to the speed limit, and the traffic on the rightmost had slightly lower travel speeds. Vehicle arrival was random, and traffic intensity was low. A high-complexity work zone (Figure 4) was set up along the participants' driving route to match the standard setup approved by the MUTCD. Three advance warning signs were placed before the transition area. The first was placed 1000-ft from the transition point, the second 2500-ft, and the third 5200-ft. The speed within the work area was set at 35 mph. We assume that the high complexity setup provides the most extreme condition, and the results can be used to make inferences for lower complexity conditions.

Equipment and Apparatus

Tobii glasses, the eye-tracker used in this study, is a wearable eye-tracker designed for human subject visual experiments. It includes illuminators, a camera, eye-modeling and gaze map algorithms, and data collection and processing units for image detection (Tang, 2020). The eye tracker continuously recorded gaze data throughout the experiment, and the timestamps where the video clips appear on the computer screen were extracted as the times of interest (TOIs) and used to calculate the gaze behaviors. The FD401CR driving simulator (Figure 1, right) was used for the driving simulation experiment. It is a high-performance, 4-axis, motion base simulator with low latency and high-frequency response that allows it to move and twist in three directions of yaw, pitch, and roll, and replicate vehicle dynamics such as acceleration, deceleration, braking, and its interaction with the virtual driving environment. The movements are factory-tuned to match real-world vehicle motion and ensure simulation sickness is reduced. It is equipped with an NVIDIA operating system and three Acer monitors that provide occupants with a 180-degree field of view. The steering wheel and pedals are integrated with the UE4 game engine that sends internal driving dynamics to create force feedback for the steering wheel and motion feedback for the simulator. The audio system is a 5.1 surround sound that provides sound cues from the simulated vehicle to produce engine noise and vehicle -road interactions.

Experiment Procedure and Data Collection

Fourteen participants were recruited to participate in both experiments under a protocol approved by the University's Institutional Review Board (IRB) through online sources and using flyers posted in specific locations on the campus. There were 57% males and 43% females, and all participants had a valid U.S. driving license at the time of the study. Participants had an average driving experience of 6 years, and 28% reported having participated at least once in a driving simulation experiment. It should be noted that older participants (above 64) were exempted from this study due to the ongoing COVID-19 pandemic at the time of this data collection. Participants were welcomed into the testing facility and given an informed consent form to read and sign per IRB directives. Following the consent, participants completed a questionnaire on demographic and driving characteristics and were directed to the sit-down experiment, and the eye-tracker was calibrated. Then, participants were instructed to adjust the desktop moni-

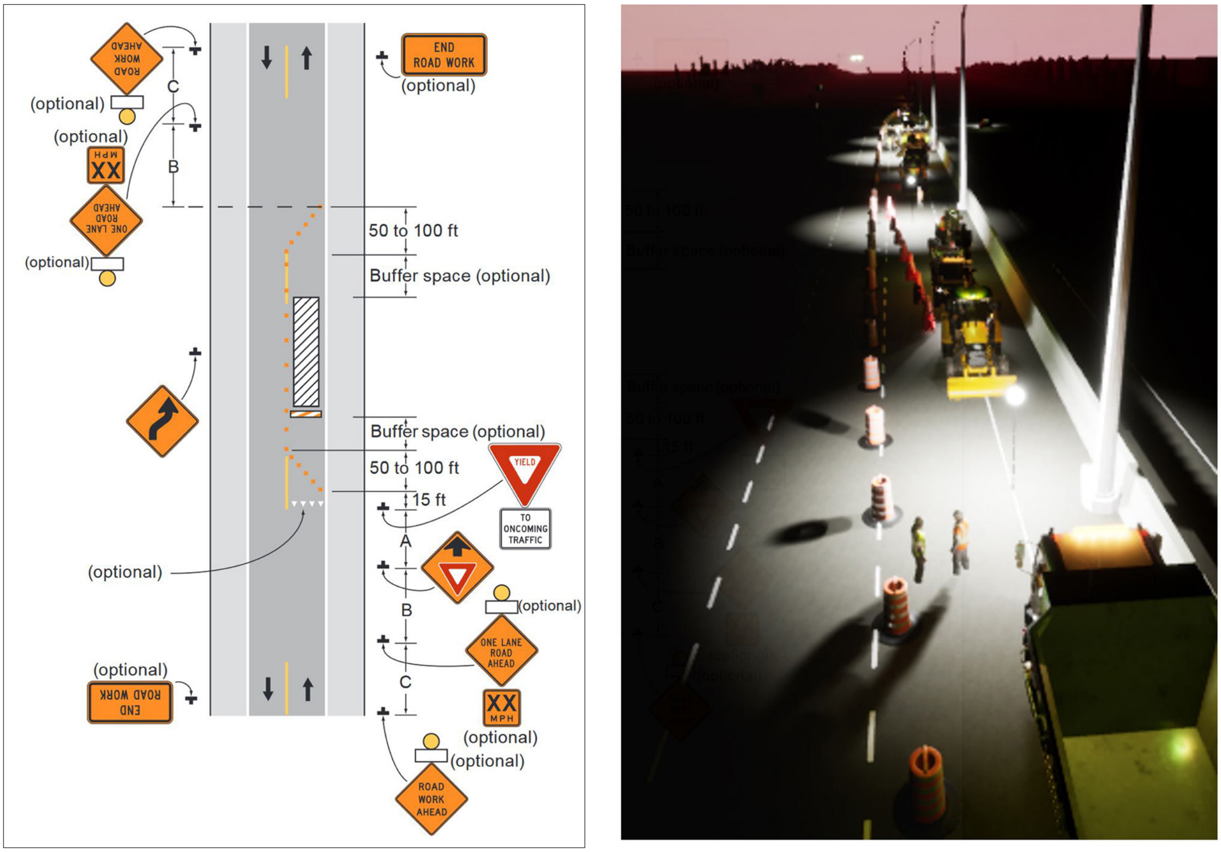

Figure 4 /

Left: Reference layout of Work Zone based on Ohio Department of Transportation (ODOT, 2019). Right: Virtual Work Zone and TCDs in UE4.

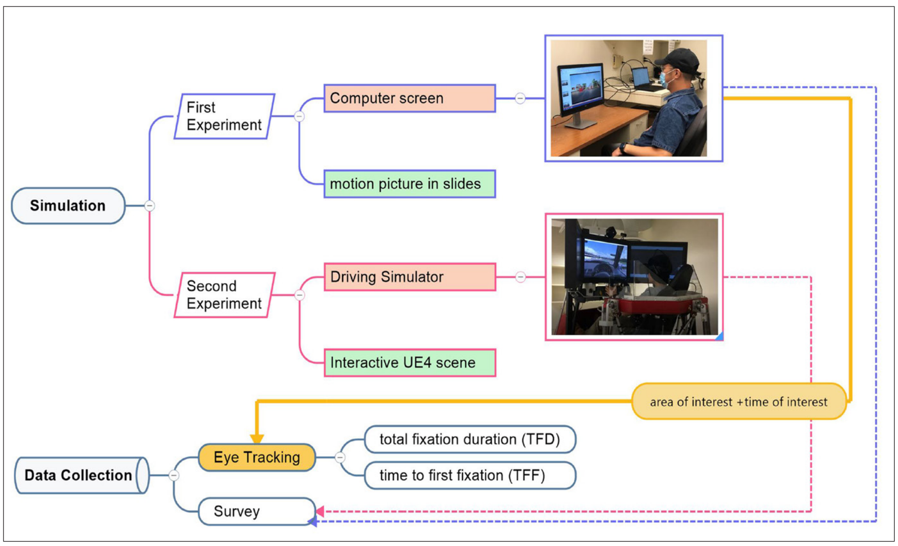

Figure 5 /

ET with screen-based video and driving simulation data collection setup tor to their eye level and focus on the monitor. To ensure consent, participants were told they would be wearing glasses that *"monitors eye movements."* However, they were not told what they should pay attention to during the sit-down experiment to ensure there was no bias from prior information. A 5-seconds long motion picture of a virtual work zone environment (different from the ones for the experiment) was then presented to the participants to familiarize them with the procedure, after which participants were asked to respond with Yes or No if they saw the workers, the trucks, and the traffic signs in the virtual environment. Following this, the actual virtual environments were then presented for four (4) minutes, and the gaze behavior of the participant was recorded. Each participant spent approximately 35 minutes in the testing facility, and a compensation of $50 was provided upon testing completion.

The eye-tracker was used to collect eye fixation and saccades. A fixation represents maintaining the eye focus on a specific AOI, while a saccade represents the fast movement of the eyes between fixations. The AOI in this study was the standing region of the TCD in the virtual environment. For each scenario, a manual schematic mapping approach was used to obtain the gaze on each AOI. To achieve this, researchers watched each ET video and mapped the gaze to a representative figure created to help in the manual mapping process. This involved using the Tobii Pro analyzer to create event markers representing the start and the end of each 5-second motion picture of the virtual environments mentioned earlier. Since there were 27 of these displayed motion pictures, there were 54 event markers for each video (representing each participant). Then the video was played back from the beginning with the fixations turned on so that the researchers could visually observe the fixation recordings from the eye tracker and see where the participant was fixating at each timestamp. These fixations were then noted for each AOI in this study. Hence, the researchers noted the fixations for each 5-second motion picture of each of the 27 scenarios for each AOI (region of the TCDs). While this approach is time-consuming, it is more accurate and reliable for this type of data collection in which the AOIs are placed randomly in the virtual environment, and the perspective of the AOI changes from one video clip to another. This provides all the metrics required in terms of saccades and fixation.

The extracted metrics included the time to first fixation (TFF) and the total fixation duration (TFD). The TFF indicates the time elapsed from the presentation of a stimulus to the first fixation on an area of interest, and the TFD indicates the total fixation duration on an area of interest over the presentation of a stimulus. The TFF and TFD were selected because they are among the most commonly used eye-tracking metrics in the literature. Also, they are intuitive to interpret, and reflect the objectives of this study, which is to evaluate visual attention in terms of how soon from exposure (first fixation) and how long during exposure (fixation duration) a participant visually registers a specific AOI, in this case, the TCDs.

The fixations and saccades were directly extracted based on the Tobii software. The software defines fixations based on the Velocity-Threshold Identification (I-VT) algorithm. The I-VT algorithm uses a velocity classification technique to classify a gaze as either a fixation or a saccade based on the directional shifts of the eye. A gaze is classified as fixation when it crosses a specified velocity threshold and as a saccade when it is below the same threshold. This study adopted the default threshold value of 30 degrees per second (more information can be found in Olsen, 2012). All data were collected at 100Hz. Similar to Bhagavathula et al. (2017), we used the linear mixed models (LMM) to assess the fixed effects of design type, cluster conditions, and the color scheme on the time-to-first fixation and the fixation duration. The interaction effects were also tested using the LMM. Where needed, post hoc analyses were conducted using Tukey's honest significant difference for comparison to obtain the main effects and simple effects of significant interactions.

DISCUSSION AND CONCLUSION

In this study, we measure driver's visual attention data through two TCD experiments. The ET results are intended to help designers evaluate variables such as

TCD modality, scene complexity, and color combinations. The research served as a pilot study of how the spatial experience can be interpolated into TCD design decisions. This ET research allows designers to evaluate various TCDs iterations and to determine which visual elements draw visual attention under different modalities, color schemes, and scene clutter.

Insights from Experiment 1

Time to the First Fixation on the Traffic Control Device

The main effects of color scheme [F (2,136) = 3.23, p = 0.04] and design [F (2,136) = 2.68, p = 0.07] were significant as well as the two-way interaction effects involving clutter and color [F (4, 136) = 1.38, p = 0.09], and all three factors combined [F (8, 136) = 1.72, p = 0.1]. The combined effects of clutter and color on the time-to-first fixation are shown in Figure 6. The TFF is not significantly different between the Orange-Green and the Red-White color schemes in all the clutter intensity conditions. The TFF on the Yellow-Black scheme was affected by the clutter intensity. Contrary to expectations, the TFF for the Yellow-Black scheme was shortest under the medium clutter intensity (mean = 1.19s, SD = 1.27) and longest under the low clutter intensity (mean =1.92s, SD = 1.09).

The differences between the color schemes within each clutter intensity were evaluated to analyze the two-way interactions further. The effects of color schemes were not significant in the "low" [F (2, 287) = 1.63, p = 0.20] and "high" [F (2, 289) = 1.91, p = 0.16] clutter intensity but were significant in the "medium" intensity [F (2, 251) = 5.96, p = 0.003] with the Yellow-Black scheme being significantly lower than the Orange-Green and the Red-White and the pairs were not significantly different. Simple effects revealed no significant differences between the color schemes for the "low" and "high" clutter intensity scenarios. Further, under glare conditions, the Yellow-Black color scheme had the least TFF (1.50s) compared to Orange-Green (1.75s) and Red-White (1.89s). However, the differences were not statistically significant across all testing conditions.

Total fixation duration on Traffic Control Devices

The results for the TFD are also shown in Figure 6. The main effects of clutter intensity [F (2, 243) = 5.95, p = 0.003] and the two-way interactions involving clutter intensity and color [F (4, 243) = 2.92, p = 0.02] were significant. Figure 6 also shows the combined effects of color and clutter intensity for the TFD. Under low clutter intensity, only the TFD on the Yellow-Black scheme was significantly lower than the Red-White scheme. There was no significant difference between all color schemes for the "medium" and "high" clutter conditions. We also investigated the two-way interactions between color schemes in each clutter intensity and results showed the effect of color were only significant under the "low' intensity [F (2, 42) = 3.31, p = 0.04] conditions and not under the "medium" [F (2, 40) = 1.01, p = 0.37] or the "high" [F (2, 22)

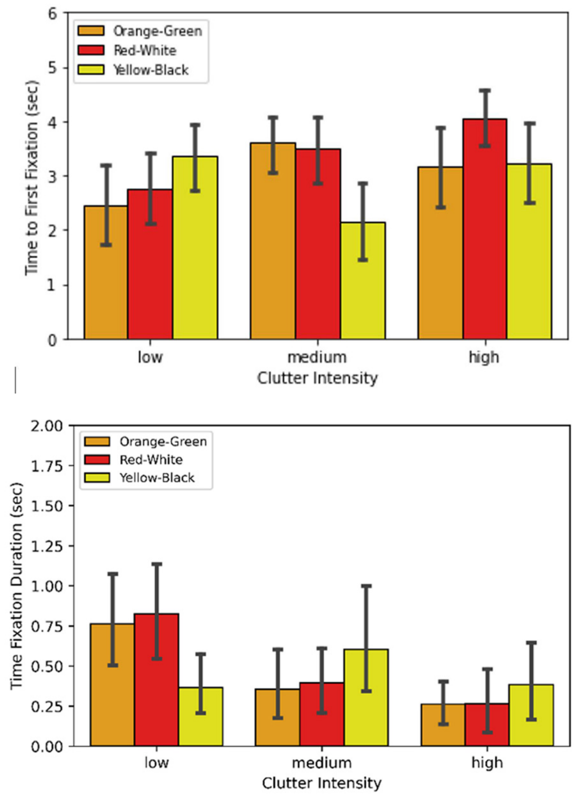

Figure 6 /

TFF and TFD interaction of color and clutter (on different scales)

= 0.48, p = 0.62] clutter conditions. Also, under the glare conditions, the TFD for the Orange-Green scheme was lowest (0.35s) compared to Yellow-Black (0.39s) and Red-White (0.46s). However, the differences were not statistically significant.

Based on the TFF and TFD against various modalities, we find there are more non-fixations on the signs with words only. Signs with both symbols and words are seen more frequently, followed by those with symbols only (Figure 7). We also find signs with symbols have more fixation duration above one second, indicating they are fixated on longer. The longer fixation could be a result of excess information (Figure 8).

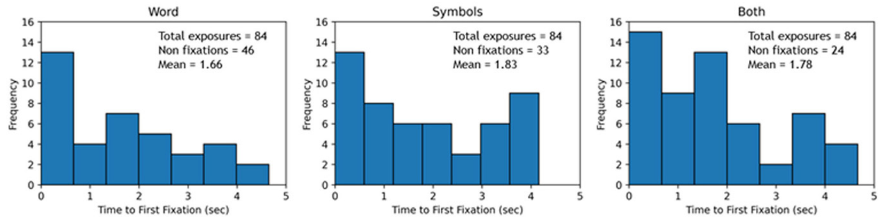

Figure 7 /

Time to first fixation (TFF). Means are not significantly different (p-value >> 0.05)

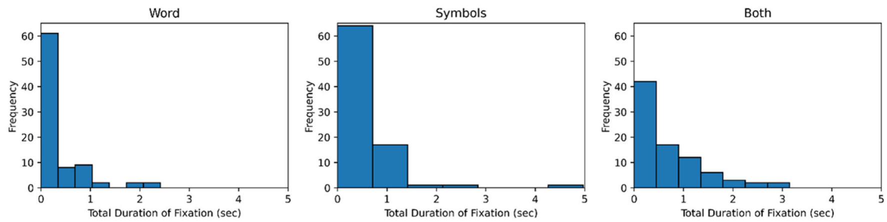

Figure 8 /

Total fixation duration. (TFD)

Table 1 / Results under no-glare lighting conditions

Measure	Design			Significance	Dunn's test	
	Orange-Blue	Red-White	Yellow-Black		Groups	*p*-value
Time-to-first Fixation (sec)	1.67	2.32	1.47	H = 6.40, p-value = 0.04	OG & RW	0.18
					OG & YB	1.00
					RW & YB	0.04
Total Fixation Duration (sec)	0.57	0.53	0.52	H = 1.78, p-value = 0.45	-	-
					-	-
					-	-

Table 2 / Summary of personal characteristics across the independent groups

Measure	Design			Significance	Dunn's test	
	Orange-Blue	Red-White	Yellow-Black		Groups	*p*-value
Time-to-first Fixation (sec)	1.75	1.89	1.50	H = 1.01, p-value = 0.6	-	-
					-	-
					-	-
Total Fixation Duration (sec)	0.35	0.46	0.39	H = 0.19, p-value = 0.9	-	-
					-	-
					-	-

The impact of glare on the readability of TCDs is also assessed. In the noon light (no glare) simulation, Yellow-Black has a significantly lower mean time-to-first fixation than Red-White at a 95% confidence interval. The TFDs are not significantly different (Table 1). Under the glare conditions, Yellow-Black has the lowest mean time-to-first fixation (TFF), though none of the color combinations are significantly different (Table 2).

In conclusion, as a result of TFF and TFD analysis on three color schemes (Orange-Green, Yellow-Black, and Red-White), there were no significant differences between the TCD design schemes in standard lighting and glare conditions. However, this pilot study had only14 participants. For more robust results, the next research phase will include a larger number of participants.

Limitations and Plans for Experiment 2

In Experiment 2, the interactive driving simulator allows for a high-fidelity experience towards driving and considers every visual element of TCDs. The qualitative survey data collected from the driving simulator is more related to the road construction workers' visibility than the TCDs design. The surveys help explain the perceptions of TCDs from dynamic experience instead of a fixed angle rendered video. The researchers have learned from the survey that the human optical system does respond to the visual aspects in specific ways. Although the simulator experiment aims to collect the survey data, we also collected driver's ET data with Tobii glasses. However, the individual ET captured through driving simulator participants does not share the same timestamp due to the different driving speeds and behaviors. As a result, we cannot statistically combine the datasets from the group of 14 participants to analyze TFF and TFD. We are interested in overcoming this "timestamp" issue for the future stage while recruiting a more significant number of participants. We are investigating an alternative method of augmenting the driving simulator experiment, such as removing individual drivers' speed control to force a universal time stamp across the ET group in the simulator experiment.

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Book Review:
Library Signage and Wayfinding Design: Communicating Effectively with Your Users
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Book Review

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There have been a large number of wayfinding publications over the last 15 years. These books tend to fall into three types:

Wayfinding Design: Books that focus on the intersection of the wayfinding discipline with the design process. These books are meant to appeal primarily to design students and a professional design audience. Books in this camp use visual best practices to illustrate successful methodologies. These books include *Wayfinding* by Craig Berger (The author of this review) and *The Wayfinding Handbook: Information Design for Public Places* by David Gibson.

Wayfinding Research: Compilations and overviews of wayfinding research and its impact on design metrics and principals. The books try to avoid subjective extrapolation to focus on cognitive research methodologies. The most well know research in this area are the publications of the United States Sign Council and the Sign Research Foundation.

Wayfinding Planning: These books are a hybrid. They provide a research overview as a foundation for practical recommendations and design practices. These books employ current design and planning examples to exemplify both research results and deep-seated processes. Examples of these books include *Signage and Wayfinding Design* by Chris Calori and *People, Signs and Architecture* by Paul Arthur and Romedi Passini.

All three types of books are important to the academic and professional world of wayfinding and sign design. Successful books may accent research, processes and design practices at different levels, but they all acknowledge that these three areas are important to understand the breadth of the field.

This brings us to *Library Signage and Wayfinding Design* by Mark Aaron Polger, a book that falls firmly in the hybrid camp, combining deep contextual research, a clear articulation of design processes and design approaches that support these practices. The book largely succeeds in the first two areas, providing clear guidance and methodologies for wayfinding development, while falling somewhat short in the design practice area. Neglecting the third area prevents the book from reaching its full potential, a marriage of the deep well of cognitive research, exemplary processes, and the alchemy that designers provide when applying these approaches in places and spaces.

The successes of the book begin with laying down a clear foundation of wayfinding research before delving into the specifics of wayfinding for libraries. The author provides an extensive overview of the most recent research practices from ethnographic methodologies to observational approaches like eye tracking. The author also lays out a foundation in existing research in wayfinding in signs, typography, and library navigation before beginning the specifics of planning methodology. This approach is well documented, and all the sources are relevant. Even for practitioners in the field this basic overview is useful and establishes a credible benchmark for the focus areas in the book.

Throughout the book there are illustrations that support these foundations, and they are all very clear and comprehensible. While as a design professor and writer of design books I may have issue with the design quality of some of these examples, they do illustrate the academic underpinnings of legibility and cognition. The before and after pictures also provide strong illustrations of the impact of these underpinnings in real life.

The book then delves into the planning stage with illustrated examples of sign audits and recommendations. This section is granular in detail, showing specific library issues and problems with existing signs and how audit and design teams resolved these problems. Some of the visual examples are excellent as well, showing how even the most basic recommendations founded on cognitive research yields impressive results for legibility and an overall understanding of navigation.

An important part of the audit stage is how the audit process itself is treated as a professional area that combines planning, management, design and technology issues. Very few books delve into the nuts and bolts of the auditing process, and particularly management and visitor analysis. However, this section has some difficulties illustrating the balance between wayfinding and place. The best example in the section, the Malcolm E. Love Library, at San Diego State University, focuses on the specific improvements (high contrast signs), but not the specific architectural and placemaking issues that define how the space will be navigated. This is a section that perhaps could have also explored similar institutions to libraries with navigational issues. Issues like illumination, identification and mapping are more universal. Sharing pertinent examples from healthcare and education could illustrate the collision of wayfinding methodologies with placemaking. Healthcare is an area where there has been extensive experimentation in many of the wayfinding solutions found in the book. The book could also have explored the reverse, where excellent wayfinding practices in libraries could be a model for other facility types.

Another element that would have made the book more effective would be isolating design issues such as the use of typography and color, and providing more detail. The book does get to the fundamentals of these issues, but a little more depth would be helpful, particularly when delving into some of the more specific topics like nomenclature.

The book correctly goes in-depth into digital content and the user experience as part of the larger wayfinding environment. The exploration of technical software specifications along with content management is excellent and provides the reader with a comprehensive view of the field. Strangely though, while this section is among the most in-depth in the book it does not provide as many visual examples. This may partly be because of the newness of the field, but as mentioned before, examples from other types of facilities could fill in, particularly with more universal areas like maps and search programs.

An additional important wayfinding element that could have played a role in the book is the architecture of the buildings. Unlike most other institutional buildings modern libraries vary dramatically in architectural approach

Figure 1 /

Vancouver Community Library by Mayer Reed is an excellent example of how library wayfinding signage can serve as a model for other institutions.

and are often considered by cities and universities as "trophy buildings." They also often organize space in creative and unique ways including reading areas, specialty book sections, and areas for display. A review of some different building approaches, particularly with newer buildings, would provide extra depth.

As with other treatments of planning and design methodology, this book really shines when articulating the best practices of various libraries. These practices range from design guidelines to the use of digital signage. For planners or designers engaged in related projects these explicit recommendations from built facilities are highly effective, particularly when many views can be applied in a number of different contexts. As such, the book responds well to the needs of end users and planners by utilizing a list-based approach which is easy to read and articulates the ideas coherently.

Library Signage and Wayfinding Design is a very useful book that should appeal to any person who develops library facilities or works in the design arena. The book can also be a particularly strong aid when writing Requests for Proposals for projects, developing a stakeholder engagement plan, or testing an idea. However, the neglect of larger spatial design issues and the need for more powerful design examples may create issues of credibility in the design community. Compared to wayfinding issues in transportation, healthcare or larger academic facilities, libraries are not often seen as locations for design excellence or innovation. Yet, aggressive and even experimental design ideas can be a source of inspiration when combined with innovative research methodologies and approaches. Indeed, the

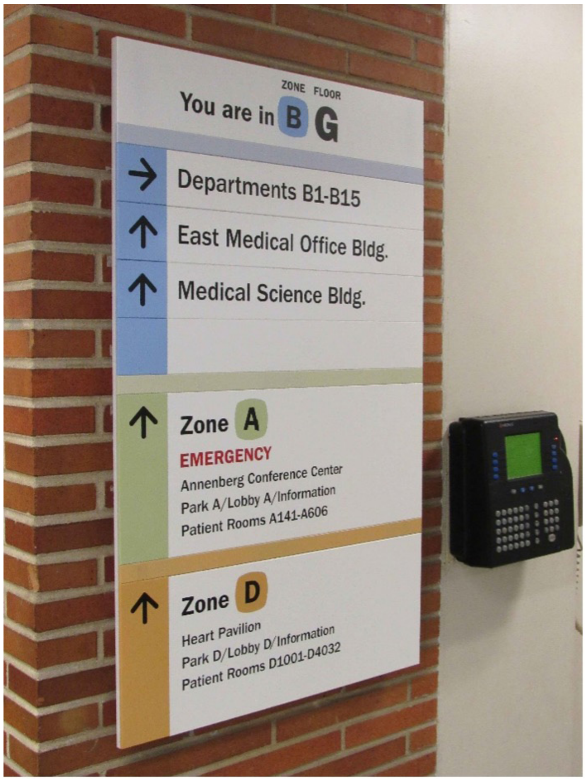

Figure 2 /

Libraries have many wayfinding issues that are similar to those found in other facilities like hospitals and labs. For example, the signage in Lankanau Hospital by Exit illustrates a variety of universal design issues including color, type and directional format.

marriage of design, place and information can provide the cues needed to take library projects to the next level.

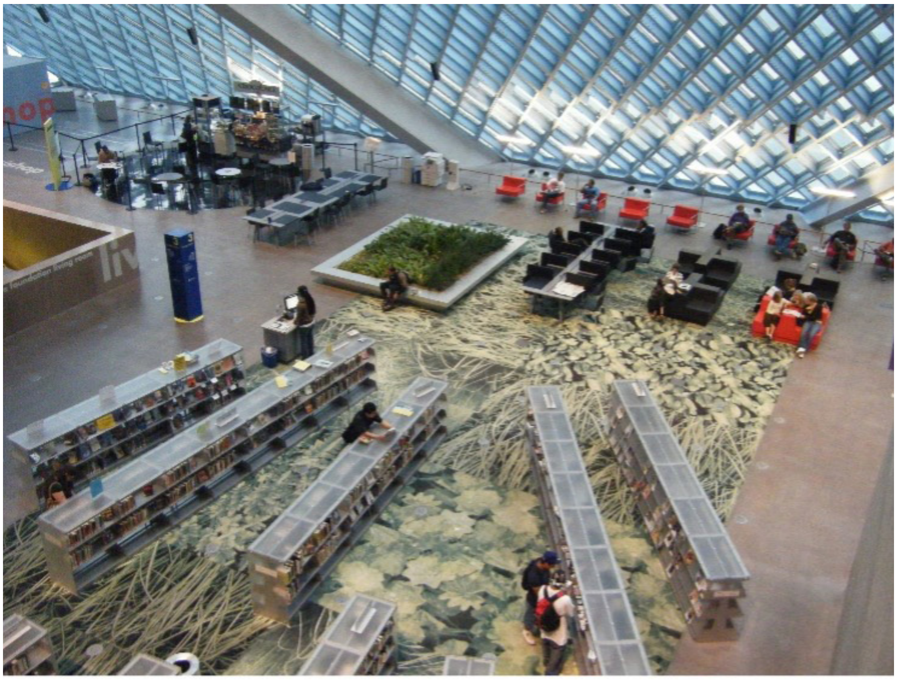

Figure 3 /

The Seattle Public Library by OMA is a massive architectural landmark with spaces that required grandiose graphic treatments.