Landmark Modality in Wayfinding: Does it Make a Difference?

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Abstract

Navigation is a process that humans use to get from A to B. Landmarks used during navigation and wayfinding can address different sensory modalities. We examined landmark information in four different variants: as a written word, as a spoken word, as a picture, or as an odor. Our 51 participants were separated into four groups. Each group received one specific variant of landmark information integrated into a learning and wayfinding video of a virtual maze with 12 intersections. At each intersection, one landmark information was presented. To assess how well the relevant landmarks could be distinguished from unknown distractor items of the same condition, the experiment concluded with a recognition phase, where 24 stimuli were presented (12 landmarks + 12 distractors). Relative frequencies of correct responses and mean response times were measured for wayfinding and recognition. Odors lead to similar correctness in wayfinding compared to the more common landmarks (pictures, written and spoken words), even though requiring longer response times. We stepped away from the traditional but limited view on landmarks towards a more holistic (i.e. including all senses) view of human orientation. Implications for future scientific research are being discussed.

Keywords: landmarks; wayfinding; recognition; modality

Introduction

Think about a path you use frequently and imagine what lies along your way whilst walking. What do you see? Maybe you see an old church or the playground you used to play on when you were a child. Maybe you imagine the street food restaurant that you can smell as soon as you turn around a corner or a train station that you can hear from the trains arriving and the announcements on the platforms before you even see it. The possibilities here are uncountable. However, they have one thing in common: they are all possible reference points, so-called *landmarks* (Caduff & Timpf, 2008; Lynch, 1960; Richter & Winter, 2014), which are defined as significant, or *salient*, points along our way used for navigation (Newman et al., 2007; Richter & Winter, 2014). When planning and describing a route, we use landmarks at *decision points*, hence, at intersections on our way where we have to decide about the direction (Michon & Denis, 2001). They are also thought to be helpful in the imagery of wayfinding (Michon & Denis, 2001). The higher a landmark´s salience, the higher the probability of it being recalled later (Fine & Minnery, 2009). The salience of landmarks describes their structural/contextual, semantic/cognitive, or visual properties (Caduff & Timpf, 2008; Röser, Hamburger & Knauff, 2011). *Visual salience* describes the landmark´s bottom-up features, like shape, color, details, etc. (Caduff & Timpf, 2008; Klippel & Winter, 2005). Here, the definition has also been extended to *perceptual salience,* which, according to Röser, Krumnack, and Hamburger (2013), means that an object/landmark is perceptually salient if it "stands out" against other, irrelevant objects. On the other hand, *semantic salience* is the personal meaning and knowledge connected to the landmark, which is why one landmark might have two different saliences for two different people (Klippel & Winter, 2005; Nuhn & Timpf, 2017). In other words, the playground you played on might be a salient landmark for you, but not for somebody who does not have this personal connection. Landmarks do not only vary in salience but also in their modality (visual, auditory, olfactory, haptic, see, e.g., Meilinger, 2005) and in their valence (positive, negative, neutral) and arousal (Hamburger & Herold, 2020; Piccardi et al., 2020). Damasio (1996) introduced his somatic marker hypothesis to explain the gap between overt decision-making and implicit processes like emotions or conditioning. From Damasio´s theory (1996), we can say that emotions and other somatic responses are connected to and influence our decisions. Balaban et al. (2017) found that negatively laden landmarks are connected to better recognition and wayfinding performances over time. They concluded that emotions might increment the landmarks´ semantic salience, which is why even over time, they are better consolidated.

Congruently, recent research has been discussing the role of odors as landmark information for wayfinding (Hamburger & Herold, 2020; Hamburger & Knauff, 2019), because odors are known to be connected to our emotions (e.g., Adolph & Pause, 2012). Research has shown that even though the olfactory system is the least dominant sensory modality in humans (Hick & Hick, 2013), odors can serve as cues for recall and enhance verbal recall and the effect of pictures on recall (Lwin, Morrin & Krishna, 2010). Still, little is known about odors as landmark information (Hamburger & Knauff, 2019). Hamburger (2020) criticized that landmark research has a long time solely focused on visual landmarks for a sensory aspect. He argued that landmark information addressing different sensory modalities should be examined to access landmarks in all facets.

To shed further light on this critical point, the present research uses written words, pictures, spoken words and odors as landmark information. We want to explore whether different landmark information modalities can be recognized and used in wayfinding equally well. Past research has primarily focused on visual landmark information (e.g.,

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Tommasi et al., 2012; Vinson, 1999). It is, therefore, our goal to compare the more “traditional” visual landmark information like pictures or written words (Hamburger, 2020; Montello, 2017; Röser et al., 2011) with stimuli like spoken words or odors, which have raised scientific interest only recently (Hamburger & Herold, 2020; Hamburger & Röser, 2014; Porter et al., 2007). When planning this experiment, we also came across research regarding haptic material, which seems to be especially useful for people with visual impairments (Koutsoklenis & Papadopoulos, 2014). The fact that we still decided against applying this category of stimuli arose from the practical difficulty of presenting comparable materials throughout the various experimental conditions. While, e.g., aftershave, alcohol and vinegar could be distinguished in all of our experiment´s conditions, it would have been difficult for participants to distinguish the three just by touching them. We also examine the difference between perceptual and semantic (Paivio, 1978) landmark information. Knowing that perceptual and semantic salience can have an effect on how much a stimulus stands out and can hence be remembered (Klippel & Winter, 2005; Röser et al., 2013), we hypothesize that using different landmark information (written words such as visual-semantical, pictures as visual-perceptual, spoken words as auditory-semantical and odors as olfactory-perceptual landmark information) lead to differences in wayfinding and recognition. This effect, we assume, will consequently be visible comparing perceptual (pictures, odors) and semantical landmarks (written words, spoken words). We measure performance in relative correctness in responses given and the respective mean response time.

Methods

We used a one-factorial design to compare four conditions of landmark information (pictures, written words, spoken words, odors) regarding the relative frequency of correct decisions taken (i.e. correct answers) and the response time in wayfinding and a recognition task. In a second analysis, the landmark modalities are only referred to as “semantic” and “perceptual”, integrating written and spoken words for the semantic condition, while pictures and odors would account for the perceptual condition.

Participants

Fifty-one participants, mostly university students (31 females), participated in the present study. Their age varied from 18 to 53 years, with an average age of about 24 years (*SD* ~ 5). Only participants with normal or corrected-to-normal vision were admitted to the study. In addition, the participants were required to have no limitations to the olfactory system (e.g., common cold, sinusitis, etc.). Participants with an epilepsy diagnosis or a diagnosed family member were not allowed to participate due to safety reasons: Participants were pseudo-randomly assigned to one of the different experimental conditions (between-subject factor design).

Material

We created the 12- decision- points- virtual maze videos with similar properties regarding walking speed and block height to Hamburger and Knauff (2011), which were presented via a laptop of the model Acer Aspire V17 Nitro BE, 17.3 inches (7th generation Intel© Core™ Processor, GPU NVIDIA GeForce GTX 1060. 16 GB RAM). For each landmark information, 24 stimuli were created, 12 of which would then be used as target stimuli for learning and wayfinding videos, and the remaining 12 would be added only for the recognition. To prevent position effects for the stimuli used during learning and wayfinding (Hurlstone, Hitch & Baddeley, 2013; Karimpur, Röser & Hamburger, 2016; Röser et al., 2013), three different stimulus sequences were used. All three routes had the same turning directions. Participants were pseudo-randomly assigned to a sequence. The precise learning and wayfinding route is depicted in figure 1. Table 1 displays target landmarks and distractors, previously validated in an unpublished project. Participants were passively conducted through the maze for all conditions, routes, and sequences. However, this will be referred to as “walking” and “turning” in the following.

For the visual-semantic condition *written word*, the words were written in black on white in a sans-serif 62-point- font before being inserted into the virtual maze using Google© SketchUp 6.4©, which adapted the stimuli to the maze´s walls, guaranteeing that all stimuli had the same size throughout the maze. The stimuli for the condition *pictures* corresponded to these settings. All visual stimuli were inserted centrally into the maze (Hamburger & Knauff, 2011) and touching the walls to avoid possible positioning effects on the landmark information´s salience (Klippel & Winter, 2005; Röser et al., 2013). Creating the *spoken words* for the auditory-semantic condition, we used a Blue Microphones-microphone (Yeti USB) set to “omnidirectional mode”. Since the spoken words were shorter than five seconds, their presentation would have been too short for participants to understand them well enough. Moreover, their absolute presentation time would have been shorter than all other three conditions if we had not decided to present the spoken words three times. So, we guaranteed sufficient identifiability and standardization in our material (five seconds presentation for all four conditions). Since we wanted to conduct basic research, we accepted that the external validity of the spoken words information could be reduced due to this procedure. Each participant was presented with all 12 target items of their assigned condition during the learning and wayfinding phase, and afterwards, the 12 targets vs. 12 distractor items during the recognition phase (total: 24 stimuli). The *odors* for the olfactory condition were essential oils or the fresh product, like fish, which the experimenter presented by holding the glass vials containing the scent under the participant´s nose for a standardized time of five seconds. The videos for the *spoken words* and the *odors* condition were identical to the other conditions regarding route and sequences, except that the intersections were empty. The stimuli were either presented by the experimenter (odors) or the laptop´s speakers (spoken words). Examples of the picture condition and an empty intersection can be seen in figure 2.

Every two intersections, the video stopped, and one stimulus was presented for five seconds. The video continued afterwards, turning left or right, taking five seconds. There were ten seconds of "walking" between each of the intersections. All videos and the recognition phase were implemented and sequenced using the software OpenSesame (version 3.2.4 Kafkaesque Koffka) to play the videos in learning and wayfinding (walking, presentation, turning). This software also recorded participants´ responses. Independent of the responses given, the videos proceeded in the correct direction to keep participants from "getting lost" and provide data for every intersection.

For the recognition phase, distractor and target landmark information were shown context-free. In other words, the stimuli were presented one after another, separated by a fixation cross without being integrated into a maze. The fixation cross guaranteed the participant´s attention to the screen in all conditions. Here, too, each stimulus was presented for five seconds to guarantee comparability.

Table 1: List of landmarks shown in the learning, wayfinding and recognition phase, and list of distractors (shown in the recognition phase only).

Landmarks	Aftershave, alcohol, aniseed, cinnamon, curry, fresh laundry, garlic, lemon, tangerine, strawberry, thyme, vanilla.
Distractors	Banana, clove, coconut, cocoa, eucalyptus, fish, lavender, nail polish, orange, peppermint, rose, vinegar.

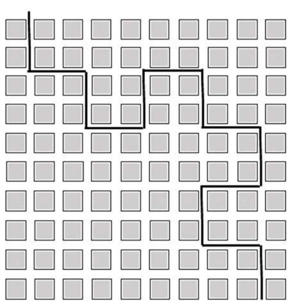

Figure 1: Route for learning and wayfinding videos.

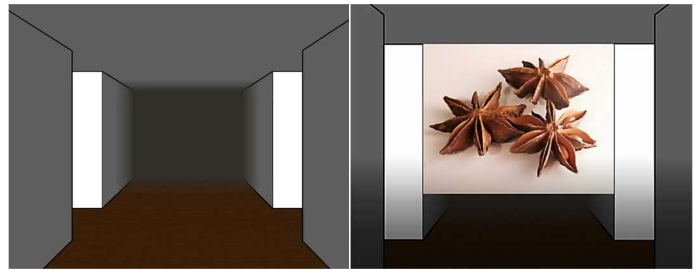

Figure 2: Examples for empty intersections (auditory and olfactory condition, left) and the visual-perceptive condition (right). Likewise, the visual-semantic condition with the written words.

Procedure

In the beginning, the participants received an informed consent form and a brief introduction to the experiment. A demographic questionnaire followed.

The experimental phases proceeded as follows: learning – wayfinding – recognition. Hence, the landmarks were seen and encoded twice before going to the recognition phase, where they would be confronted with the distractors, which had not been shown before. Having focused our experiment on measuring wayfinding, we decided to proceed this way. Moreover, this procedure prevented participants from merely learning the items with and without a direction, which would have made the learning phase pointless. Between each of the three phases, the participants could take short breaks to guarantee their well-being and focus on the task, especially for the *odors* condition, which we thought could have been tiresome for the participants and their noses. Whenever participants felt the need to neutralize and "reset" their sense of smell, they could smell coffee, which we kept in a closed box in the laboratory.

In the learning phase, the participants should watch the video and memorize where "they" turned at the intersections connected to the presented landmarks.

After the learning phase, where participants virtually "walked" through the maze another time, they decided whether to turn left or right at the intersections with landmarks by pressing the left or right arrow key. If the response times exceeded five seconds, the video would continue, and the program would register a missing entry for the intersection. Once all 12 intersections were completed, the video ended and the recognition phase started with its instruction.

In the recognition phase, participants decided whether or not the item had been present in the previous phases by pressing the corresponding keys on a keyboard. The experiment ended with a short debriefing.

Results

The present research had a between-subject factor with four levels: odors, written words, spoken words and pictures. We subdivided the initial design by introducing item groups, hence, perceptual and semantical landmarks, as a between-subject factor for further analysis. The *spoken* and *written words* accounted for semantical, while the *odors* and *pictures* accounted for the perceptual item group. The dependent variables were the relative frequency of correct responses throughout the wayfinding and recognition phase. Furthermore, we assessed the mean response times in these two phases.

Due to technical issues, one participant had to be excluded from the statistical analyses. Hence, a total of 50 participants was included in the following analyses. A subtotal of 26 participants took part in the semantic conditions (*written* and *spoken words,* n= 13 each), while the remaining 24 were in the perceptual conditions *pictures* and *odors* (n=12 each).

For the analyses, we assumed homogeneous error-variances, which have been tested for by Levene-tests. However, in cases where this assumption was violated, we still conducted our analyses because we considered the various ANOVAs to be robust procedures due to the similar group sizes.

Wayfinding

Wayfinding performances throughout the four conditions. The relative frequency of correct decisions for all four conditions in wayfinding together was M= .84, SD= .18 correct decisions, and the mean response time was M= 1395.38 ms, SD= 735.42 ms. There was no significant difference in wayfinding between the conditions for the relative frequency of correct decisions, $F(3,46)$= 1.59, p= .21, η^2= .09. The descriptive results are depicted in figure 3.

For the mean response times, there was a significant effect for the condition, $F(3,46)$= 4.12, p<.05, η^2= .21, which, according to Cohen (1988), is a big effect. Tukey- post hoc tests revealed that in the odors condition, participants decided significantly slower than in the written words condition (M_{diff}= 814.71 ms, 95% CI [64.52, 1564.90], p< .05), and the spoken words (M_{diff}= 819.70 ms, 95% CI [69.51, 1569.89], p< .05) condition, but only slower at a descriptive level if compared to pictures (M_{diff}= 679.82 ms, 95% CI [-85.23 ms, 1444.87ms, p= .10). The descriptive results are depicted in figure 4.

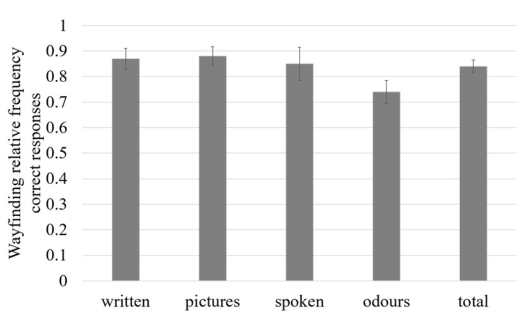

Figure 3: Relative frequency of correct responses in wayfinding. Error bars denote the *SEM*.

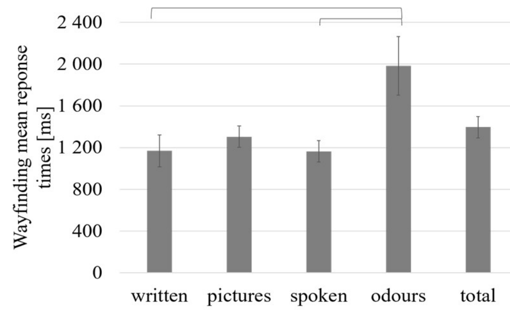

Figure 4: Mean response times in ms for the wayfinding phase. Error bars denote the *SEM*. Horizontal lines denote significant Tukey- post hoc comparisons at p< .05.

Wayfinding performances regarding semantic vs. perceptual landmarks. For these analyses, spoken and written words accounted for semantical, while odors and pictures accounted for the perceptual item group.

In line with the findings in the previous paragraph on the differences between the four conditions of landmark information regarding relative correctness, no significant difference was found in the relative frequency of correct decisions between perceptual and semantic conditions, $F(1,48)$= 1.15, p= .29, η^2= .02 ($M_{semantic}$= .86, $SD_{semantic}$= .19 vs. $M_{perceptual}$= .81, $SD_{perceptual}$= .16).

In line with the findings in the previous paragraph regarding differences in mean response time between the four conditions, here, there was a significant difference in mean response times between perceptual and semantic conditions, favoring the semantical condition as faster, $F(1,48)$= 5.77, p< .05, η^2= .11, which, according to Cohen (1988) is a big effect; ($M_{semantic}$= 1166.28 ms, $SD_{semantic}$= 460.17 ms vs. $M_{perceptual}$=. 1643.57 ms, $SD_{perceptual}$= 893.56 ms).

Recognition

Recognition performances throughout the four conditions. The relative frequency of correct decisions for all four conditions together was M= .91, SD= .16 decisions and the mean response time was M= 1632.98 ms, SD= 911.07 ms. There was a significant main effect for the condition, $F(3,46)$= 9.71, p< .001, η^2= .39 which, according to Cohen (1988) is a big effect. Tukey- post hoc tests revealed that in the *odor* condition, the relative frequency of correct decisions was significantly lower than in all other three conditions ($M_{diff\_odors\_written=}$ -.22, 95% CI [-.35, -.07], p= .001; $M_{diff\_odors\_pictures}$= -.24, 95% CI [-.38, -.09], p< .001; $M_{diff\_odors\_spoken}$= -.24, 95% CI [-.38, -.10], p< .001). These differences are visualized in figure 5.

For the mean response times, the condition revealed a significant effect, $F(3,46)$= 25.31, p< .001, η^2= .90, which is a big effect (Cohen, 1988). Post- hoc Tukey comparisons revealed that odors were significantly slower recognized than written words ($M_{diff\_odors\_written}$= 1616.22 ms, 95% CI [973. 93 ms, 2258.51 ms], p< .001) and pictures ($M_{diff\_odors\_pictures}$=1692.02 ms 95% CI 1037.02 ms, 2347.03 ms], p< .001), but not if compared to spoken words

($M_{diff\_odors\_spoken}$= 544.67 ms, 95% CI [-97.62 ms, 1186.95 ms], p=.12). These results are visualized in figure 6.

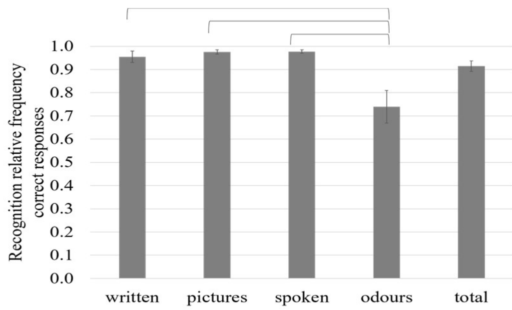

Figure 5: Relative frequency of correct responses in the recognition task. Error bars are *SEM*. Horizontal lines denote significant Tukey- post hoc comparisons at p= .001 (comparison with written words) and p< .001 for remaining comparisons.

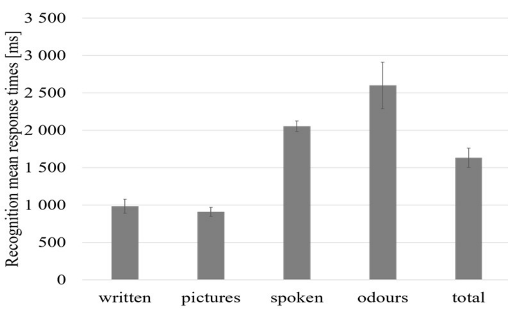

Figure 6: Mean response times in ms during recognition. Error bars are *SEM*. Horizontal lines denote significant Tukey- post hoc comparisons at p< .001.

Analyses regarding semantic vs. perceptual landmarks. For these analyses, spoken and written words accounted for semantical, while odors and pictures accounted for the perceptual item group.

There was a significant difference in relative correctness for the recognition phase between perceptual and semantic landmarks, $F(1,48)$= 6.41, p< .01, η^2= .12, hence a mean effect (Cohen, 1988), $M_{semantical}$ = .97 correct decisions, SD= .07, $M_{perceptual}$ = .86 correct decisions, SD= .21.

The response times did not differ significantly between the item groups, which could have been assumed when looking at the single conditions´ results, which in this analysis have been united, $F(1,48)$= .82, p= .37, η^2= .02 ($M_{semantic}$= 1520.46 ms, $SD_{semantic}$= 620.82 ms; $M_{perceptual}$= 1754.89ms, $SD_{perceptual}$= 1148.76 ms).

Further post-hoc analyses

We conducted additional post hoc regression analyses after checking the assumptions for regression. The mean response time predicted wayfinding relative frequencies of correctness with R^2= .24 (corrected R^2= .22), which is a moderate-strong explanation of variance according to Cohen (1988), $F(1,48)$= 15.07, p< .001.

For recognition, too, the mean response time predicted the relative frequency of correctness, R^2= .44 (corrected R^2= .43), $F(1,48)$= 37.97, p< .001. These results indicate that the longer participants took to decide during wayfinding or recognition, the lower the relative correctness of their decisions. The condition significantly predicted the relative frequency of correctness in recognition with a mean goodness-of-fit R^2= .19 (corrected R^2= .18), $F(1,48)$= 11.58, p= .001. In wayfinding, the condition had not significantly predicted the correctness performances, R^2= .07 (corrected R^2= .05), $F(1,48)$= 3.39, p= .07. For wayfinding, in all four conditions, the relative correctness was similar; hence, the condition did not contribute to a difference in performance, while in recognition, it did. The regression results were in line with the ones previously found and shed further light on the importance of the single factors involved.

Discussion

In the present research, we examined the role of landmark modality on wayfinding and recognition performances measured as the relative frequency of correctness and mean response times.

Knowing that perceptual salience, which is the landmark´s bottom-up properties, can affect wayfinding and recognition, we expected that the modalities would result in different performances (Röser et al., 2011; Röser et al., 2013). The surprising finding was that this was not the case for wayfinding, where all four conditions lead to similar wayfinding performances. Therefore, we assume that for *odors*, different cognitive mechanisms were active. Knowing that we can use odors to create memory (e.g., Herz, 1998) and that the olfactory system is connected to the hypothalamus, thalamus, amygdala, limbic system and the formatio reticularis (Hick & Hick, 2013), the *odors* condition might have activated both perceptual and emotional processes. This interpretation is in line with Hamburger and Knauff (2019) as well as Hamburger and Herold (2020). Moreover, odors could possibly have higher semantic salience (Klippel & Winter, 2005; Nuhn & Timpf, 2017), connecting the landmark information to episodic memory associated with our emotions (Reisberg & Heuer, 2004). This association could favor a deeper information processing, which leads to wayfinding performances comparable to pictures, written or spoken words (Balaban et al., 2017; Craik & Lockhart, 1972). This interpretation is coherent with Lwin et al. (2010), who found that odors can enhance the recall of verbal information and even increment the enhancing effect of pictures on verbal recall.

It is probable that when looking at a picture, we speak it out mentally, or we can imagine its smell. Our finding that perceptual and semantic items do not differ regarding correctness underlines this. This would lead to a better consolidation and is in agreement with the double-coding theory (Clark & Paivio, 1991; Röser et al., 2013; Sadoski &

Paivio, 2013). Further cognitive mechanisms could be thought to be involved. Probably, *written words* and *pictures* had high correctness rates due to the dominance of the visual system (Hick & Hick, 2013). *Spoken words* could have been double-encoded (Clark & Paivio, 1991) semantically and perceptually, leading to a better consolidation. For a long time, we have known about the usefulness of visual and acoustical landmarks in wayfinding and recognition (e.g., Hick & Hick, 2013; Röser et al., 2011), but landmark research was thus far mainly focused on visual landmarks (Hamburger, 2020). The present research is another step in opening the path to exploring new (sensory) types of landmark information for wayfinding.

The assumption that the four conditions of landmark information would differ was only supported by the longer response times for the *odors,* which can be understood considering that the olfactory system is humans´ slowest sense, while the human visual and auditory sense are faster and more differentiated (Hick & Hick, 2013). More precisely, in wayfinding, decisions were taken faster under the *semantic* conditions *spoken words* and *written words* while during recognition, *pictures* and *written words* had shorter response times than *odors*. One could argue that the finding of different response times contradicts our finding of the equal usability of the landmark information. However, as we see it for real-life wayfinding, decision-making correctness should be weighed more than decision speed. In the end, we want to find our way, and in most situations, milliseconds do not make a difference in navigation (only in extreme situations). Longer response times should rather be seen as an indicator of cognitive cost in maintaining comparable correctness performances, especially regarding the *odors* condition (DeLeeuw & Mayer, 2008). More detailed and more precise information in this direction could also be obtained by using an olfactometer to apply odors in future research (Bestgen et al., 2016; Johnson & Sobel, 2007), allowing to measure processing times. Nonetheless, we showed that odors could function well as landmark information even in a simplified laboratory setting. The finding of similar correctness between the four conditions also contrasts hypotheses of automatic encoding for visual vs. controlled encoding for auditory-verbal stimuli (Lang, Potter & Bolls, 1999). It is evidence of cross-modal processing, as discussed in Guttman, Gilroy and Blake (2005) and in line with findings by Hamburger and Röser (2014), who found comparable recognition performances between written words, pictures and sounds. They further suggested that the cognitive processes underlying wayfinding and recognition are different. Further research will be necessary in order to explore this hypothesis more thoroughly.

In our opinion, our senses might rather interact instead of working as separate entities, and humans could apprehend to use all of their (available) senses and optimize the way they orientate in everyday life. In the following, we will discuss possible limitations and proposals for future research. Future projects could combine the different modalities exploring whether the wayfinding performances can be enhanced by increasing encoding depth *sensu* the double-coding theory (Clark & Paivio, 1991; Sadoski & Paivio, 2012). The present experiment was realized in a standardized laboratory setting in contemplation of our goal to conduct basic research to explore the role of auditory, olfactory, visual-semantic and visual-perceptive landmark information. Future research could try to replicate our findings in natural settings, where, however, effects will be harder to interpret because various factors will interact in those settings. This would enable research to also examine locomotion processes, which Montello and Sas (2006) distinguish from wayfinding because it describes the physical execution of what is planned in wayfinding processes. According to Montello and Sas (2006), these two processes together make up navigation. Our setting was eventually the least confounded choice for taking first steps towards the exploration of the single modalities´ effect in wayfinding, which is also supported by the fact that we kept the valence and validity of landmarks and distractors comparable thanks to a prior internal study and research like Hamburger and Herold (2020). At the moment, our laboratory is experimenting with VR-environments and head-mounted displays for a greater immersion effect and, thus, augment external validity whilst maintaining the highest experimental control possible. Hence, we aim to resolve the conflict between experimental control on the one hand and ecological validity on the other science is faced with until today. To further explore how mental representations of landmark information are generated, we could also have included control tasks such as sketch maps. We believe that this could have contributed to a more detailed understanding. However, this project had been planned as an approach to “alternative” landmark information to reveal further insights into landmark-based wayfinding. In our opinion, the present research may contribute to re-thinking the role of olfaction in general and in the field of landmark-based wayfinding. We do not have to focus on visual stimuli only, but we can begin to see humans as more complex organisms who manage their daily challenges using all of their senses, if necessary, combined (Guttman et al., 2005).

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