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The Effect of External Versus Internal Focus of Attention on Visual Task Performance in Simulated Homonymous Hemianopia

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Abstract

Patients with homonymous hemianopia (HH) experience vision loss of one half of the visual field, resulting in difficulties in daily tasks and a reduced quality of life. Currently, rehabilitation strategies focus mainly on compensatory scanning training, with an internal focus (IF) of attention on eye movement. Literature on attention and motor control suggests that the adaptation of an external focus (EF) of attention (e.g. focus on the environment) might be more beneficial for motor learning. In this study we examined whether instructions with an EF resulted in better visual task performance compared to an IF. The visual performance task included a virtual supermarket environment - using virtual reality - in which healthy participants had to navigate and locate products while experiencing simulated HH. No significant differences were found between the IF group and EF group. However, the group that received the EF instructions had an overall faster completion time on the task, suggesting a trend toward a potentially beneficial role for EF on visual task performance. Although the effect was small, it emerged from a minimal manipulation consisting only of changes in instructional wording. The role of attentional focus may therefore become more pronounced during repeated or intensive visual rehabilitation training. This study was the first to examine the effect of attentional focus on visual task performance. Additional research is needed to replicate and validate our results in order to gain a better understanding of the impact of instruction type in visual rehabilitation.

Keywords: Homonymous Hemianopia, Attention, Rehabilitation, Visual Perception, Virtual Reality.

The Effect of External Versus Internal Focus of Attention on Visual Task Performance in Simulated Homonymous Hemianopia

Homonymous hemianopia (HH) is a visual condition that results in a loss of perception of one half of the visual field. It is a result of unilateral damage to the post-chiasmal visual pathways. It is most often acquired after a stroke, with an overall presence of 30% in stroke patients (Zhang et al., 2006). Individuals with this condition experience a range of problems, such as difficulties with orientation, multitasking, and colliding with objects when walking (De Haan, Heutink, et al., 2015). As a result, individuals with HH often experience reduced independence and quality of life (Chen et al., 2009; Chang, 2025; De Haan, Heutink, et al., 2015).

Although some patients with HH spontaneously develop effective scanning behavior to compensate for their visual field defect (Zihl, 1995), the majority of patients do not (Postuma et al., 2024). Spontaneously developed adaptations can also prove ineffective. The systematic review of Postuma et al. (2024) concluded that in search and reading tasks, spontaneous adaptations tend to lead to less effective eye movements. Fortunately, training interventions can be effective in eliciting more effective visual behaviour and therefore improving visual performance.

Current rehabilitation programs focus mainly on compensatory scanning training, which can be beneficial for reducing some of the symptoms of HH by learning an effective eye movement strategy (De Haan, Melis-Dankers, et al., 2015; De Haan et al., 2016; Postuma et al., 2024). Systematic practice and visual scanning training can be beneficial for improving visual search (Rowe et al., 2025; Zihl, 1995). Postuma et al. (2024) concluded that training can improve visual scanning by reducing the number and duration of fixations, the number of saccades (i.e. quick eye movements between fixation points), and by increasing the saccade length. Although compensatory scanning training offers possibilities for rehabilitation, effective scanning strategies are mostly task-specific resulting in a lack of generalizability to everyday activities (Postuma et al. 2024; Schuett et al., 2009).

One underexplored factor potentially influencing the effectiveness of rehabilitation strategies is attentional focus. Attention can be directed internally or externally, where an internal focus (IF) of attention refers to a focus on someone's own body movements, and an external focus (EF) of attention refers to the effect that someone's movements have on the environment (Wulf et al., 1998). Research on motor learning suggests that an EF of attention leads to superior learning compared to an IF (Wulf, 2013; Wulf & Lewthwaite, 2010). For instance, in the study of An and Wulf (2023), participants who received EF instructions (e.g. focus towards where the ball will land) showed better accuracy in a golf task than participants who received IF instructions (e.g. focus on own force control). This can be explained by the constraint action hypothesis, which proposes that an IF causes individuals to try to consciously control their – otherwise automatic – movements, thereby constraining their motor system and reducing automaticity (McNevin et al., 2003; Wulf et al., 2001; Wulf & Lewthwaite, 2010). In contrast, an EF facilitates automaticity and reduces mental effort. As a result, an EF of attention leads to more accurate and effective motor performance than an IF of attention (McNevin et al., 2003; Wulf et al., 1998; Wulf et al., 2001).

Current HH training programs focus mainly on IF processes where people learn to move their eyes in a certain way. If the constraint action hypothesis would apply to both motor and visual performance, compensatory scanning strategies in HH might lead to a constraint motor system by means of conscious control of the eye. If this is the case, this would likely be associated with increased mental effort and interfere with effective processing of the visual information. Therefore, rehabilitation of HH might be more effective when emphasizing an EF of attention. To our knowledge, no studies have investigated the effect of an external versus an internal attentional focus on visual task performance. Exploring this effect might provide new insights that could improve rehabilitation of HH.

Investigating visual performance and rehabilitation strategies in patients with HH can be methodologically challenging due to its variable nature. For instance, differences in lesion location and previously followed rehabilitation programs can provide difficulties for comparing research outcomes. Recent research in virtual and extended reality have found that visual search can be studied effectively and in a safe manner with the use of simulated virtual impairments (Barbieri et al., 2024; Veerkamp et al., 2025). Furthermore, scanning behaviours of participants with HH were found to be similar to scanning behaviours of participants with simulated HH (Tant et al., 2002). Even though simulated HH cannot reflect the full clinical complexity of HH, it provides opportunities for assessing performance in a controlled setting.

The aim of the study is to test whether an EF of attention might lead to improved visual task performance in individuals with simulated HH, compared to an IF of attention during a visually demanding task. Based on the constrained action hypothesis (McNevin et al., 2003; Wulf et al., 2001), we hypothesize that participants with an EF of attention have an overall better visual task performance than participants with an IF of attention, speculating that an EF will lead to more automaticity and therefore to better performance.

To investigate this, a visually demanding task is performed in a virtual supermarket environment. In this task, participants have to navigate through the supermarket environment and search the cluttered shelves to find prespecified products, while HH is simulated. Before the start of the experiment, participants were systematically assigned to the IF group or EF group. The IF group received instructions that directed their attention internally (e.g. to their own bodily movements) and the EF group received instructions that directed their attention externally (e.g. to the environment). By assessing the effect of focus of attention on visual task performance, we aim to gain a better understanding of how different instructions can contribute to the rehabilitation of HH.

Methods

Participants

In total, 24 participants were recruited through convenience sampling. The sample size was based on this study being a preliminary study, aimed to provide direction for future studies. Participants were selected based on having normal or corrected to normal vision. Participants were asked to report any history of a neurological disorder, since the presence of such a disorder might influence attentional processing and visual perception. Eligibility required participants to be at least 18 years old. Before taking part in the experiment, all participants provided written informed consent. The study was approved by the Ethics committee of the University of Groningen (study approval code: PSY-2526-S-0129).

Apparatus

The experimental set-up included a Meta Quest 3 VR headset (Meta, Menlo Park, California, United States). The headset was attached with a usb-c Link cable to a Lenovo Ideapad gaming laptop (Lenovo, Hongkong SAR, China), which was used to run a virtual supermarket environment via Unity software (version 2023.2.1f1). The VR headset provided a field of view of 100° horizontally and 96° vertically, with display resolution of 2064 x 2208 pixels per eye. It was equipped with an integrated Pupil Neon eye-tracker (Pupil Labs GmbH, Berlin, Germany), which is a calibration-free eye-tracker that calibrates itself based on machine learning models. The eye-tracker was connected to a smartphone with the Neon Companion application installed on. This application was used to register the eye movement data at 200 Hz, and transmit this data via Wi-Fi to the Unity software, which in turn translated this data into 3D coordinates at a rate of 72 Hz. Lastly, the VR headset was accompanied by two handheld Meta controllers.

VR Environment

The supermarket environment, originally developed by Van Der Laan et al. (2021), resembled the supermarket environment used in Veerkamp et al. (2025), with minor modifications to suit the aims of the present study. The supermarket contained multiple aisles and a total of 719 products sorted on theme, resembling the layout of a Dutch Albert Heijn supermarket (Figure 1a). At the end of the aisles, products sold at a discount were displayed – these products were considered as out of context (not in the original aisle location). Furthermore, the supermarket was present with static avatars, shopping carts, and boxes with which participants could collide. The environment was presented with an average frame rate of 72 Hz.

HH was simulated using gaze-contingent masking at 72 Hz. The mask was presented on either the left or right half of the visual field, and was grey coloured (RGB=79,79,79**;** Figure 1b). The mask moved with the movement of the eye in such a way that the same hemifield remained masked relative to a central fixation.

Figure 1a

VR Supermarket Environment

Figure 1b

VR Environment Including Simulated HH

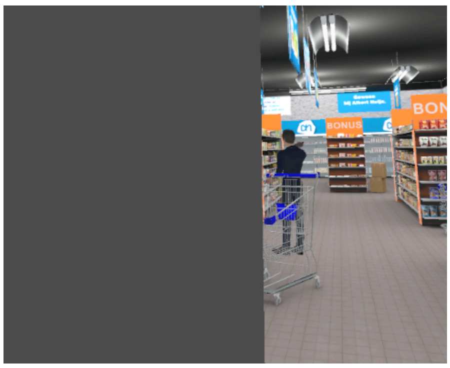


Figure 1c

Checkered Square Near the Register

Figure 1d

Experimental Set-up

Visual Performance Task

The visual performance task was performed in the VR supermarket environment. The protocol was similar to the one in Veerkamp et al. (2025) and required participants to navigate through the supermarket to locate the products on their shopping list. Movement through the supermarket was done by means of teleportation. The shopping list was presented by means of a verbal recording of the products in English, which participants could request to hear with a button press on the hand-held controller. The order by which the participants had to find certain products was determined by the occurrence of the products on the shopping list. When the participant had successfully selected all the products, they had to return to a black and white checkered square that would appear on the floor of the supermarket near the register (Figure 1c). Each product search was considered a trial, with the participant performing two blocks with each including four trials. Outcome measures were completion time, the number of collisions, the number of wrongly selected products, the number of shopping list requests and the number of teleports used.

Procedure

The experiment was conducted in a spacious room at the Faculty of Behavioural and Social Sciences in Groningen. Before the experiment, the participants were asked to read the information sheet and fill out the informed consent form. After informed consent was obtained, participants were asked about their age, gender, nationality, dominant hand, gaming experience and any history of a neurological disorder. Participants were systematically allocated to either the IF group or EF group and to left-sided or right-sided HH based on the order of participation, using a predefined sequence to ensure equal group sizes.

Participants were seated in a swivel chair with sufficient space provided to rotate (see Figure 1d). The laptop running the experiment was located on a desk next to the swivel chair. The right-held controller was shown to the participants prior to fitting the headset, to inform them about the location of the buttons they would need to use in the supermarket environment. Participants were asked to inform the researcher if they experienced any discomfort during the experiment and were reminded of the opportunity to take breaks between the blocks. The participants were also monitored by the researcher to check for any signs of discomfort.

Participants started with a familiarization of the virtual supermarket environment and the simulated HH. For this, a simplified supermarket environment was used where only one shelf contained a few products and the rest of the shelves remained empty. The controller was placed in the participant's right hand and its functions were explained. By pressing on either the 'A' or 'B' key on their controller, participants would hear a verbal recording of the shopping list, which only contained one product in the familiarization phase. There was no limit to the number of replays. Movement through the supermarket was done by means of teleportation in steps of 0.5 m by pointing the handheld controller in the desired direction and pressing the trigger button. When the target product was found, participants could select the product by pressing the trigger button for three seconds when standing right in front of the product. If the correct product was selected, the participants would hear a 'pling' sound. If participants selected the wrong product, they would hear a lower pitched sound. Collisions with shelves, obstacles or avatars resulted in a vibration of the handheld controller and a movement 0.5 m backwards. After all the predetermined products were correctly selected, the participant returned to the black and white checkered square near the register and ended the familiarization by pressing the trigger button. During the familiarization, the smartphone was not connected to the VR headset to prevent overheating. As a result, the mask used to simulate HH remained fixed on one side of the visual field and did not move in relation to the eye movements. The familiarization phase took as long as participants needed to get comfortable with the virtual environment and the simulation.

After the familiarization, participants completed the experimental task. Between the familiarization phase and the experimental blocks, the smartphone was connected to the eye tracker to allow the gaze-contingent mask display. The shopping list now contained four products per block, with one product that was placed out of context. In case of unfamiliarity with the English translation of the products, the researcher would translate the products to Dutch. Each block took approximately four minutes to complete.

At the start of each experimental block, participants in the EF group and IF group received a different set of instructions. Prior to block 1, participants in the EF group received the following external instruction: "*During the task, focus your attention on the products and shelves in the supermarket. Direct your attention to the locations of the products and how they are arranged in the environment as you search.*" Participants in the IF group received an instruction that directed their attention internally, namely: "*During the task, focus your attention on your own eye movements. Try to be aware of how your eyes move from place to place while you search for the products.*" A shortened version of the instructions was repeated prior to block 2. The instructions were shortened into "*During the task, focus your attention on the products and shelves in the supermarket*" for the EF group, and into "*During the task, focus your attention on your own eye movements*" for the IF group. The EF and IF instructions were separated from the general task instructions explained during the familiarisation to improve clarity.

At the end of the experiment, participants were asked how they felt and if they had an idea of the intent of the study. Subsequently participants received disclosure about the type of instructions they received. The total duration of the experiment including the familiarization phase, experimental phase and the disclosure lasted approximately 20 minutes.

Data Processing and Analysis

Pre-processing of the data was done using a Python script (version 6.0.0). Outliers were removed using the IQR method. Completion time per trial was measured in seconds, from the first teleportation until the participant successfully grabbed the correct product on the shopping list. Additionally, the number of collisions with obstacles, the number of wrongly selected products, the number of shopping list requests, and the number of teleports were also averaged per trial. Lastly, gaming data were converted from ordinal to scalar form. For instance, when a participant indicated gaming three hours per week followed by two weeks of no gaming, an average was computed of one hour of gaming per week.

The relationship between focus of attention and visual task performance was studied using a between-subjects design. Here, the independent variable was instruction type (external or internal focused) and the primary dependent variable was average completion time of the supermarket task per trial. Other secondary dependent variables examined were the average number of collisions per trial, the average number of wrongly selected products per trial, the average number of shopping list requests, and the average number of teleports the participants used per trial. Multiple Analyses of Variance (ANOVA) were performed to test for differences between the EF and IF instruction groups for the primary and secondary dependent variables. An additional ANOVA on difference scores was conducted to test whether a learning effect was present between the first and second block, and whether this effect differed between the IF and EF group. Furthermore, the influence of control variables on the average completion time per trial was examined by means of ANOVA and Spearman analysis. Control variables included the side of the mask simulating HH, prior gaming experience and nationality. A significance level of .05 was used for all analyses. ANOVA assumptions were checked by visual inspection of boxplots and Q-Q plots and by use of the Shapiro-Wilk test and the Levene's test. A log-transformation was applied in the case of non-normal data. If that was insufficient, a Mann-Whitney U analysis would be performed.

Results

Data Exclusion

From the sample of 24 participants, six participants were excluded from the analyses due to technical problems. Specifically, the gaze-contingent mask did not work properly due to connectivity failure between the Unity Software and the eye-tracker, resulting in invalid data from the first block (n=3) or both blocks (n=3). Hence, the analyses were only performed on the data of the participants where the mask functioned properly during both the first and second blocks. In addition, five trials were identified as outliers and removed before further analysis. Three of these outliers concerned the first trial of the first block, suggesting that, for some, the task was still unclear when the experiment started.

After exclusion, a sample of 18 participants remained, including 14 females and four males with a mean age of 24.2 (*SD*= 7.8). Table 1 presents the distribution of participants over the instruction type and mask-side conditions. ADHD (*n*=2), ADD (*n*=1) and migraine (*n*=2) were reported and no participants were excluded based on these criteria. Most participants had a Dutch nationality. Other present nationalities were Portuguese (*n*=2), Bulgarian (*n*=1), French (*n*=1), and Irish-Chilean (*n*=1). 17 participants were right-handed and one participant was left-handed, which was recorded because the participants had to use a controller with their right hand, which may be more beneficial for the right-handed group. Furthermore, two participants who wore glasses to correct their vision preferred to do the experiment without their glasses. Only the trials of these participants that were defined as outliers were excluded from the analysis.

Table 1

Distribution of Participants Across Instruction Type and Mask-Side

Variable	Left-Sided Mask	Right-Sided Mask	Total
IF Instruction	4	5	9
EF Instruction	4	5	9
Total	8	10	18

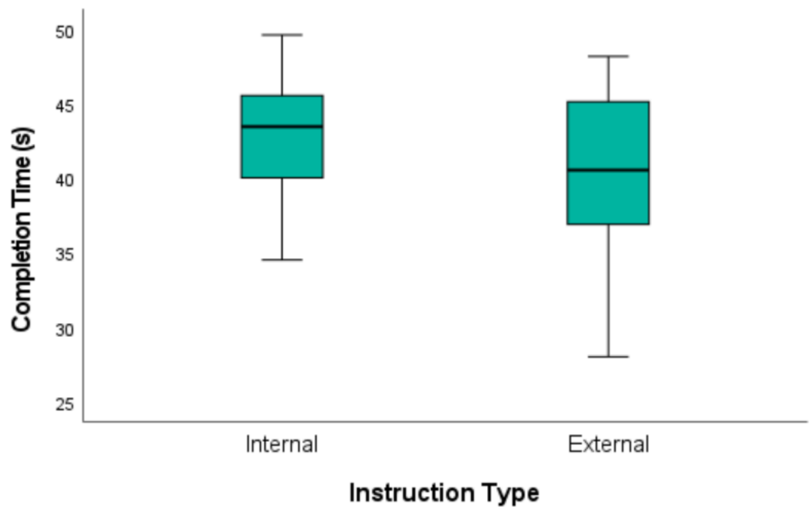
Effect of Instruction Type on Completion Time

An ANOVA was performed to examine whether there is a difference in the average completion time per trial between the IF and EF group. Upon inspection of the Q-Q plots, no major deviations were observed, and the normality assumption was met for both groups. The Shapiro-Wilk test also reported no signs of non-normality for the IF group (W= .95, p= .74) and EF group (W= .93, p= .51). Levene's test showed no violation of the assumption of homogeneity of variances ($F(1,16)$= 0.73, p= .40). The third ANOVA assumption, independence of observations, has been met.

Figure 2 shows the difference between the average completion time per trial for the IF and EF group. The average completion time per trial was 43.39 seconds (*SD*= 4.74, 95% CI [39.74, 47.03]) for the IF group and 40.45 seconds (*SD*= 6.27, 95% CI [35.63, 45.26]) for the EF group. On average, the EF group completed trials 2.94 seconds faster than the IF group, however, no significant difference was found in average completion time per trial (F= 1.26, p= .28).

Figure 2

Average Completion Time per Trial for the IF and EF Group



Note. Average completion time scores per trial in seconds are shown for the group that received IF instructions (left boxplot) and the group that received EF instructions (right boxplot).

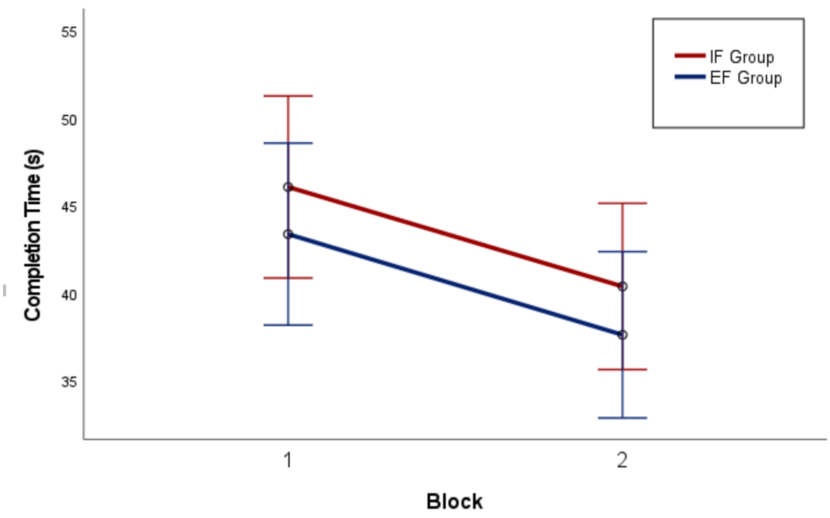
Effect of Instruction Type on Learning Effect

An additional analysis was done to test whether there is a learning effect between block 1 and 2 and whether this effect differs between the IF and EF group. For this, an ANOVA was performed on the differences in completion time between block 1 and 2 for both instruction groups. The Q-Q plots and the Shapiro-Wilk test indicated no signs of non-normality for the difference in completion time for the IF group (W= .95, p= .72) and the difference in completion time for the EF group (W= .97, p= .91). Levene's test indicated no signs of unequal variances of the differences in completion time between the IF and EF group (F(1,16)= 0.28, p= .60).

The average difference in completion time between the two blocks was 5.69 (SD= 8.03) seconds for the IF group and 5.76 (SD= 9.48) seconds for the EF group. The results of the ANOVA on difference scores show a significant time effect (F(1,16)= 7.66, p= .01), indicating that overall, the participants were faster in completing the second block compared to the first block (see Figure 3). On average, the EF group performed 2.70 seconds and 2.77 seconds faster than the IF group on the first and second block, respectively. No significant interaction effect was found between instruction type and the difference in completion time between both blocks (F(1,16)= 0.00, p= .99), meaning the learning rate was equal for the EF group and IF group.

Figure 3

Completion Time on Block 1 and Block 2 for the IF and EF Group



Note. The figure above shows the average completion time per trial in seconds for block 1 and block 2, for the IF group (red line) and the EF group (blue line). The error bars represent the

95% confidence intervals for the average completion time per trial for both blocks for both groups.

Effect of Instruction Type on the Number of Collisions, Wrongly Selected Products, Shopping List Requests and Teleports

Several analyses were conducted to investigate the effect of instruction type on the secondary dependent variables in the model: the average number of collisions per trial, the average number of wrongly selected products per trial, the average number of shopping list requests and the average number of teleports per trial. The descriptives of these secondary variables for both the IF and EF group are presented in Table 2.

Table 2

Descriptive Statistics of the Secondary Dependent Variables

Variable	IF Group		EF Group	
	M	*SD*	*M*	*SD*
Collisions	0.12	0.17	0.10	0.13
Wrong Products	0.04	0.09	0.03	0.06
Shopping List	0.61	0.21	0.49	0.16
Teleports	45.34	3.76	47.63	6.82

Note. The table presents the mean scores and the standard deviations for the average number of collisions per trial, the average number of wrongly selected products per trial, the average number of shopping list requests per trial and the average number of teleports per trial, for both the IF group and EF group.

Number of Collisions

The Shapiro-Wilk test showed significant results for the IF group (*W*= .76, *p*= .01) and EF group (*W*= .74, *p*= .01), indicating non-normal distributions of the average number of collisions per trial. Therefore, a Mann-Whitney U analysis was performed to test whether instruction type had an effect on the number of collisions. Visual inspection of the distributions of the average number of collisions per trial for the IF and EF group showed dissimilar shapes. As a result, the Mann-Whitney U test was interpreted as a test of difference in distributions instead of as a test of difference in medians. No significant difference was found in the average number of collisions per trial between the IF group (mean rank= 9.39) and EF group (mean rank= 9.61) (*U*= 39.50, *z*= -0.10, *p*= .92).

Wrongly Selected Products

The Shapiro-Wilk test showed significant results for the average number of wrongly selected products per trial for both the IF group (*W*= .56, *p*< .001) and for the EF group (*W*= .55, *p*< .001). Therefore, a Mann-Whitney U was performed to test whether instruction type had an effect on the average number of wrongly selected products per trial. The distributions of the average number of wrongly selected products per trial had different shapes for the IF group and EF group. The results showed no significant difference between the IF group (mean rank= 9.56) and EF group (mean rank= 9.44) for the average number of wrongly selected products per trial (*U*= 40.00, *z*= -0.06, *p*= .95).

Shopping List Requests

An ANOVA was performed to investigate the effect of instruction type on the average number of shopping list requests per trial. The Shapiro-Wilk test indicated no signs of a violation of normality for the IF group (*W*= .95, *p*= .73) and for the EF group (*W*= .93, *p*= .48), as did the Q-Q plots. Levene's test showed no signs of unequal variances (*F*= 0.08, *p*= .78). No significant difference in the number of shopping list requests was found between the IF group and EF group (*F*= 1.89, *p*= .19).

Teleports

The Shapiro-Wilk test showed non-significant results for the IF group (*W*= .92, *p*= .38) and significant results for the EF group (*W*= .83, *p*= .04) for the average number of teleports per trial. A Mann-Whitney U was performed to test whether instruction type had an effect on the average number of teleports per trial. The distributions of the average number of teleports per trial for the IF group and EF group differed in shape. The results showed no significant difference in the average number of teleports per trial for the IF (mean rank= 8.94) and EF group (mean rank= 10.06) (*U*= 35.50, *z*= -0.44, *p*= .66).

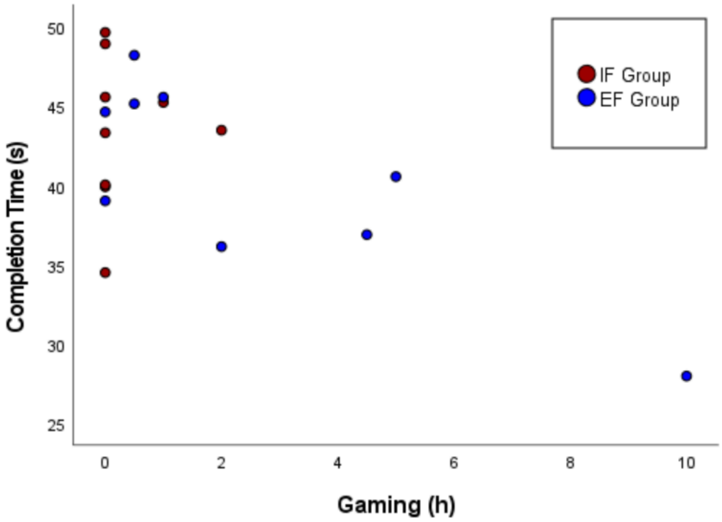
Additional Analyses on Control Variables: Side of HH Simulation, Gaming Experience, and Nationality

An ANOVA was performed to check whether the side of HH simulation had any effect on the average completion time per trial. The results of the Shapiro-Wilk test for the group with the left-sided mask (*W*= .90, *p*= .28) and right-sided mask (*W*= .87, *p*= .11) and the Levene's test (*F*(1,16)= 0.04, *p*= .86) indicated no signs of violations to the assumptions of normality and equal variances. The mean of the average completion time per trial was 44.16 seconds (*SD*= 4.90, 95% CI [40.07, 48.26]) for the group with left-sided simulated hemianopia and 40.11 seconds (*SD*= 5.70, 95% CI [36.04, 44.19]) for the group with right-sided hemianopia. There was no significant effect of mask-side on the average completion time per trial (*F*= 2.53, *p*= .13).

Secondly, the relationship between prior gaming experience and average completion time per trial was investigated (see Figure 4). The data of the prior gaming experience is not normally distributed, hence a Spearman analysis was conducted. We found no significant correlation between prior gaming experience and the average completion time per trial (ρ= -.30, *p*= .22).

Figure 4

Distribution of Completion Time for Prior Gaming Experience



Note. The y-axis represents the average completion time per trial in seconds. The x-axis represents the average number of hours per week spent on gaming, reported by the participants. The red dots indicate participants in the IF group and the blue dots indicate participants in the EF group.

Lastly, a Mann-Whitney U test was used to test whether there is a difference in average completion time per trial between Dutch and non-Dutch participants. Distributions of the average completion time per trial were not similar for both groups. No significant difference in the average completion time per trial was found between the Dutch participants (mean rank= 9.43) and the non-Dutch participants (mean rank= 9.75) (U= 27.00, z= -0.11 p= .92).

Ethical Control, Manipulation and Feedback From Participants

No discomfort was reported by any of the participants. After receiving disclosure about the type of instructions they received, some of the participants reported not being aware of this manipulation. One participant in the IF group made the remark that it was distracting to focus on their eye movements, which led them to rotate the swivel chair more. Another participant made the comment that since the task in itself is already external-focused (finding a product), their attention would naturally be directed externally despite receiving an IF instruction. Furthermore, some participants in the EF condition were not aware that the mask moved in accordance with their eye movements, while participants in the IF condition did report being aware of this. It is important to take this participant feedback into consideration when interpreting the results of this study.

Discussion

The aim of this study was to investigate the effect of an IF and EF instruction on visual task performance, with as primary measure completion time and as secondary measures the number of collisions, wrongly selected products, shopping list requests and the number of teleports. On average, we found that the EF group completed trials faster than the IF group. Although this difference did not reach statistical significance, the direction of the effect is consistent with our hypothesis that an EF leads to better visual task performance. Our secondary measures did not show any significant differences between the IF group and EF group. We believe systematic investigation is warranted to assess the potentially meaningful performance advantage towards an EF of attention.

Our hypothesis stated that an EF of attention would result in better visual task performance, by means of increasing automaticity and reducing mental effort, which would translate into a faster overall completion time in the EF group compared to the IF group. Although no statistically significant difference was found, the EF group completed the trials 7% faster than the IF group, resulting in an advantage for the EF group of several seconds. This difference was consistent for the first and second block, even though a significant learning effect was found, indicating that the difference was not caused by different visual learning patterns between the two groups. Our findings partially support our hypothesis, although to a smaller degree than expected, and suggest that an IF of attention might limit effective processing of visual information by constraining the visual motor system, increasing mental effort and reducing automaticity. Less efficient visual search strategies might have contributed to the difference in completion time, nevertheless, we were unable to measure the efficiency of the participants' eye-movements due to technical difficulties.

Important to note is that there was no difference in the number of teleports used between the IF and EF group, meaning that the difference in completion time is not related to the length of the path taken in the VR supermarket environment. This difference in completion time can also not be accounted for by the number of collisions and wrongly selected products, since no differences on these measures were found between IF and EF group. Interestingly, the number of collisions and wrongly selected products was low, which was unlike what we expected, since collisions and orientation problems are commonly reported by patients with HH (de Haan, Heutink, et al., 2015). Participants in both groups might have conducted the experiment extra carefully due to its perceived difficulty and their unfamiliarity with simulated HH, thereby reducing the number of errors. Lastly, no difference in the number of shopping list requests was found between the IF and EF group. Altogether, these results suggest that the secondary measures do not account for the difference in completion time between the IF and EF group, which makes it more likely that factors like visual search contribute to the faster completion time of the EF group.

The effect of an EF instruction type might not be very large due to numerous reasons, some prominent being the use of a limited number of trials, the complex study design and a lack of power. Another reason could be that the supermarket task is already quite externally-focused in itself. The goal to find specific products might naturally direct the participants attention to the environment of the supermarket, thereby failing to effectively direct the participants' attention internally. One participant also indicated that after a while they stopped focusing on their eye movements since this was distracting them from the task. Additionally, some participants reported not having noticed the instructions or not being directed by them. One reason for this could be that the task instructions were already clear during the familiarisation phase, which might have caused participants to pay less attention to the set of instructions that were aiming at directing their attention internally or externally. If the manipulation did not consistently direct the focus of attention, this might have also led to a weaker effect. Lastly, it is possible that findings from motor learning do not successfully translate to visual learning and that an EF might not have an effect on visual task performance. Nevertheless, the effect in the direction of our hypothesis and the consistent advantage of the EF group over time suggest promise for this translation to visual learning.

Although the size of the effect was small, it is important to note that the effect was achieved by minimal manipulation, by use of a different phrasing of the instructions. Therefore, it would be interesting to examine whether this trend toward an EF advantage continues, and potentially gets stronger, when investigated in an experimental setting over a longer period of time. A subtle difference between the two instruction groups in this study, in which data contained large variability due to the complex nature of the task, might potentially translate into a meaningful performance difference in longer (training) programs. An EF instruction type can easily be implemented in multiple stages of the rehabilitation process and afterwards in everyday practice, while not adding to any costs. A small initial performance gain, can result in a substantial advantage when consistently implemented, which is why we believe it is valuable to follow up on our results, despite not having yielded significant results.

Two control variables to consider when interpreting the results are simulated hemianopia side and gaming experience. Firstly, the group with right-sided HH had a faster completion time per trial than the group with left-sided HH, although differences were not significant. This finding can be explained by the concept of pseudoneglect, a tendency to have an attentional bias for the left hemifield (Bowers & Heilman, 1980; Jewell & McCourt, 2000), which is hypothesized to be related to right hemispheric dominance for visuospatial functioning. Following this theory, simulated visual field loss of the left side might result in a slower completion time, by means of interfering with the tendency to focus more to the left side of the visual field. Therefore, mask-side might have had an effect on the average completion time. However this had no effect on the interpretation of our results when comparing the IF and EF group, since both groups had an equal number of participants with right-sided and left-sided hemianopia.

The second control variable of interest is prior gaming experience. No significant correlation between prior gaming experience and the average completion time per trial was found. However, most participants had little or no gaming experience, consequently the variability in gaming scores was low. Interestingly, the participant with the most gaming experience, who was assigned to the EF group, also had the fastest completion time per trial. If prior gaming experience had an effect on the completion time per trial, this may have introduced bias in the direction of the EF group. Therefore, results should be interpreted with caution, and replication of our results with a larger sample size is needed to verify a potential trend towards better visual performance for the EF group.

Our study had several limitations. We encountered technical difficulties with the gaze-contingent mask due to a lost connection between the Meta Companion app and the Unity Software, which resulted in exclusion of six participants. Also, all eye-tracking data was lost since the eye-tracker was overheated and we decided to stop the recording in order to let the gaze-contingent mask work as well as possible. Nonetheless, the mask simulating HH did not always perfectly remain in position, occasionally causing a gap in the participants' far periphery. Although this was inconvenient, we believe that the mask sufficiently blocked the functional field akin to HH.

Next to limitations, our study also showed some strengths. For instance, the high level of detail in the VR supermarket environment closely resembled a real life activity (doing grocery shopping). This made the study more applicable to daily practice and might lead to a better translation from an experimental to a rehabilitation setting. Additionally, the use of a VR set-up to simulate HH provided a safe, controlled environment which allowed for research in a naturalistic setting while avoiding variability related to HH (e.g. lesion location). Lastly, the task was accessible to both participants with minimal or more advanced gaming experience, since it required only the use of two buttons on the hand-held controller.

In conclusion, no significant differences were found between the IF and EF group, however, our results suggest that an EF of attention might lead to better visual task performance in participants with simulated HH. Although there is a growing body of literature on rehabilitation strategies in HH and on attention research, to our knowledge this is the first study to bridge these two topics and investigate the effect of attentional focus on visual task performance. For future research we recommend investigating this effect with the use of a more simplistic set-up, including more trials, in participants with simulated HH and in healthy controls. Using a more simplistic task will increase experimental control and provide opportunities for directing the attention of the participants without additional noise. Moreover, adding more trials provides for the opportunity to test the further course of the learning effect that we found. Finally, a questionnaire could be administered at the end of the experiment aimed at verifying whether the participants attention was directed internally or externally through self-report. This additional research is needed to improve our understanding of how EF instructions can improve visual task performance and potentially contribute to the rehabilitation of HH.

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