Development and applicability assessment of a rehabilitation plan for Hemispatial Neglect patients using Augmented Reality

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Abstract: The impact of Hemispatial Neglect is clear. Since it is a consequence of stroke, namely right-brain hemisphere stroke, its prevalence is significant, affecting the lives of numerous people. Moreover, it is a highly impairing disease which deeply compromises self-sufficiency, autonomy and restricts the day-to-day capabilities of the patient.

The current study conducts a comprehensive analysis of the disease and the underlying brain regions where lesions often lead to the appearance of symptoms, identifies the currently used rehabilitation and therapy strategies to tackle the disease, proposes a novel solution for the rehabilitation of Hemispatial Neglect patients using Augmented Reality and auditory stimuli and tests its applicability on healthy individuals.

The results obtained, namely the qualitative results, identify some improvements to be implemented to the strategy proposed but, nonetheless, substantiate its applicability since the results and the feedback were positive, the participants performed all tasks with ease and no adverse reaction was observed. The quantitative results, although not the main focus of this research, also highlight useful details which should be considered prior to clinical application of the strategy. Once the aforementioned improvements are incorporated, the solution will be ready for the next research phase – application on Hemispatial Neglect patients.

Keywords: Stroke; Hemispatial Neglect; Augmented Reality; Virtual Cueing; Visual and Auditory Cueing

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1. Introduction

The syndrome of Hemispatial Neglect is a neuropsychological condition that follows an injury sustained in one hemisphere of the brain and is characterized by a disorder of attention where patients typically fail to orientate, report or respond to stimuli located on one side of space and may also compromise other areas, like touch, hearing, smell, pain or memory recollection [1] [2]. The vast majority of these patients suffer from contralesional unilateral neglect – the side of the field of view affected is the opposite of the brain hemisphere that sustained the lesion and so, patients have a tendency to prioritize objects in the same side as their brain damage [3]. Most cases of hemineglect occur after a lesion on the right hemisphere of the brain (up to 80% of right brain hemisphere strokes cause unilateral neglect - more specifically, strokes affecting the large middle cerebral artery, right inferior parietal lobe or the temporo-parietal junction) and so, there is a tendency for the left side of space to be disregarded [4].

The etiology of the Hemispatial Neglect is vast and often involves right hemispheric lesions in the brain. The causes include neurodegenerative diseases, traumatic brain injury or neoplasia but the main cause of the most prominent and long-lasting neglect is right-hemispheric stroke [3]. Neglect can occur in 70% to 80% of patients in the chronic phase after a stroke in the right hemisphere and, thus, it's a highly incident pathology [1].

To assess the extent and severity of the Neglect, numerous tasks and examinations have been developed in the recent years. The most commonly used test battery for HN diagnosis is the Behavioral Inattention Test (BIT) – composed of conventional and behavioral tests – it allows the assessment of the visuo-spatial difficulties of the patient [5].

The treatment of Hemispatial Neglect patients has been a relevant concern in the recent years because strokes are extremely prevalent worldwide and the most effective rehabilitation pathway is still not consensual.

Pharmacological and behavioral strategies have been tested. Pharmaceutical approaches focus on dopaminergic therapies using medication such as levodopa or amphetamines, noradrenergic drugs, or cholinergic compounds. Still, the results obtained with this approach are inconstant and lack robustness [4]. Behavioral treatment ranges from sustained attention [6], trunk rotation [7], unilateral eye patching [8] or prism adaptation [3]. However, the most robust and promising results are obtained with cueing.

2. Background

The quicker rehabilitation of patients with Hemispatial Neglect has been achieved using strategies based on cueing. These strategies focus on stimulating either the lesioned part of the field of view (usually the left side) or the lesioned hemisphere of the brain (usually the right) after a stroke. Different types of cues have been tested, such as tactile, proprioceptive, or olfactory [8] [9] [10], but the most effective are the visual and auditory cues.

In fact, a study conducted by Olk et al. [11] tested the impact of visual cues on patients performing the Line Bisection test (a pen and paper test where the patient is asked to mark the middle point of a line). The results of the experiment showed that cues at one end of the line bias the bisection performance to that side of the line – cues on the right side of the line accentuated the error while cues on the left improved the performance of the patients. Numerous other studies corroborated the positive impacts of visual cueing [12] [13] [14].

Regarding auditory stimuli, Hommel et al. [9] analyzed the impact of auditory stimuli on patients with hemispatial neglect. A comparison between verbal and nonverbal cues was performed and the results showed that only the nonverbal stimuli produced significant improvements in symptom amelioration. In fact, the nonverbal sounds are processed in the right side of the brain, which suggests that these types of cues stimulate the lesioned part of the brain, reducing neglect. A different study compared the impact of classical music, white noise, and silence on neglect. The largest improvements were obtained under classical music and white noise conditions (non-verbal stimuli) [15]. Other applications of auditory stimuli have been investigated – an experiment conducted by Van Vleet and Robertson [16] tested the impact of auditory stimuli on neglect patients performing the Cancellation Test (a pen and paper test where the patient is asked to identify certain objects among a number of distractor objects). The patient was asked to perform this task while listening to auditory beeps of 1000Hz, 60dB and 2000msec of duration. These cues were provided congruently (left) or incongruently (right) with the target or bilaterally and the results showed that auditory cues increased the search efficiency.

Different other theories have been presented to justify the positive impacts of cueing in Hemineglect patients. For instance, and even though the exact brain regions responsible for their activation are still not clear, the two most important neurophysiological processing components have been dissociated in this pathology: the spatial component (responsible for recognizing objects in the three-dimensional space) and the motor component (responsible for accurately recruiting motor function). Cueing may reduce the dysfunction regarding these components together by promoting the patients to direct their attention to the lesioned side of the body, increasing spatial and motor activation [1]. Other experiments offer different explanations: cueing increases the metabolic activity in the right brain hemisphere; cueing may activate cerebral pathways complementary to the harmed ones [1] [9]; cueing stimulates arousal which may increase spatial attention [15].

The positive effects of cueing are clear. Moreover, with the recent emergence of novelty technologies such as Augmented and Virtual Reality, an opportunity rises – the incorporation of these state-of-the-art technologies in rehabilitation strategies for patients with Hemispatial Neglect. AR and VR strategies have numerous advantages. For instance, it enables the straightforward presentation of training scenarios that are difficult to present by other means, easy manipulation of the stimuli/cues to better adapt to each subject, the control and absolute consistency of training variables, the provision of different natures of cueing and the ability to incorporate the collection of physiological data and feedback tailored to each subject according to its impairment. Additionally, it decreases doctor involvement in AR-based rehabilitation techniques, reducing inherent subjectivity and providing a standardized therapeutic path

Virtual and Augmented Reality cueing is already being applied in Hemispatial Neglect rehabilitation context. A study conducted by Myers and Bierig [17] analyzed different aspects of patient behavior when undergoing a VR experience. The patient was immersed in a three-room virtual house with interactable objects. The flow of the layout of the rooms was biased to the left and moving objects moved from the right to the left. Afterwards, 3 different measures were recorded: the maximum angle of head rotation to the left and to the right, the time to reach the maximum angle in each direction and, in the case of patients who ignore the left side, the number of cues the patient requires to turn to the left. The results were clearly positive and suggested the applicability of VR in HN rehabilitation. Regarding AR, in an experiment accomplished by Smith et al. [18], patients with HN underwent a task where they were presented with different virtual objects quickly passing through the real field of view and were asked to identify a specific object (balls) while ignoring other objects (birds). These patients performed different tasks from the BIT battery [5] before and after the experiment to assess improvements. A clear upwards trend can be noted, which once again suggests the applicability of these novelty technologies in the rehabilitation of visuo-spatial pathologies.

3. Methods

The goal of the present study is to develop a cross-modal intervention to promote a quicker rehabilitation of individuals with Hemispatial Neglect, to be tested on a preliminary group of healthy individuals to assess the applicability of the model, using different tools including Augmented Reality. Nine participants contributed to this experiment (mean age = 30.8 years, standard deviation = 13.274 years). None of these patients had any pre-existing visuo-spatial or incapacitating pathologies. Prior to the application of the solution, the participants were presented with an informed consent and an informative sheet.

The intervention is composed of 4 distinct phases: the first phase included preliminary tasks to assess the extent of the neglect, any important particularities of the subject that should be taken into account and to provide a straightforward method to analyze the benefits and applicability of the plan by comparing the answers before and after the second phase; the second phase comprised Augmented Reality visual cueing through a mobile application developed by the author using Unity [19] and auditory cueing developed with the Adobe Premiere software [20] to stimulate the spatial attention, motor activation and accuracy of the subject; in the third phase, the subject was asked to repeat the tasks performed in first phase with a few variations in order to identify possible improvements, their significance, and the applicability of the solution; finally, in the fourth phase the participant was presented with a version of the Game Experience Questionnaire to quantitively assess the game experience [21].

The phase 1 was composed of 4 exercises, which were obtained from the BIT Behavioral and Conventional subtests: Clock Test (identifying the hour presented on a clock and copy that same clock) and Article Reading (reading an excerpt of text displayed in 3 similar columns) exercises from the BIT Behavioral and Line Bisection (marking the middle point of 3 8-cm lines displayed in a stairway fashion) and Task Cancellation (identifying wanted objects among a number of distractor objects) from the BIT Conventional subtests. These tests addressed the most common and significative symptoms of Hemispatial Neglect – spatial and motor neglect.

Phase 2 of this solution can be seen as the intervention itself: it encompassed 2 sub-phases: first, the patient underwent a visual cueing Augmented Reality game and afterwards 2 tasks which involved auditory cueing. The first AR game consisted in flashes of 2 red spheres in the upper part of the field of view– 1 in the left side of the FoV and 1 in the right side. These flashes appeared either unilaterally or bilaterally and the participant was asked to identify where the flashes occurred (left, right or both). The flashes lasted 1 second and the time interval between flashes was also 1 second. The symmetry of the flashes is maintained throughout the exercise and it also makes use of gradients – the flashes initially appear closer to the center of the field of view and move towards the periphery over time. The second game consisted of different red shapes (cubes, cylinders, and spheres) appearing sequentially in random positions of the field of view of the participant. It was then asked to identify which shape appeared. The cues also appeared for 1 second with 1 second intervals. Regarding the auditory tasks, the first one consisted of 0.6-second-long beeps appearing in either the left, right or both ear channels of the participant, which was tasked to identify the ear channel where the beep occurred (focus of *where* rather than *when*) – there was a time interval of 3 second between cues. The second auditory task also consisted of 0.6-second-long beeps, but this time they always appeared in both ear channels. In this case, the time intervals between cues was either 1, 2, or 3 seconds and the participant was asked to raise its right arm as fast as possible after the beeps appeared (focus on *when* rather than *where*).

The outline of the second phase accounts for important details. First of all, red spheres were chosen due to their higher contrast with real-world backgrounds – the color red is usually associated with danger or threat and so, draws attention more effectively. The geometry of the flash (sphere) was chosen to also contrast with the background, since it is not a common form to appear in the upper part of the field of view. Furthermore, Augmented Reality technology was chosen to perform this task instead of Virtual Reality since it has been shown in previous studies that using visual cue superimposition in the real environment provides better results and higher transferability to the everyday lives of the patients [22]. Also, by using AR instead of VR, it is possible for the patient to, in a possible future, use it in its quotidian with more ease (at home, outside or even at work) since it does not significantly alter the subject's perception of the real world, providing a quick and simple method to ameliorate hemineglect symptoms – there is a smoother scalability between the clinical environment and the patient's day-to-day by using AR. Additionally, the first visual cueing test using Augmented Reality takes advantage of gradients. The red sphere flashes start off in a near-central position and move towards the periphery of the field of view over time. This allows not only to more accurately identify where the key dysfunction lies, but also to compel the subject to direct the attention to the more lesioned areas of the field of view. Furthermore, neither of the first two exercises (AR test and first auditory test) promote motor activation. Thus, the second auditory test complements the prior exercises, by demanding motor skills, originating a comprehensive, cross-modal intervention plan which stimulates different domains of the subject, causing positive and long-lasting improvements on the HN symptoms of the patient.

In the phase 3 of the intervention plan, the subjects were asked to repeat the tests from phase 1 with some adjustments to collect data for posterior analysis regarding the impact of the intervention plan. The Line Bisection Test was repeated under the same conditions as phase 1. The Task Cancellation was also issued. However, in order to not allow the subjects to recognize any patterns or recall the position of the wanted objects from memory which could bias the results, 2 different wanted objects were requested. The Clock Test was performed once again but presenting a different hour while maintaining a pointer in each side of the clock. Finally, the Article Reading exercise was performed again using a different article of text.

In all exercises, qualitative and quantitative data was collected. Qualitative data was mainly based on questions and observations done by the author and observations made by the participants. Regarding quantitative data, in the Line Bisection test, the distance from the subject's bisection to the actual midpoint was collected. Deviations to the left were registered as negative and deviations to the right were registered as positive. In the Cancellation Task, the number of omissions in the upper and lower halves was registered as well as the impact that size and color have on the performance of the participants was recorded. In the Clock test, whether the participant correctly identified the hour and the subsequent copy were collected. In the Article Reading exercise, the number of words omitted was registered. In phase 2, the results were also gathered for statistical purposes – the number of correctly identified cues in the different exercises was collected.

Finally, the participants filled out a version of the Game Experience Questionnaire (reflects the experience regarding the AR games solely, without accounting for the remaining tasks) [21]. They were presented with the first and third modules of the GEQ, since the second module measures Social Presence and, thus, is not applicable in the current study. The first module is the Core Module or Core Questionnaire. It assesses the game experience quantitively on seven components: Immersion, Flow, Competence, Positive and Negative Affect, Tension, and Challenge. It is composed of 33 items. The linking between the components and the items is as follows:

Competence: Items 2, 10, 15, 17, and 21.
Sensory and Imaginative Immersion: Items 3, 12, 18, 19, 27, and 30.
Flow: Items 5, 13, 25, 28, and 31.
Tension/Annoyance: Items 22, 24, and 29.
Challenge: Items 11, 23, 26, 32, and 33.
Negative affect: Items 7, 8, 9, and 16.
Positive affect: Items 1, 4, 6, 14, and 20.

The third module of the GEQ is the Post-Game module. It assesses the participant's experience after the experience ends on four components: Positive Experience, Negative Experience, Tiredness and Returning to Reality. It is composed of 17 items. The linking between the components and the items is now presented:

Positive Experience: Items 1, 5, 7, 8, 12, 16
Negative experience: Items 2, 4, 6, 11, 14, 15.
Tiredness: Items 10, 13.
Returning to Reality: Items 3, 9, and 17.

The minimum score in each item is 0 and maximum score is 4.

4. Results and Discussion

The results obtained from the Line Bisection test are presented in Table 1. The participants performed this exercise in under a minute. The median and interquartile range show a reduced error and variability throughout the 3 lines. The median of the results is extremely reduced (either 0 or 1 millimeters – since the lines were 8 cm long, 1 millimeter corresponds to 1.25%). Furthermore, the interquartile range shows the small variability of the results. All the participants carried out this task effortlessly and their answers never presented any significative deviation from the middle point of the different lines (total error rate of 7.2%). It is also observable that, even though the participants did not have any type of visuospatial pathology and the errors are residual, the results in the Line Bisection task were significantly better after the intervention in the three lines, with improvements as high as 80% (which occurred in the center line). It is also observable that, even though the participants did not have any type of visuospatial pathology and the errors are residual, the results in the Line Bisection task were significantly better after the intervention in the three lines, with improvements as high as 80% (which occurred in the center line) – there are 2 possible justifications underlying these results: it could be argued that this cross-modal intervention plan is, in fact, effective in increasing the spatial attention of the participant, even if it is completely healthy and lacking any visuo-spatial pathology. The second justification lies on the fact that, even though there are improvements, the errors are still extremely low in both phases and the participant sample is reduced. Thus, the worse results in the first phase could be due to accidental errors, which can be caused by a number of factors (lack of attention, nervousness, etc.) and are relatively common. The learning factor (participants learning how to perform the task in the first phase and consequently having a better performance in the second

Table 1: Results obtained from the Line Bisection Test for each participant (in millimeters) before and after phase 2.

Participant	Left		Center		Right	
	Before	After	Before	After	Before	After
P.B.	-2	0	0	0	0	0
M.F.	0	1	-5	1	1	1
L.P.	3	0	2	0	3	1
M.P.	0	-3	0	1	2	1
B.G.	0	1	-1	0	0	-1
M.R.E.	1	0	0	0	-2	0
J.C.B.	1	0	1	0	1	-1
J.B.	0	0	0	0	0	0
R.B.	0	0	-1	0	-1	0
Median	0	0	1	0	1	1
Interquartile Range	1.5	1	1.5	0.5	2	1

Table 2: Results obtained from the Task Cancellation for each participant before and after phase 2.

Participant	Identifications		Omissions Before		Omissions After	
	Before	After	Upper	Lower	Upper	Lower
P.B.	46/48	36/38	0	2	0	2
M.F.	47/48	37/38	1	0	0	1
L.P.	48/48	33/38	0	0	1	4
M.P.	47/48	38/38	1	0	0	0
B.G.	47/48	33/38	1	0	1	4
M.R.E.	48/48	38/38	0	0	0	0
J.C.B.	47/48	37/38	1	0	0	1
J.B.	48/48	38/38	0	0	0	0
R.B.	47/48	38/38	1	0	0	0
Percentage Error (%)	1,63	4,11				

application of the exercise) can also play a part in the performance improvement. Nonetheless, this error diminishment should be considered prior to the clinical application. It is also important to notice that the participants performed this exercise without any difficulty and without expressing any type of adverse reaction to it.

Previous experiments conducted in this field corroborate the findings of the current study, namely done by Van Deusen [23] or Gamberini et al. [24], which revealed extremely reduced errors in the Line Bisection test applied to healthy participants and also the applicability of the test, where errors never topped deviations of 0.48 ± 5.55 millimeters for the left lines and 0.59 ± 4.35 millimeters for left plus center lines.

Regarding the Cancellation Task, the results are presented in Table 2. The participants carried out this exercise with ease and comfortably and completed it in around 5 to 7 minutes. The error for phases 1 and 3 is 1.6% and 4.1%, respectively. In the first phase, the number of identified objects is 47.2 ± 0.6 out of 48 and in the second phase it is 36.4 ± 2.0 out of 38. The standard deviation is considerably higher in the second phase when compared to the first. In this case, the number of omitted objects in the upper and lower half of the image is shown instead of the right and left halves because the participants do not have any visuo-spatial pathologies and, thus, it is expected that no patterns will occur in the omitted objects between the right and left halves of the image, corroborated by, for example, the work of Warren et al. [25] where healthy subjects presented error rates under 4% and no patterns regarding upper and lower omissions.. Finally, it is also worth noting that, when analyzing the impact of the size and color of the target on the performance of the participants, no patterns were identified since the error is extremely low and when there were omissions, the large and small targets were omitted similarly - of all the omissions, approximately 48% corresponded to omissions of white targets and 52% to black targets; 43% corresponded to large targets and 57% to small targets. It was also observed that the participants performed this task with a standardized method of scanning, prioritizing left to right and then top to bottom. Thus, the worse results in the lower half of the second application of the Cancellation Task may have some possible justifications: the duration of the intervention plan is too long, causing the participants to feel weary when performing this exercise (it was claimed by 2 participants that the duration of these Cancellation Tasks was rather extended); the exercise of the Task Cancellation in phase 3 is harder than the Task Cancellation in phase 1 (since the increase in the error percentage only happens in phase 3);

the difficulty in sustaining attention for long periods of time in repetitive scanning exercises (the factor of fatigue can have a large impact in this task since it is applied after phase 1 and 2). Finally, and since the participant sample is reduced, similarly to the Line Bisection task, it could be argued that the rise in the omission rate in the lower half of phase 3 is due to accidental errors because the percent error is minor in both phases. It is also important to notice that 2 participants claimed that the duration of these exercises was fairly long. Thus, and since the results are worse in lower half of the second exercise, the duration of this task should be shortened.

In a clinical application of this solution, it would be important to also register the number of omissions in the left and right halves, since it could highlight the severity of the neglect, the bias towards the right ride and possible improvements before and after the intervention (phase 2). It would also be fundamental to analyze the scanning method and compare it to the scanning method of healthy participants and the impact that the size and color of the icons has on the performance of the HN patients, which do not have a significant effect on the performance of healthy participants.

Prior researches done in the area coincide with the results of this experiment. A study conducted by Warren et al. [25] showed that 81 healthy participants prioritized a left to right, top to bottom scanning method with reduced errors and deviations (similar to the results obtained in the current study) – largest error occurred in a test where the mean correct identification was 38.5 out of 40 with a deviation of 1.9 (corresponding to an error of 3.75%). A more recent study done by Benjamins et al. [26] concluded that age, gender and level of education do not have an affect performance on the Cancellation Task – an important conclusion to consider when applying this solution to HN patients.

In the Clock Test, the participants performed both tasks without difficulty – all participants correctly identified the hour presented and drew and analogous clock without any significative deviations or asymmetries. This exercise had a duration of approximately 2 minutes. Nonetheless, a previous study conducted by Berger et al. [27] revealed that clock drawing tests which require time setting had higher sensitivities, and lower misclassification rates (sensitivities of 81 to 93% compared to 58 to 72% obtained by methods that do not require Time Setting; overall misclassification rates of 0.19-0.25 out of 1 compared to 0.30-0.35). Thus, when applying this exercise in a clinical practice, the Clock Test should be changed – instead of asking the participant to identify the hour presented on the clock, the participant should be presented with an hour written on the sheet of paper (using a 24 or 12 hour format depending on the nationality or preference of the participant – for example, 18:35/6:35pm) and then asked to draw a clock with the given hour while maintaining pointer on each side of the clock

Similar to the Clock Test, the participants carried out the Article Reading exercise without difficulty. This exercise took around 1 to 2 minutes to be completed. A study conducted by Lindell et al. [28] assessed the sensitivity and efficiency of the Article Reading test and, like in the current study, revealed a normal performance of healthy participants, with errors near zero (of the healthy participants, 100% showed normal performances – a performance was considered normal if a maximum of 1 word was omitted). It also showed a large number of omissions when applying this exercise to Hemispatial Neglect patients.

Regarding the phase 2 of the research, quantitative results were also obtained. After collecting the data for all participants, it was possible to conclude that all participants were able to complete the tasks without difficulty and provided the correct answers in every task, as it was expected. Furthermore, the participants clearly expressed satisfaction and ease when performing the Augmented Reality tasks. The results obtained by all the participants can lead to a few conclusions: the cadence of the stimulus is appropriate in all tasks which was also confirmed verbally by the participants), the color and shape of the AR stimuli is also suitable, the gradients used in the first AR exercise are also adequate, the positions in which the stimuli appears on the AR tasks is appropriate and the auditory stimulus chosen is adequate and perceptible.

After the AR and auditory tasks, the patients were asked whether they thought the cadence of the exercises was suitable and all the answers were positive. Regarding the experience, three participants claimed that the immersion of the solution was compromised due to the HMD – it put too much pressure on the nose, causing discomfort. These participants held the glasses with their hands to relieve some of this pressure while performing the tasks. Also, they stated that the glasses defocused that game slightly – this must be taken into account prior to the clinical application of this solution and possibly switch the brand of the HMD used. The exercises had a duration of 2 minutes each. After the exercise was explained to the participants, they were asked if they wanted to practice, prior to the exercise itself, using a training application which consisted of a shorter version of the main application, with a different cadence of stimuli. The participants that requested training had an approximately 30 seconds long practice session using the training application. The training phase was not applied to all participants because they showed clear understanding of the requirements of the task – furthermore, the results

Table 3: Results obtained from the Core module of the Game Experience Questionnaire

Participant	Competence	Positive Affect	Flow	Sensitive and Imaginative Immersion	Challenge	Negative Affect	Tension/ Annoyance
P.B.	3.6	3.8	2.6	2	0,6	0.3	0
M.F.	4	3.8	2.6	2.2	0.8	0.3	0
L.P.	4	3.4	2.4	2.2	0.6	0.3	0
M.P.	4	3.8	3.6	2.3	0	0	0
B.G.	3.4	4	1.6	3.2	0.4	0.5	0
M.R.E.	4	3.6	2.8	2.3	0	0	0
J.C.B.	4	3.4	2.8	1.3	0	0	0
J.B.	3.6	3	2.4	2.8	1.6	0.5	0
R.B.	4	3.6	2.6	1.8	0.6	0	0
Average	3.8	3.6	2.6	2.2	0.5	0.2	0

Table 4: Results obtained from the Post-Game Module of the Game Experience Questionnaire.

Participant	Positive Experience	Negative Experience	Tiredness	Difficulty Returning to Reality
P.B.	2	0	0	0
M.F.	2	0	0	0
L.P.	1.8	0	0	0.3
M.P.	3.5	0	0	1
B.G.	2.2	0.2	0	0
M.R.E.	0.3	0.3	0	0
J.C.B.	0.7	0	0	0
J.B.	1	0	0	0.7
R.B.	2	0	0	0.3
Average	1.7	0.1	0	0.3

showed that the training did not have an impact on the performance of the participant, since all participants correctly identified all cues.

The results obtained from the Game Experience Questionnaire are shown in Table 3 and Table 4. The maximum possible score was 4 and minimum was 0. These results are a central part of this research since they provide quantitative results to qualitative aspects of the solution prior to its clinical application. When analyzing the results of the GEQ, it is important to bear in mind the target population group of this solution. Since it is going to be applied, mainly, to people over the age of 65 (since this is the age group more susceptible to stroke), the solution should be pleasant, fluid and seamless (Positive/Negative Affect, Positive/Negative Experience, Sensitive and Imaginative Immersion), intuitive (Competence), of low difficulty (Challenge), it should not cause any discomfort, boredom, tension, nausea or dizziness (Tension/Annoyance, Difficulty Returning to Reality) and should have an appropriate duration so it won't be wearing to the patient (Flow, Tiredness).

In fact, the participants in the current study rated the experience as positive (both in-game and afterwards (Positive Experience/Affect >> Negative Experience/Affect)), easy and accessible (high Competence and low Challenge), comfortable and with an appropriate duration (Tension/Annoyance and Tiredness with scores of 0, low Difficulty Returning to Reality and high Flow). However, it is also important to notice that the Sensitive and Imaginative Immersion component has an intermediate value (2,24 out of 4). This is most likely due to the aforementioned claims of the participants regarding the HMD – the nose pressure and the defocusing done by the glasses reduces the immersion of the experience which justifies the score in this component. The remaining components substantiate the validity and applicability of the solution.

The overall duration of the intervention was around 30 minutes. However, with the adjustments previously proposed (namely to the Cancellation Task), the duration should decrease. Nonetheless, this duration seemed appropriate, since it did not tire the participants, who also expressed satisfaction while performing the different tasks. When applying the solution to HN patients, the total duration is expected to increase since it is expected that the scanning process in the Cancellation Task will be slower, the drawing of the clock and the reading of the article will take longer and the AR and auditory tasks will also take more time since the training version will be presented to every patient. The intervention induced overall satisfaction in the participants and the previous work done in the field corroborate the applicability of the solution.

5. Conclusion

The goal of the present study was the development of a non-invasive, cross-modal intervention plan aiming to rehabilitate HN patients and the assessment of its applicability through testing on healthy individuals, prior to its clinical application. The outline of this solution was devised after reviewing previous work done in the area of Hemispatial Neglect and associated therapy and rehabilitation strategies. Moreover, it was developed with the support of members from the start-up NEVARO and the solution was validated by Dr. Pedro Alves from the Department of Neurology, *Hospital de Santa Maria*. The work conducted by previous authors, namely by Smith et al. [18] and Hommel et al [9], substantiated the applicability of virtual and auditory cueing in the amelioration of HN symptoms, laying the foundations for this work, which tried to expand the knowledge in the field using a cross-modal solution that, up to the author's knowledge, hasn't been experimented before.

The solution was designed around the AR and auditory cues, with tasks requiring visuo-spatial capabilities applied before and after this phase to assess changes, oscillations, and possible improvements in the performance of the participants. For a more comprehensive approach, these tasks were chosen in a way which allows the assessment of the spatial and motor neglects independently. Similarly, the strategy employed in the cueing exercises prioritized on stimulating the spatial capabilities (Augmented Reality cues and identifying the ear channel in the auditory cueing exercise) and muscular activation of the participant (raising an upper limb in the second exercise of the auditory cues). At the end of the intervention plan, the participants filled two modules of the Game Experience Questionnaire (Core and Post-Game) – the results obtained from this questionnaire are central to this phase of the research (assessment of the applicability of the solution through testing in healthy individuals) since it quantitively scores qualitative aspects of the solution, elucidating about its robustness and allowing the identification of possible enhancements and/or adjustments to be implemented.

The results from the nine participants validate the applicability of the solution. All tasks were completed without difficulty and the results were near perfect in every task. No adverse or unforeseen reaction was observed in any participant. All these observations regarding the Augmented Reality tasks are corroborated by the results from the GEQ, which further substantiate the strategy's pertinence. The only observations pointed out the long duration of the Cancellation Tasks and the deficiencies of the HMD, which decreased the immersiveness of the experience. Thus, before the clinical application of this intervention plan, the duration of the Cancellation Tasks should be reduced to a number of icons which does not tire or bore the participant. The Bells Test from the Behavioral Inattention Test has 35 total targets and 280 distractors (total of 315 icons) [29]. The applied Cancellation task has 48 targets and 326 distractors in phase 1 and 38 targets and 336 distractors in phase 3 (total of 374 icons). Thus, the size of the Cancellation Task used in this research should emulate the Bells Test in size – the number of targets and distractors must be reduced prior to the clinical application. Regarding the HMD, and as aforementioned, it should either be switched or adjusted in order to solve the identified issues. To choose the best solution, an internet search should be performed to analyze reviews regarding different HMDs and pick the most proficient one to deliver the most comfortable and immersive experience possible.

After all the adjustments are implemented, the solution will be prepared for the next clinical phase – application in Hemispatial Neglect patients, since the qualitative and quantitative results obtained from this research corroborate the pertinence and applicability of the strategy.

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