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Executive Summary of the Thesis

Digitization of task to detect visuo-spatial deficits in neurological population

Laurea Magistrale in Mechanical Engineering - Ingegneria Meccanica
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1. Introduction

In recent years many sectors have embraced the idea of a digitalization process to improve their efficiency [1]. One of them is the health field (Digital Health-DH) to which the digitalization of diagnostic tools or instruments provides an interesting approach. Its main advantages are:

- automated collection of precise, real-time, and reliable data;
- reproducibility and customization of diagnostic tools that allow clinicians to modify test parameters according to clinical or patient's need [2];
- possibility to experiment with everyday situations without the need to move from the clinical setting, i.e., using immersive Virtual Reality (VR) applications.

From this perspective, the project of a set of six digital applications, i.e., two in the bi-dimensional form to be performed on a computer and four in VR, has been designed. The main focus of these applications is the ability to assess a specific neurologic syndrome, i.e., Unilateral Spatial Neglect (USN). The targeted end users are patients with a neurological lesion (stroke–traumatic brain injuries or brain tumors).
The postprocessing phase of the outputs obtained and the section related to testing has been performed and briefly described below.

2. Unilateral Spatial Neglect

Unilateral spatial neglect is a common neurologic syndrome caused by brain injuries (stroke, traumatic brain injuries, brain tumor, etc.) following a lesion to a different frontoparietal cortical and subcortical network. Both left and right hemisphere lesion can cause USN, but right lesion cause more severe USN than left lesion [3]. The main risk that USN patients run is due to the lack of awareness of having the disorder which increases the possibility of physical injury and isolation [4]. About 50% of neurological survivors are affected by USN in an acute form and in about 40% this becomes chronic and still present one year after its onset [5].
The importance of identifying this disorder is fundamental in the recovery of sensory-motor and cognitive deficit: studies define that it is faster in the first 2-3 weeks after the brain lesion [6].
The tests currently used for the assessment of

USN are mainly "pen-and-paper" tests and, given the symptomatic complexity of the disorder, there are various types of tasks, such as Cancellation and Line Bisection.
Its main advantage is the ease of execution which allows them to be administered even in the first 24 hours after a stroke [4]. Below a brief description of the two reference types for the designed set of applications is presented.
In cancellation activities, the task required of the patient is the identification and selection of target elements presented on a paper. Figure 1 shows an example of a Cancellation test.

Figure 1: Example of Bell Test [7]

In the Line Bisection test, the patient is asked to draw the midpoint of a series of horizontal lines of different lengths, for example 8,16, and 24 cm [4], thus dividing them into two segments, as shown in Figure 2.

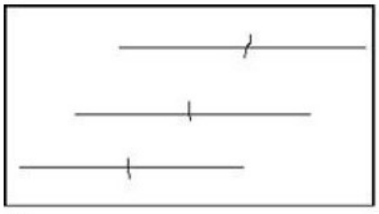


Figure 2: Example of Line Bisection Test [4]

Despite their common use, the traditional tests described above have some limitations. Studies show that these may not be sensitive enough for the detection of mild USN, especially in the chronic phase [8], and they often lack of ecological validity, moving away from a real understanding of the patient's actual performance in daily life [9]. Furthermore, a match between the results obtained during the diagnostic phase and real-life performance [8] is not always guaranteed and, being time-consuming and often tedious for the patient, can lead to a lack of engagement and motivation which could affect the patient's performance.
Therefore, thanks to technological progress, it is possible to overcome the limits imposed by traditional tests [10], promoting the development and use of USN evaluation techniques in digital form.

3. VE Design Factors

The American Academy of Clinical Neuropsychology (AACN) and the National Academy of Neuropsychology (NAN) have defined guidelines [11] to be followed to validate the use of digital technology in a clinical setting. Having sensitive patient data available, greater attention has been paid to the choice of the final operator, concluding that the best candidate for this purpose is a clinician with IT skills who can configure and solve problems related to the system, perceive the possible distractions of the user, and to encrypt the data saved locally.
A recurring problem in VR applications is the possible generation of cybersickness which can lead to nausea and dizziness in the user. Having to place the applications in a clinical context, the generation of these symptoms would lead to VR exclusion from use. To overcome the problem, hardware, and software were chosen with characteristics capable of reducing undesired effects.
Applications must also meet the standard criteria adopted for the development of psychometric tests, such as providing evidence related to reliability (defined as the ability to reproduce a consistent result over time), validity (defined as the ability of an instrument to measure exactly what it was designed for), and the utility.

4. Project Development

Figure 3 shows the set of applications designed for USN diagnostics in digital form.

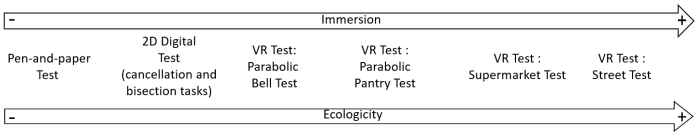
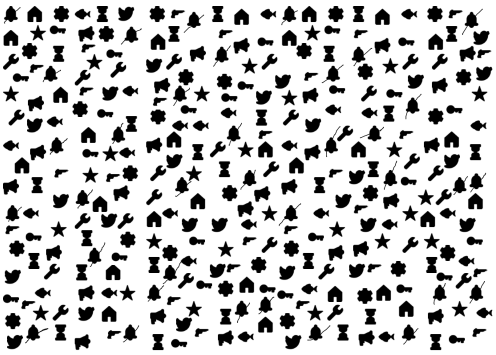


Figure 3: Set of designed applications

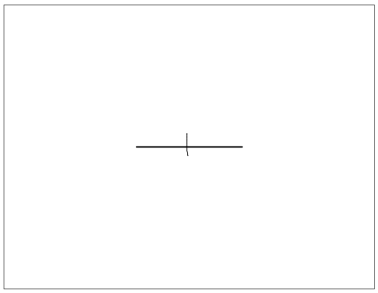
In particular, 2D applications have been designed through the use of Processing engine (4.1.2), with Java as the chosen programming language, while the VR applications through Unity3D engine (2021.3.10f1), using a device SDKs associated with Oculus Quest 2 head-mounted displays (HMDs).

4.1. 2D applications

The designed 2D applications replicate traditional tests such as the Bell Test and the Line Bisection Test, in digital form with automated data collection. In particular, the requested task is respectively to find all the bells present in the scene and to identify the midpoint of the segment.
Figure 4 shows the visual output obtained at the end of the two activities: the selection took place by tracing a line with the mouse.



(a) Bell Test



(b) Line Bisection Test

Figure 4: Output images of 2D applications

At the end of the activity, a set of output files containing information on the time history of the patient's actions during execution is saved locally. Through MatLab (R2022b), a visual analysis containing the information necessary for diagnostics, as shown in Figure 5 for Bell Test and in Figure 6 for Line Bisection Test, is provided to the clinician.

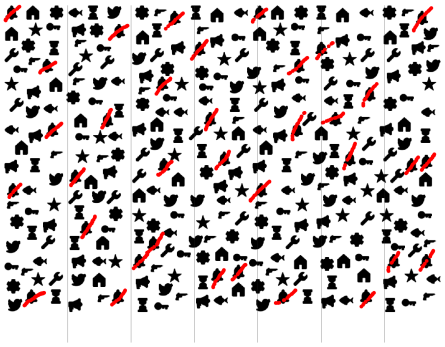


Figure 5: Output postprocessing images of 2D Bell Test application

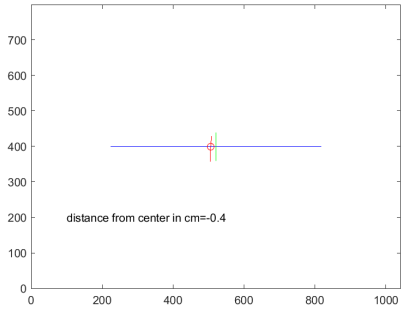


Figure 6: Output postprocessing images of 2D Line Bisection Test application

4.2. VR applications

The designed VR applications aim to assess the USN through exercises that can transport the user in increasingly realistic situations, allowing an increase in the user's motivation and, at the same time, providing tools to clinicians to analyze the user's behavior in daily life.
The starting point is the design of an exercise with a low level of immersion to give a further alternative to traditional tests: the Parabolic Bell Test replicates the homonymous traditional test with greater difficulty by presenting twice the elements commonly used and increasing the viewing range to 130 degrees, as can be seen in Figure 7.

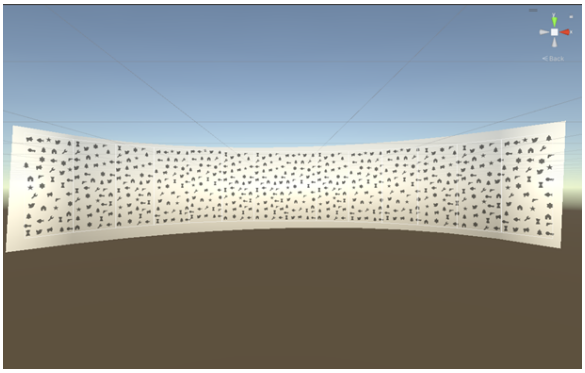


Figure 7: Parabolic Bell Test scenario in Unity3D

To increase the sense of presence, the second designed application represents a more realistic situation, i.e., the search for products in a pantry using only the hands. As in the previous exercise, also in the case of the Parabolic Pantry Test, the required task is included in the Cancellation category since the user must search for all the target elements present within the structure presented in Figure 8.

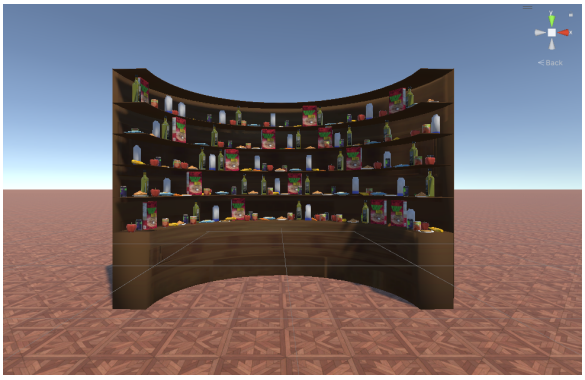


Figure 8: Parabolic Pantry Test scenario in Unity3D

The maximum level of immersion and ecologicicty is expressed in the last two designed applications, i.e., the Supermarket Test and the Street Test shown in Figure 9. The user finds himself immersed in familiar environments, such as a supermarket and a street, in which to perform daily tasks. The main advantage is the understanding of the patient's behavior outside the clinical setting to have more information on his possible difficulties in a real environment equipped with distractive stimuli of different natures, such as visual, auditory, and dynamic.

(a) Supermarket Test

(b) Street Test

Figure 9: Supermarket Test and Street Test scenarios

Being large scenarios, physical exploration alone is not enough. To allow research in the entire scenario, both for the Supermarket Test and the Street Test, two movement systems have been integrated, i.e., the teleport and the linear movement with the joystick, and have been evaluated in the testing phase in relation to the generation of cybersickness and ease of execution.
At the end of each proposed application, an output file, that contains information on the patient's execution and has been processed through the use of VBA Macros, is provided to the clinical staff. Through the reports, data regarding the number of targets, the number of elements per spatial area, the spatial positions of the user's teleporter, and possible incorrect selections are collected.
The use of the designed applications allows the clinician to obtain the information necessary for the assessment, being able to concentrate on viewing the patient's behavior during execution without taking notes about the performance of the task.

5. Pilot Study

To assess the validity of the designed applications, focusing on the usability and manifestations of undesired symptoms, a pilot study has been performed. A sample of 56 healthy subjects (34 male and 22 female) with a mean age of 26 years has been recruited for the testing phase, carried out mainly at Politecnico of Milan- Bovisa Campus.
To provide an initial index of the participants physical condition, a compilation of the Simulator Sickness Questionnaire (SSQ) has been requested before the start of the test. Furthermore, generic information on the application execution and on the devices to be used has been provided to the participant.
Later each subject performed the seven designed applications in a random way to reduce the generation of order effect that could influence the acquired data. All applications, except for 2D applications to be performed on a computer, have been performed in standing configuration to put the subject in the worst condition because of the greater probability of manifestation of symptoms associated with cybersickness. At the end of the entire experience, each subject has filled out the System Usability Scale (SUS) to assess the usability of the designed system.

SUS Score	n	%	Grade	Adjective Rating
>80.3	31	60	A	Excellent
68-80.3	13	25	B	Good
68	0	0	C	Okay
51-68	7	13	D	Poor
<51	1	2	F	Awful

Table 1: Results obtained through SUS Score calculation [12]: n represents the number of subjects with a SUS score inside the described category and % the percentage

The results obtained through SUS show that 85% of the participants have evaluated the overall experience with a score higher than the minimum threshold requires (i.e. score of 70), of which values are reported in Table 1.
Through data acquired from SSQ compilation at the end of each execution, it is clear that the tasks with greater manifestations of symptoms associated with cybersickness, especially in Nausea (N) and Disorientation (D) categories, are Supermarket Test and Street Test with linear movement of the joystick. However it is noticeable that the same scenarios with the teleport provide opposite results: in that condition, the perceived symptoms remain equal or even reduced with respect to the start of the test, as Figure 10 shows.

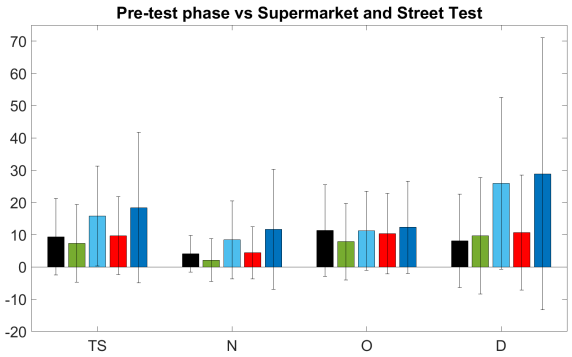


Figure 10: Mean comparison, with standard deviations, between pre-test phase (black bar), Supermarket Test with teleport (green bar), Supermarket Test with linear movement with the joystick (light blue bar), Street Test with teleport (red bar), and Street Test with linear movement with the joystick (blue bar).On the x-axis, the 4 categories of the Simulator Sickness Questionnaire: TS is the Total Score, N is the Nausea, O is the Oculomotor, and D is the Disorientation.

The obtained results are consistent with the previous study: linear movement with the joystick is considered more intuitive for users but, at the same time, it has a greater probability to exhibit symptoms [13]. The movement preferences of the subjects are coherent with the above: 67% of the subjects have reported preferring teleport to linear movement with the joystick. However, the carried out Chi-squared test shows that there is no significant difference between the symptoms perceived during the execution of the proposed applications: the p-value of the Total Score, which is an indicator of the overall severity of the perceived symptoms, is greater than the required threshold, concluding that the symptoms perceived during the experience are overall negligible with respect to the pre-test phase.
To further investigate the validity of the designed applications, an analysis of the occurrence of pathological subjects in the recruited sample has been performed. In particular, the percentage of subjects that resulted pathological with respect to a calibrative sample [14] has been calculated: further proof of the influence of the movement method on the symptoms manifestation has been found, as it is visible in Table 2. It is noticeable that, in the initial phase, 21% of the subjects reported having a proneness

to nausea: it has been decided to investigate the influence of this data on the number of pathological people obtained previously, concluding that this predisposition is not necessary for the manifestation of the symptoms.

NAUSEA (N)	n	%
Pre	0	0
2D applications	1	2
Parabolic Bell Test	2	4
Parabolic Pantry Test	0	0
Supermarket Test with teleport	1	2
Supermarket Test with linear movement with the joystick	4	7
Street Test with teleport	1	2
Street Test with linear movement with the joystick	4	7
OCULOMOTOR (O)	**n**	**%**
Pre	3	5
2D applications	1	2
Parabolic Bell Test	4	7
Parabolic Pantry Test	1	2
Supermarket Test with teleport	2	4
Supermarket Test with linear movement with the joystick	1	2
Street Test with teleport	2	4
Street Test with linear movement with the joystick	3	5
DISORIENTATION (D)	**n**	**%**
Pre	5	9
2D applications	5	2
Parabolic Bell Test	7	7
Parabolic Pantry Test	3	2
Supermarket Test with teleport	7	4
Supermarket Test with linear movement with the joystick	15	2
Street Test with teleport	6	4
Street Test with linear movement with the joystick	16	5
TOTAL SCORE (TS)	**n**	**%**
Pre	3	5
2D applications	2	4
Parabolic Bell Test	4	7
Parabolic Pantry Test	1	2
Supermarket Test with teleport	2	4
Supermarket Test with linear movement with the joystick	6	11
Street Test with teleport	2	4
Street Test with linear movement with the joystick	4	7

Table 2: Number (n) and percentage (%) of pathological people for each category and application

In fact, not all subjects that resulted pathological are included in the group of proneness to nausea, as it is reported in Table 3.

Applications	N	O	D	TS
Pre	-	1/3	1/5	1/3
2D applications	1/1	0	2/5	1/2
Parabolic Bell Test	0	1/4	2/7	1/4
Parabolic Pantry Test	-	0	0	0
Supermarket Test with teleport	1/1	1/2	1/7	1/2
Supermarket Test with linear movement with the joystick	3/4	0	7/15	3/6
Street Test with teleport	0	0	2/6	0
Street Test with linear movement with the joystick	2/4	1/3	5/16	1/4

Table 3: Number of pathological people prone to nausea with respect to the total number of pathological people: if there are not pathological people in a category, a dash (-) is shown in the corresponding box; if there are not pathological people prone to nausea in a category, a 0 is placed in the corresponding box. Notice that: N is Nausea, O is Oculomotor, D is Disorientation, and TS is Total Score.

6. Conclusion

The presented thesis work is focused on enhancing the advantages of digitization in the medical field with a specific focus on the tools used for USN assessment. The main improvements that digitalization can provide in this area are the acquisition of automatic, precise, fast, and reliable data and the possibility of reproducing everyday situations while remaining inside the clinic setting. Since the medical field has greater restrictions on the introduction of new tools, the guidelines for the development of a set of digital applications have been investigated. The designed set includes 6 applications with different levels of complexity and ecologicity: from two-dimensional computer applications to immersive VR applications that reproduce everyday situations. The decision to propose a set containing various applications has been made to provide clinicians with a complete tool that can satisfy multiple needs, both from an economic point of view and from the clinicians and patients needs. To investigate the usability of the designed applications, a pilot study on a sample of 56 healthy subjects has been conducted. Statistical analysis was carried out using the data collected through the administration of the System Usability Scale (SUS) and the Simulator Sickness Questionnaire (SSQ): 85% of the subjects evaluated the experience positively. In addition, the presence of symptoms related to cybersickness has been verified through the use of the Chi-squared test and Oneway ANOVA: the applications with the linear movement with the joystick presented a significant difference in symptoms associated with the Disorientation category compared to the pre-test phase. However, the analysis shows that there is no significant difference in the overall indicator, i.e., Total Score, concluding that the difference of the symptoms perceived during the execution of the various applications is negligible overall.
For the sake of completeness, the influence of a predisposition to nausea on cybersickness has been investigated: the data analysis shows a greater probability of experiencing symptoms in this category of subjects but not an absolute certainty that they will present themselves.
It is noticeable that, despite the overall positive evaluation obtained through the analysis of the data collected, the proposed study has some

limitations. Having been designed for use in the clinical setting, the tools used may not be present in a clinic or may be too expensive. A further limitation of the study concerns the sample tested which includes healthy subjects, excluding patients from the analysis. However, the proposed study aims to understand the usability of the designed set, excluding the analysis of the neurological component for which the applications have been designed. Future developments could integrate the analysis of data extrapolated from each application during the testing phase to verify the validity of the designed applications as an assessment tool.

References

[1] B. Shah, J.L.Y. Allen, H. Chaudhury, J. O'Shaughnessy, and C.S.B. Tyrrell. The role of digital health in the future of integrated care. *Clinics In Integrated Care*, 15 (100131), 2022.

[2] M. O'Reilly-Jacob, P. Mohr, M. Ellen, C. Petersen, C. Sarkisian, S. Attipoe, and E. Rich. Digital health low-value care. *Healthcare*, 9(100533), 2021.

[3] S.P. Stone, P.W. Halligan, and R.J. Greenwood. The incidence of neglect phenomena and related disorders in patients with an acute right or left hemisphere stroke. *Age and Ageing*, 22:46–52, 1993.

[4] G. Vallar and E. Calzolari. Unilateral spatial neglect after posterior parietal damage. *Handbook of Clinical Neurology,The Parietal Lobe*, 151:287–304, 2018.

[5] M. Mancuso, A. Damora, L. Abbruzzese, E. Navarrete, B. Basagni, G. Galardi, M. Caputo, B. Bartalini, M. Bartolo, C. Zucchella, M.C. Carboncini, S. Dei, P. Zoccolotti, G. Antonucci, and A. De Tanti. A new standardization of the bells test: An italian multi-center normative study. *Frontiers in Psychology*, 9(2745), January 2019.

[6] P.J. Friedman. Clock drawing in acute stroke. *Age Ageing*, 20:140–145, 1991.

[7] L. Gauthier, F. Dehaut, and Y. Joanette. The bells test: A quantitative and qualitative test for visual neglect. *International Journal or Clinical Neuropsychology*, XI(2): 49–54, 1989.

[8] E. Pedroli, S. Serino, P. Cipresso, F. Pallavicini, and G. Riva. Assessment and rehabilitation of neglect using virtual reality:a systematic review. *Frontiers in Behavioral Neuroscience*, 9(226), August 2015.

[9] D.Y. Kim, J. Ku, W.H. Chang, T.H. Park, J.Y. Lim, K. Han, I.Y. Kim, and S.I. Kim. Assessment of post-stroke extrapersonal neglect using a three-dimensional immersive virtual street crossing program. *Acta Neurologica Scandinavica*, 121:171–177, 2010.

[10] T. Ogourtsova, P. Archambault, S. Sangani, and A. Lamontagne. Ecological virtual reality evaluation of neglect symptoms (evens): Effects of virtual scene complexity in the assessment of poststroke unilateral spatial neglect. *Neurorehabilitation and Neural Repair*, 32(1):46–61, 2018.

[11] P. Kourtesis and S.E. MacPherson. How immersive virtual reality methods may meet the criteria of the national academy of neuropsychology and american academy of clinical neuropsychology: A software review of the virtual reality everyday assessment lab (vr-eal). *Computers in Human Behavior Reports*, 4(100151), 2021.

[12] B. Klug. An overview of the system usability scale in library website and system usability testing. *Weave: Journal of Library User Experience*, 1(6), 2017.

[13] E. Bozgeyiklia, A. Raijb, S. Katkooria, and R. Dubeyc. Locomotion in virtual reality for room scale tracked areas. *International Journal of Human-Computer Studies*, 122: 38–49, 2019.

[14] R.S. Kennedy, N.E. Lane, K.S. Berbaum, and M.G. Lilienthal. Simulator sickness questionnaire: An enhanced method for quantifying simulator sickness. *The International Journal of Aviation Psychology*, 3 (3):203–220, 1993.