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Monitoring Home-Based Activity of Stroke Patients: A Digital Solution for Visuo-Spatial Neglect Evaluation

M. Morando, E. Bacci Bonotti, G. Giannarelli, S. Olivieri, S. Dellepiane, F. Cecchi

Abstract— **The possibility to prescribe home-based rehabilitation activity after stroke strongly increases the amount of exercises to perform, thus helping the maintenance of relearned skills, the completion of the rehabilitation program, the practice of physical and mental concentration. Even more important is the monitoring of the patient activity at home, as it is provided by the Remote Monitoring Validation Engineering System (ReMoVES) platform [1]. The present work refers to the implementation and integration in ReMoVES platform of a digital and web-based version of Albert's [2] and Line Bisection [3] tests devoted to visuo-spatial neglect evaluation and its remote monitoring. A statistical analysis devoted to validating test-retest reliability is proposed. Concurrent correlation between digital and traditional administration of the tests is presented, in order to evaluate the validity of the remote monitoring of the home-administration through ReMoVES platform.**

I. INTRODUCTION

Patients suffering from the neuropsychological syndrome of unilateral spatial neglect (USN) fail to orient, report, or respond to stimuli in contralesional space after a cerebral stroke. Since it is not caused by primary sensory or motor dysfunction, USN is considered a higher-order disorder [4]. Specific neuro-rehabilitation is then required, helping the re-acquisition of the functional ability and a better quality of life, along with appropriate tests to evaluate the disorder recovery.

To this end, ReMoVES platform has been equipped with cloud data-acquisition capabilities to allow the therapist to remote monitoring the patient activity and progress. In addition to specific exercises proposed for the training of visual attention in the neglected region, appropriate tests to continuously evaluate the visuo-spatial disorder severity have been added.

The present work refers to the implementation and integration in ReMoVES platform of a digital and web-based version of Albert's [2] and Line Bisection [3] tests devoted to visuo-spatial neglect evaluation and its remote monitoring. The tests have been implemented by following the traditional paper-based test version. The validity of the approach is based on a statistical study where the parameters usually extracted by the therapist attending the test are correlated with the parameters automatically extracted from the web-based version. In the following, the implemented test version is described, along with the data and key indicators which allow the monitoring of the actual patient performance.

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II. METHODS

ReMoVES platform has been developed by Department of Naval, Electrical, Electronics, and Telecommunications Engineering (DITEN) of Universitá degli Studi di Genova, as a platform that addresses the problem of continuity of care in a smart and cost-effective way [1].

Two brand-new serious games have been developed and have been included in the ReMoVES platform. These activities are the digital version of paper-and-pencil tasks that are commonly applied in mapping visuo-spatial neglect in clinical practice. A similar solution have been already deployed in [5]. We introduce novelty thanks to the ReMoVES platform: the patients can run the task repeatedly at their home, without the clinician supervision.

A. Digital Albert's test

In this test, patients must cross out forty 2.5 cm lines that are placed in pseudo-random orientations on a piece of paper, using a pencil. The actual disposition of these lines is standardised, allowing for a systematic analysis of subjects' performance on the left, the right, and the centre of the page. Scoring is based on the number and location of lines left uncrossed [2]. In the digital version the patient interacts with a touchscreen (Fig. 1a). Invalid and accidental touches are automatically ignored by the system. The paper-based and the digital test differ on these aspects:

- patient must be capable to hold a pencil / patient must be able to use a touch screen;
- the digital version can provide more granular information on the speed execution and the cross out order.

B. Digital Line Bisection test

To complete the test, one must place a mark with a pencil through the centre of a series of horizontal lines. The test is scored by measuring the deviation of the bisection from the true centre of the line [3]. In the digital version the patient interacts with a touchscreen (Fig. 1b). The paper-based and the digital test differ on these aspects:

- patient must be capable to hold a pencil / patient must be able to use a touchscreen;
- the digital version allows customisation of the colour, width, height, position and rotation of the line in order to provide multiple variants of the standard test and in-depth analysis;
- the digital version displays a new line whenever the patient manages to cross out the line, continuously up to two minutes. This allows repeating the measurements

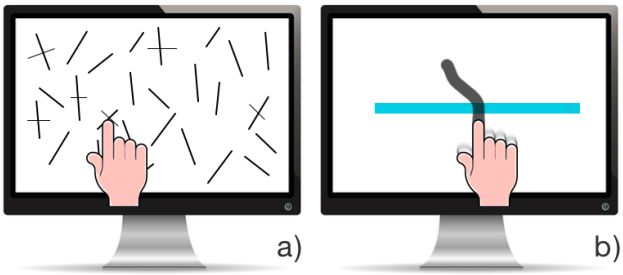

Fig. 1. a) Digital and web-based version of Albert's test included in ReMoVES platform b) Digital and web-based version of Line Bisection test included in ReMoVES platform

more times than the traditional test that is based on just three lines.

C. Statistical study

We are providing preliminary results. We want to offer an overall description of the method that has been tested with 10 subjects so far.

[6] reported an excellent test-retest reliability for the Line Bisection test ($\rho = 0.73$) and for the Albert's test ($\rho = 0.79$). More recently, [7] examined the test-retest reliability of the Line Bisection test in elderly patients with stroke who repeated the test within the hour. The intraclass correlation coefficient (ICC) was excellent for patients with neglect (ICC$= 0.97$).

In [8] an excellent correlation of Albert's test with the Line Bisection test ($\rho = 0.85$) was found when comparing the performance of 57 elderly patients with stroke.

[9] examined a computer-based method of administering the Albert's test in patients with neglect, without neglect, and age-matched control subjects. Significant differences were found between subjects with neglect and those without neglect, as well as subjects with neglect and age-matched controls.

Similarly, the two digital versions implemented in this paper are at present under validation for test-retest reliability and for investigating convergent correlation. As proposed in [10], test-retest reliability (or ICC) is considered excellent with values larger than 0.75; correlation values larger than 0.6 are considered excellent in convergence analysis.

In our clinical trials, the subjects repeated the Line Bisection test and the Albert's test twice; we collected these indicators and these test-retest results:

- Line Bisection test
  - Offset: mean of the measured deviations from the centre of the lines during the whole session. Resulting Pearson correlation coefficient is $\rho = 0.83$
  - Rate: how many lines the patient manages to cross out every second. Resulting Pearson correlation coefficient is $\rho = 0.94$
- Albert's test
  - Uncrossed: count of the lines left uncrossed on the same side of the touchscreen. Resulting Pearson correlation coefficient is respectively $\rho = 0.98$ and $\rho = 0.80$ for left and right sides;
  - Execution order: left to right, right to left or undefined crossing out pattern followed by the patient. Six out of the ten patients kept the same strategy: the resulting ratio is $r = 0.6$.

Finally, concurrent evaluation of digital and traditional administration of the tests has been addressed, in order to assess the feasibility of the remote monitoring of the home-administration through ReMoVES platform. For the subject #1 –affected by a rare right-sided visuo-spatial neglect– both digital tests detect the presence of this syndrome while the traditional test didn't provide relevant results. For subject #9 conventional and digital Albert's tests produced nearly identical results, highlighting left hemispatial neglect; likewise, the patient showed difficulty and confusion during the execution of Line Bisection Test in both modes. For subject #10 a significant correlation between traditional and digital Line Bisection tests emerges. The tests administered to other subjects did not provide significant results in either electronic or paper form.

III. Conclusion

By the implemented automated test, it is easy to prove that the disease severity of a visual USN can be assessed even for de-hospitalised patients, without the need of their transfer to the clinical ambulatory. The developed assessment approach is also proposed for a further correlation with parameters extracted by the ReMoVES games. In such a way, it will be possible to evaluate whether repetitions of physical and cognitive exercises at home favour the maintenance of intensive rehabilitation program results acquired during the hospitalization period.

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TABLE I

LINE BISECTION TEST: OFFSET

	Sub. 1	Sub. 2	Sub. 3	Sub. 4	Sub. 5	Sub. 6	Sub. 7	Sub. 8	Sub. 9	Sub. 10
Test	-22.3%	+2.7%	+4.6%	-0.5%	-5.0%	+5.1%	+10.0%	-1.5%	+2.1%	+9.1%
Retest	-24.0%	+6.4%	+6.8%	+3.3%	-6.5%	+2.0%	-4.1%	-0.7%	-4.1%	+13.2%

The mean offset from the centre of the line is provided as percentage. Negative values are offset to the left. Test-retest correlation is: $\rho = 0.83$

TABLE II

LINE BISECTION TEST: RATE

	Sub. 1	Sub. 2	Sub. 3	Sub. 4	Sub. 5	Sub. 6	Sub. 7	Sub. 8	Sub. 9	Sub. 10
Test	0.56	0.35	0.37	0.82	0.76	0.30	0.74	1.27	0.16	0.62
Retest	0.42	0.51	0.34	1.15	0.94	0.35	0.66	1.37	0.10	0.57

The bisection rate is provided as lines crossed every second. Test-retest correlation is: $\rho = 0.94$

TABLE III

ALBERT'S TEST: UNCROSSED ON THE LEFT

	Sub. 1	Sub. 2	Sub. 3	Sub. 4	Sub. 5	Sub. 6	Sub. 7	Sub. 8	Sub. 9	Sub. 10
Test	1	0	0	3	3	0	1	4	17	0
Retest	0	0	0	5	6	0	2	4	17	0

Number of lines uncrossed on the left side of the screen. $\rho = 0.98$

TABLE IV

ALBERT'S TEST: UNCROSSED ON THE RIGHT

	Sub. 1	Sub. 2	Sub. 3	Sub. 4	Sub. 5	Sub. 6	Sub. 7	Sub. 8	Sub. 9	Sub. 10
Test	3	0	0	5	3	0	1	4	6	1
Retest	0	0	0	3	5	0	1	3	5	0

Number of lines uncrossed on the right side of the screen. $\rho = 0.80$

TABLE V

ALBERT'S TEST: PATTERN

	Sub. 1	Sub. 2	Sub. 3	Sub. 4	Sub. 5	Sub. 6	Sub. 7	Sub. 8	Sub. 9	Sub. 10
Test	L	M	R	M	L	L	M	M	M	R
Retest	L	M	L	M	R	M	L	M	M	R

Crossing out pattern: R is from right to left, L is from left to right, M is from middle or not a defined pattern. $r = 0.6$

TABLE VI

RELEVANT RESULTS SUMMARY

	Sub. 1	Sub. 2	Sub. 3	Sub. 4	Sub. 5	Sub. 6	Sub. 7	Sub. 8	Sub. 9	Sub. 10
Diagnosis	Right neglect	Post-stroke no neglect					Post-stroke no neglect		Left neglect	Left neglect
Trad. Albert									16 L - 1 R	
Digit. Albert	1 L - 3 R								17 L - 6 R	
Trad. Bisection									confused	+10.0%
Digit. Bisection	-23.6%								confused and slow	+11.2%

Small differences between left and right in Albert's test and percentages in -10%/10% range in Line Bisection test offset are omitted (empty cells).