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EEG-based neglect assessment: A feasibility study

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HIGHLIGHTS

- We propose an objective EEG-based neglect assessment test.
- Our test does not require physical input from patients unlike traditional tests.
- We studied the feasibility of the proposed test with healthy individuals.
- Attention to left and right sides of the screen was evaluated statistically.
- Average accuracy of 74.24% was achieved.

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ABSTRACT

Background: Spatial neglect (SN) is a neuropsychological syndrome that impairs automatic attention orienting to stimuli in the contralesional visual space of stroke patients. SN is commonly assessed using paper and pencil tests. Recently, computerized tests have been proposed to provide a dynamic assessment of SN. However, both paper- and computer-based methods have limitations.
New method: Electroencephalography (EEG) shows promise for overcoming the limitations of current assessment methods. The aim of this work is to introduce an objective passive BCI system that records EEG signals in response to visual stimuli appearing in random locations on a screen with a dynamically changing background. Our preliminary experimental studies focused on validating the system using healthy participants with intact brains rather than employing it initially in more complex environments with patients having cortical lesions. Therefore, we designed a version of the test in which we simulated SN by hiding target stimuli appearing on the left side of the screen so that the subject's attention is shifted to the right side.
Results: Results showed that there are statistically significant differences between EEG responses due to right and left side stimuli reflecting different processing and attention levels towards both sides of the screen. The system achieved average accuracy, sensitivity and specificity of 74.24%, 75.17% and 71.36% respectively.
Comparison with existing methods: The proposed test can examine both presence and severity of SN, unlike traditional paper and pencil tests and computer-based methods.
Conclusions: The proposed test is a promising objective SN evaluation method.

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1. Introduction

Every year, 15 million people around the world experience stroke including 795,000 cases in the United States (CDC and NCHS, 2015). The consequences of a stroke are strongly related to the lesion volume and its location in the brain (Agis et al., 2016). Such consequences may range from minor problems such as headache up to significant complications in which individuals may experi-

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ence cognitive, motor, visual, or affective impairments. Examples on these impairments include: sudden weakness, vision problems, difficulty in speaking, loss of memory, or paralysis on the side of the body opposite to the affected brain hemisphere (Donnan et al., 2008).

Spatial neglect (SN) is a neuropsychological syndrome that is one of the most common consequences of right-side brain damage after stroke (Heilman et al., 1993), occurring in 28.60% of the stroke population (Becker and Karnath, 2007). SN occurs as a result of brain lesions in the right inferior parietal cortex, the superior temporal cortex or the ventral frontal cortex (Committeri et al., 2007). In addition, it can occur due to disconnections in attentional networks (Baldassarre et al., 2014). Patients with SN are characterized by their inattention to stimuli that appear on their contralesional side which was thought usually to be the left visual side (Li and Malhotra, 2015). However, it was shown later that right-sided SN can be found with higher percentage using multitasking (Blini et al., 2016a). An individual with left-sided SN may demonstrate difficulties such as inability to focus attention on the left, missing food found on the left side of the plate, missing words on the left side of the page while reading, forgetting to dress the left side of the body, getting confused by moving objects and fear of walking in crowded places (Unsworth, 2006).

During the last few decades, many paper and pencil tests have been used to assess SN (Plummer et al., 2003). The Behavioral Inattention Test (BIT) is one of the most commonly used SN assessment methods and includes tasks such as line crossing, line bisection, letter and star cancellation, copying and drawing symmetric figures (Wilson et al., 1987). One drawback of such tests is that they are static. In other words, the objects shown on the page are stationary so they do not reflect the dynamic nature of objects in the real life (Seki and Ishiai, 1996). In addition, the evaluation of some tests like copying and drawing figures leaves room for error and variations in interpretation and scoring among raters. Furthermore, the variability in performance on paper and pencil tasks is relatively high. For example, an individual with SN may perform normally on a line bisection test but demonstrate impairment on star cancellation or vice versa. As a result of these combined limitations, an individual with SN may not meet criteria for SN on these tests, but nonetheless SN is observed while they are engaged in functional activities such as eating, dressing, or walking through a crowded place. Recently, computerized tests for SN assessment have been proposed and developed to address these shortcomings (Pedroli et al., 2015). Such tests have the potential to highlight SN cases which often go undetected by paper-and-pencil tests (Bonato and Deouell, 2013).

Passive BCI is mainly concerned with monitoring and interpreting user's brain activity (Zander and Kothe, 2011) unlike active BCI, it is not designed for voluntary control. Passive BCI concept is employed in many applications such as measuring working memory load (Grimes et al., 2008), assessing driver's vigilance state (Schmidt et al., 2009), and assessing attention (Brouwer et al., 2013). In this paper, we introduce a novel electroencephalography (EEG)-based passive BCI system that can be used as a robust and objective SN assessment test. This test may provide additional benefits beyond what current assessment methods provide. First, the EEG system has the potential to provide a visual map of the areas being attended to by the patient by identifying targets that were not attended to within the available field of vision. This provides more precise information about the severity of peripersonal and extrapersonal visual neglect. Many current assessment methods provide only sufficient information to diagnose SN, and limited detail on its severity. Therefore, EEG assessment can address a component of assessment that is missing from current approaches. Additionally, the EEG assessment system has the potential to automate SN assessment, updating in real-time on an ongoing basis, with easier repeatability than paper and pencil tests. With further development, this test can be integrated into functional daily tasks to provide an assessment of SN within a dynamic and natural setting. Particularly, we will integrate this EEG test into a virtual-reality based intervention in which real-time EEG readings will trigger visual and tactile cues when visual cues are missed on the neglected side. Finally, EEG has the potential to examine the presence and severity of SN in both acute and chronic stroke, as there is no learning effect or timing effect. In this test, EEG signal is recorded while the participants observe visual stimuli illustrated on a screen at random locations. These visual stimuli include both targets and distractors that change over time independently of each other. We performed a feasibility study to show the performance of the system through the participation of healthy individuals. The aim behind starting the experiments with healthy participants is to validate the proposed system under less complex conditions compared to those associated with SN. Therefore, the preliminary experiments were performed on healthy participants, using a version of the test that simulates apparent symptoms of SN. During SN simulation, all the targets on the left visual field (left side of the computer screen) were hidden to shift the attention to the right side. Therefore, such simulation can be used to study differences in attention to left and right sides of the screen in healthy participants. The nonparametric Wilcoxon test was used to statistically evaluate the differences between the EEG responses due to distractors located on the right and the left side of the screen corresponding to attention and inattention cases respectively. To assess the system's ability to recognize absence or existence of a target based on the EEG data, a two-class problem that utilizes naïve Bayes classifier was formulated. Results showed that the system achieved accuracy exceeding 70%.

2. Related work

A unique feature of computerized tests is that they can measure reaction time which provides a quantitative measure that can be used to reflect improvement in attention during the recovery process (Deouell et al., 2005). An example of such tests is a computer-based system in which participants were asked to press a keyboard button when they observe a white square that could appear in random locations on a black background along the horizontal meridian (Anderson et al., 2000). To imitate the real-life environment, another computer-based test that measures reaction time besides accuracy of detection of a visual target was introduced (Deouell et al., 2005). The presented design, named as Starry Night Test, showed a sequence of targets on a black background comprising continuously changing distractors. In another study, a computerized visual reaction time task was proposed in which a modified version of a driving simulator test was used, which was originally designed to assess attention and executive functions (van Kessel et al., 2010). In this study, participants were instructed to press a button when they observed a rectangle that could appear either on the middle, left or right of the lane. The source of distraction in that task originates from the fact that the participant had to track the lane while doing the task. Vossel and Fink (2016) measured reaction times using a test that contains one target and one distractor represented as white square and white circle respectively. Targets could either be shown on the left or the right side of the screen without a distractor, or with a distractor (white circle) presented simultaneously on the opposite sides of the screen.

Recently, virtual reality (VR) has been employed to design SN assessment tests (Pedroli et al., 2015). A VR version of some classical paper and pencil tests was proposed where the patients had to use a robotic pen to complete the tasks (Fordell et al., 2011). In a different study, a test named as the locomotor obstacle avoid-