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An Example of the Assessment of Human Laterality Using Virtual Reality

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ABSTRACT: Laterality is an intensively studied phenomenon that is still not fully understood and explained. An essential aspect of these researches is the methods of functional evaluation of laterality in both physiology and pathophysiology in humans. Hands are an important and specialized organ, and their functionality plays a significant role not only in daily activities, but also in social relations. The paper presents a new approach to the assessment of lateralization hands in healthy adults using Virtual Reality (VR) technology. VR is an innovative, interactive and attractive method with a significant emotional impact (among VR exercises were particularly liked and preferred by the subjects). The proposed test tasks in Virtual Training allow the effective and quantitative functional assessment the hand(s), both dominant and non-dominant. In the future, the implementation of e-virtual personal training/ e-rehabilitation (for example, in the patient's home conditions and under internet/ remote medical supervision), apart from the classical rehabilitation of dysfunctional hands in specialized medical centers, gives the possibility of additional personalized training and emotional patients involvement (the home rehabilitation) to achieve the best effects of improving the hand function, especially in order to restore the functionality of the dominant hand.

KEYWORDS: Laterality, handedness, dominant and non-dominant hand, virtual reality.

I. INTRODUCTION

Cerebral lateralization, the asymmetric and dominant control of different behaviors by the left and right hemispheres, is characteristic of the brain in many animal species, suggesting a long evolutionary lineage [1-3]. By allowing different functions to operate in parallel across the hemispheres, cerebral lateralization increases neural efficiency. In addition, hemispheric dominance reduces duplication of functioning and, as a result, minimizes the generation of simultaneous and incompatible responses from the two hemispheres, offering an adaptive advantages. The right hemisphere is specialized to attend to novel stimuli and to control social behavior, recognize faces, and process global information using spatial cues. The left hemisphere is specialized for focused attention needed to perform learned tasks, to follow rules, and to categorize stimuli. The process of forming/ deciding about the domination of the body side - laterality – i.e. the functional superiority of one side over another, also defined as "functional asymmetry", is very important in the motor development of human. It is important to consider two distinct types of lateralization: individual and population lateralization. Individual lateralization is that present in individual members of a group/ population but favoring the right in some individuals and the left side in others, resulting in no directional bias within the population. Population lateralization, also referred to as directional lateralization, is present when the majority of individuals are lateralized in the same direction. Handedness in humans is an example of the latter. An significant role in process of laterality is played by specialization and coordination of hand movements, which consists in fact that the movements of both upper limbs are different, with the leading (dominant) hand performing the main action, and the subordinate hand (non-dominant) provides better (more convenient) working conditions for dominant hand. The dominance of the right hand over the left one is the most common (around 90%:10%), so human civilization is in fact a "right handed civilization". It is true that left – handed men have difficulty using a lot of right – handed tools. Experimental and clinical studies on

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brain asymmetry show that the dominant hemisphere of the brain is the left hemisphere in the right-handed persons, and the right hemisphere in the left-handed ones [4-6]. Different laterality models have been defined. The basic, considered as a norm, are two unilateral models: (a) right-sided laterality model (prevailing in the human population) and (b) left-sided one. Homogeneous right-sided laterality means the domination of the right hand, right leg and right eye. And left-sided laterality presents functional ascendancy of these organs on the left body side, respectively. In addition, other laterality models have been defined, that are less advantageous/ favorable than one-sided domination, such as: (c) a crossed model (means the domination of the hand, leg and eye on different body sides) and (d) an unsteady/ undefined model (in general the dominance cannot be determined for hand, leg or eye). In 1971 Carolus Oldfield [7] presented a proposal evaluation and analysis of handedness, and basis on this algorithm the manual hand assessment is available on-line the website http://zhanglab.wikidot.com/handedness [8]. Nowadays, there are many different techniques, methods and algorithms to assess not only the upper limbs but also the lower limbs, or the coordination of the hand/ leg with the eye/ ear, which may be used in both health and diseases [9-11]. Particularly, very interesting and promising is new modern Virtual Reality (VR) technology creates interactive, multimodal sensory stimuli that offer unique advantages to (neuro)science research and applications, such as for example combine VR with brain imaging methods, as well as development in VR systems for animal model study [12-14]. Moreover, practicing (bio)scientists, (neuro)psychologists or therapists/ rehabilitants, too, stand to gain from progress in VR environments, which provides a high degree of control over the clinical experience [15-18]. VR has the potential to solve many problems that are common to real – world exposure therapy and has generally produced favorable results. VR treatment has been applied to a range of disorders, including fear conditioning, anxiety disorders and brain damages. For example, one of the most widely explored applications of VR to psychiatric rehabilitation is in the area phobia, or to neurological treatment is to aid analgesia. The important medical approach is also VR neurorehabilitation, which have been focused on two areas: balance disorders and recovery of function after stroke (for example VR system: http://www.neuroforma.en).

The paper presents the results of study on the assessment and comparison of the dominant and non-dominant hands in healthy adult right-handed volunteers, using virtual reality environments, for virtual training/ exercises with a choice of body side (right, left or both) and difficulty level of tests (easy, medium or difficult).

II. SUBJECTS AND METHOLOGY

A. *Subjects*

In the study were involved twenty adult healthy volunteers, ten women and ten men, aged 18-43 (Table 1). The dominance of hands was determined in each person by the interview and the test questionnaire [11], and also simple physical trials. The subjects were right – handed, and physically and professionally active. They performed sessions of exercises and tasks in a computer virtual reality platform. The subjects practiced at least twice the selected/ defined virtual training session for right, left and both hands. Written informed consents were obtained from all participants.

Parameters	Subjects (n=20)	Women (n=10)	Men (n=10)
Age (years)	31±8 (18-43)	31±9 (18-43)	31±7 (23-43)
Weight (kg)	67±13 (52-87)	60±10 (52-81)	74±14 (60-87)
High (m)	1.71±0.08 (1.56-1.84)	1.66±0.06 (1.56-1.74)	1.77±0.06 (1.70-1.84)
BMI (kg/m^2)	22.9±3.0 (18.0-29.0)	22.0±3.2 (18.0-29.0)	21.0±2.6 (19.9-26.3)

Table 1. Characteristics of the studied group (average values with standard deviation and interval for minimum and maximum values in brackets are given).

B. *Virtual Reality Sessions*

Training sessions were prepared using the computer NEUROFORMA system, which is a specialized virtual platform for rehabilitation/ telerehabilitation (http: //www.neuroforma.en). The subjects performed tasks and exercised with both hands and successively with right or left hand on three different levels of difficulty: easy, medium and difficult (Figure 1). The subjects stood in front of the screen with a 3D-Kinect camera, and saw their mirror image among the created virtual reality of selected exercises (Figure 2). All tasks were presented in a form similar to interactive computer games. Each person might also keep track of the progress of the session, i.e. how much time and

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how many elements of the task remained until the end of each 1-minute round. This information was displayed as a movable vertical "beam" on right and left side of the screen. In addition, summary results were displayed on the screen after the exercise/ task programs. The virtual programs included two-round training sessions consisting of two blocks: (a) movement exercises as BOX, BUTTERFLY, and (b) cognitive-movement tasks as BALLS, ARITHMETIC OPERATIONS [19].

Figure 1. The example of choosing hands and the level of difficulty for cognition BALLS exercises in NEUROFORMA's Virtual System [19].

The exercise of BOX required opposing "punching" with white markers ("sights") that appeared on the "training bags" on right or left side of the screen (right hand - left bag and left hand - right bag). An additional requirement was to avoid emerging black markers. The time of displaying the white sights decreased with increasing the difficulty level, and then it was necessary to hit faster. In addition, black markers appeared directly under the white ones, so hand was quickly withdrawn. The practitioner received the point for each hit white sight, and lost the point for hitting the black sight. This exercise was easy to perform both the dominant and the non-dominant hand, and was willingly chosen by the practitioners.The next BUTTERFLY exercise was following a trajectory of a butterfly, but the butterfly moved in a chaotic, unpredictable way. There were also various distractors, i.e. distracting elements, they moved similar as the butterfly. The speed and trajectory of the butterfly were determined by the selected level of difficulty. The practitioner received points for every second in which he managed to keep his hand on the butterfly.

Figure 2.The illustration of performance of the Virtual Session in Bioinformatics Laboratory MMRC PAS, for BOX and BUTTERFLY exercises (from our database library) [20].

In turn, in the group of cognitive exercises, especially these liked by practitioners, were BALLS, for which it was necessary to knock down colored balls, according to the rule displayed in a frame on the screen. At the higher levels of

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difficulty, the time was shorter for completing this task and the number of balls increased. The practitioner received points for each correctly thrown ball.The last ARTHMETIC OPERATIONS exercise required estimating - according to the command displayed on the screen - the largest or the smallest result of basic arithmetic operations. With the increase in the level of difficulty, the choice of answers increased, the response time was reduced, and the spread between individual displayed results decreased. The practitioner received a point for every correct result indicated by the hand. The calculations were most often too slow. For shorter times, the dominant hand allowed to keep up and indicate the result faster than the non-dominant.

C. *Statistical Analysis*

The data was analysed using the STATISTICA 9.0 PL statistical package software. Whitney-Mann and Wilcoxon tests were applied to assess differences of scores in the sessions. The $\chi 2$ test was used to estimate scoring distributions. The results are expressed as mean with standard deviation (SD). A p value <0.05 was considered statistically significant.

III. RESULTS AND DISCUSSION

In the study group, no statistically significant differences in the level of virtual exercise performance were observed due to gender and age of the subjects. Figures 3 and 4 illustrate the results obtained. Figure 3 presents a comparison of the average scores obtained in the study group for the exercises of both hands (panel on the left), and exercises for the dominant and non-dominant hands (panel on the right). Figure 3 shows the individual results for each of the exercisers for the BUTTERFLY exercise, which was the most sensitive and the best indicated the functional lateralization of the hands.

As shown in Figure 4, EASY LEVELS were performed very well, not only for both hands, but for each hand independently. The highest and the least diversified results were obtained in exercises such as BOX (100.0%) and cognitive BALLS (99.9%). In following the BUTTERFLY trajectory, equally high average results were also obtained (99%) at these levels. The correct calculations for the ARTHMETIC OPERATIONS indicated by the non-dominant hand were on average slightly lower (98%). Everyone promoted for these levels of the exercises. Exercises on the MEDIUM LEVELS were also performed correctly and advanced to the subsequent higher level. Subjects achieved lower results by about 1% (BOX, BALLS) to 7% (ARITHMETIC OPERATIONS). Exercises on DIFFICULT LEVELS, the results were more varied and lower than on easy and medium difficulty levels. These were statistically significant differences compared to the easy level ($p < 0.001$). Better results were still obtained in BOX and cognitive BALLS, either for both hands and for the dominant hand. The results for the non-dominant hand significantly decreased. The BUTTERFLY is the exercise that best exposed the handedness ($p < 0.001$). For ARITHMETIC OPERATONS were also achieved lower scores at high levels.

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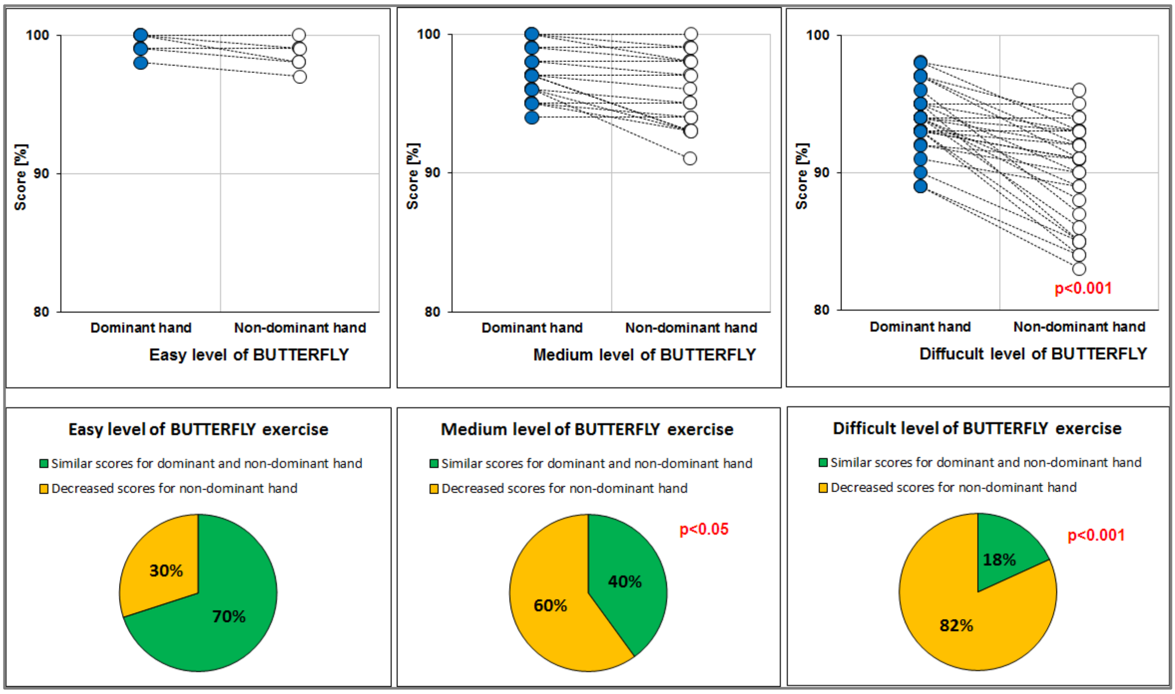

Figure 3. The example results of subjects for following the BUTTERFLY on easy, medium and difficult level of exercise for the dominant and the non-dominant hand (top panel: value p for comparison between right and left hands; down panel: p for comparison with the easy level).

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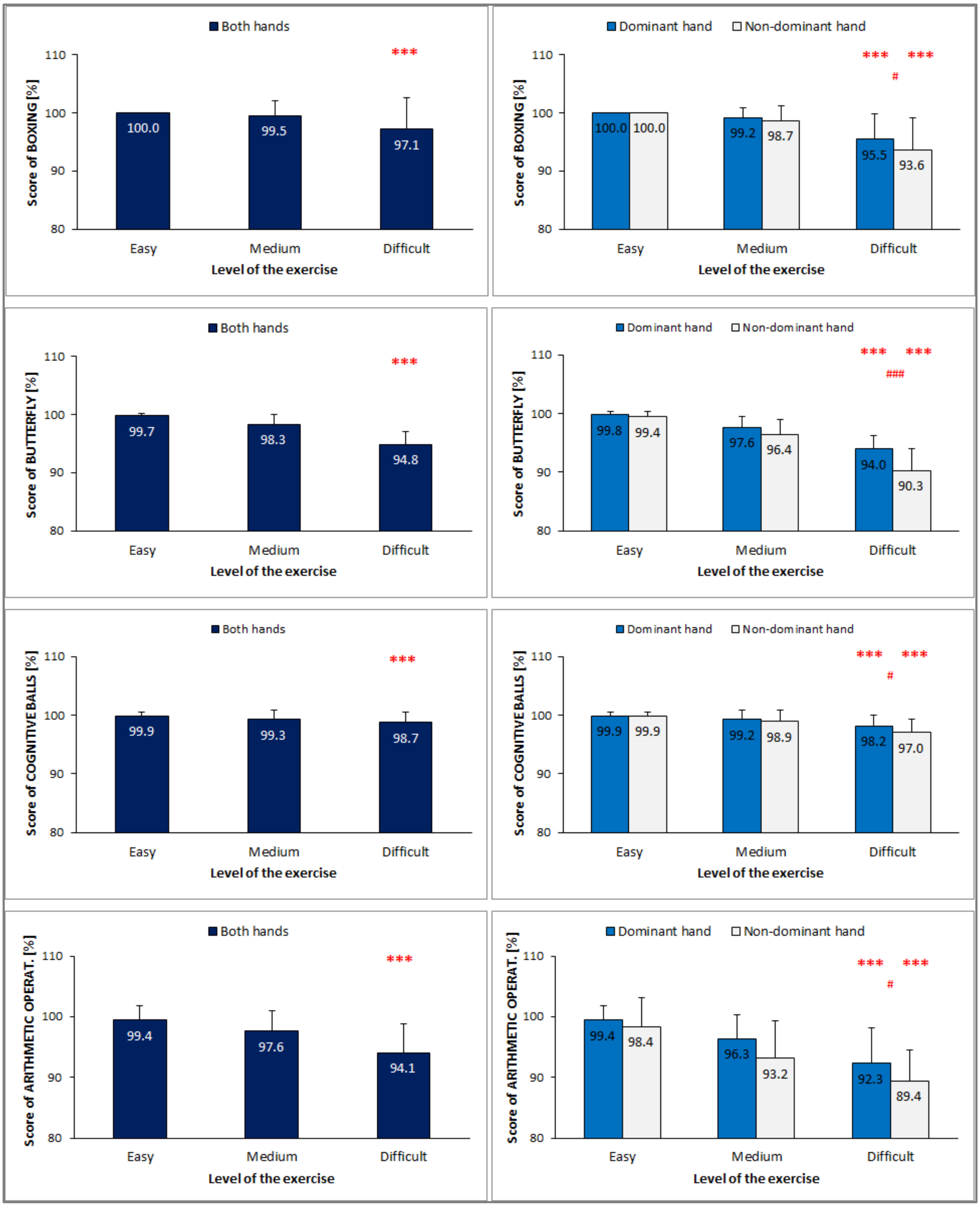

Figure 4. Results of both, dominant and non-dominant hands in all virtual exercises for easy, medium and difficult levels. Values are presented as mean ± SD. ***P<0.001 for comparison of easy versus the difficult levels; #p<0.05, ###p<0.001 for comparison of dominant versus the non-dominant hand.

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All participants signaled greater fatigue of the non-dominant hand at the highest levels of exercises. In addition, in the exercises with cognitive elements, the dominant instead of the non-dominant hand was used more often, especially when the time to complete the task decreased. As already indicated, the BUTTERFLY exercise required following of the hand after it, and as a result caused fatigue symptoms of the exerciser's hand, and when it was a non-dominant hand, it did not follow the butterfly's trajectory. Finally, lower results were observed compared to the easy levels, and in particular, significant smaller scores for the non-dominant hand.

IV. CONCLUSION AND FUTURE WORK

The research on functional efficiency of a dominant and non-dominant hand using virtual reality methods (created for example by the NEUROFORMA platform, in an interactive form and with a decision algorithm analyzing results and correctness of the task), indicate not only the usefulness, but also the sensitivity of these methods in the study and evaluation (quantitative / comparative) of handedness.

The research shows that in virtual reality:

• functional laterality of the hands is revealed, the quantitative evaluation of which is the result of the virtual test,

• the level of performing the virtual task with both hands is similar / similar to the results obtained with the dominant hand, and the trend of more frequent use of the dominant hand was observed (this was particularly evident in the case of difficult exercises),

• when the task / test is associated with a certain physical effort, fatigue is felt earlier and more clearly in the hands of the non-dominant,

• tasks with cognitive elements are more eagerly performed and motivated (emotionally engaging practitioners despite, for example, signs of fatigue) to achieve better results and advance to a higher levels.

Technologies using virtual reality (VR) are universal systems that can be generally used to assess the efficiency / effectiveness of the human systems in health and disease conditions [13]. The VR system can adapt to the capabilities and / or limitations of the practitioner on an ongoing basis [15]. VR environments allow researches to manipulate multimodal stimulus inputs, so the user's sensorimotor illusions of being "present" in the represented environment is maximized by an open display such as a computer monitor. Including exercises with interesting cognitive elements additionally engages emotionally and motivates to continue the undertaken tasks. The presented virtual measurement/ training is an example of an innovative, non-invasive, method of assessing the musculoskeletal system, with a potentially wide spectrum of applications, both in the conditions of physiology and pathophysiology, in the clinic. For example, in rheumatoid arthritis (RA), in which 90% of patients have a bilateral hand occupation, in therapy and rehabilitation, hand exercises are a very important element of their improvement [21-23]. The presented Virtual Reality can be a real, non-invasive/ "friendly"/ personalized support in the prevention and/ or monitoring of the rehabilitation and progression of hand deformities, especially for improving and maintaining their proper function, including maintaining the dominant hand function.

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Each author's contribution was equal.

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