Accepted Manuscript

Accepted Manuscript (Uncorrected Proof)

Title: Psychological and Psychophysiological Responses to Challenge Variations for Virtual Hand Training in Game-based Smart Rehabilitation System

Authors: Amin Amin Asgharzadeh Alvar[1]*, Ali Esteki[1], Iraj Abdollahi[2]

1. *Department of Biomedical Engineering and Medical Physics, Faculty of Medicine, Shahid Beheshti University of Medical Sciences, Tehran, Iran*.
2. *Department of Physiotherapy, University of Social Welfare and Rehabilitation Sciences, Tehran, Iran.*

*Corresponding author: Amin Amin Asgharzadeh Alvar, Department of Biomedical Engineering and Medical Physics, Faculty of Medicine, Shahid Beheshti University of Medical Sciences, Tehran, Iran. E-mail: a.asgharzadeh@sbmu.ac.ir

To appear in: *Basic and Clinical Neuroscience*

Received date: 2021/07/15

Revised date: 2021/09/4

Accepted date: 2021/09/21

Accepted Manuscript (Uncorrected Proof)

This is a "Just Accepted" manuscript, which has been examined by the peer-review process and has been accepted for publication. A "Just Accepted" manuscript is published online shortly after its acceptance, which is prior to technical editing and formatting and author proofing. *Basic and Clinical Neuroscience* provides "Just Accepted" as an optional and free service which allows authors to make their results available to the research community as soon as possible after acceptance. After a manuscript has been technically edited and formatted, it will be removed from the "Just Accepted" Web site and published as a published article. Please note that technical editing may introduce minor changes to the manuscript text and/or graphics which may affect the content, and all legal disclaimers that apply to the journal pertain.

Please cite this article as:

Amin Asgharzadeh Alvar, A., & Esteki, A., Abdollahi, I. (In Press). Psychological and Psychophysiological Responses to Challenge Variations for Virtual Hand Training in Game-based Smart Rehabilitation System. *Basic and Clinical Neuroscience*. Just Accepted publication Oct. 2, 2021. Doi:http://dx.doi.org/10.32598/bcn.2021.3532.1

DOI: http://dx.doi.org/10.32598/bcn.2021.3532.1

Accepted Manuscript (Uncorrected Proof)

Abstracts:

Background: Maintaining motivation is one of the most important characteristics of rehabilitation strategies for successful treatment. Understanding the underlying mechanism of mental state is helpful for developing new therapeutic methods based on virtual reality and serious game technologies.

Objective: The present study aims to develop a cost-benefit game-based hand rehabilitation system and assess the influence on the psychological state of subjects when they interact with a virtual reality environment in different task difficulty levels.

Methods: First, we introduced a low-cost smart hand rehabilitation system based on the Leap Motion tracker; then, the experimental study was performed with 20 healthy participants. Their mental states were evoked using interaction with two separate games in four different difficulty levels. Three measures from the SAM self-reported test described as a psychological response to this condition, and also four features were extracted from Photoplethysmogram signal in order to quantify psychophysiological responses of Autonomic Nervous System.

Results: Comparison of the different difficulty levels revealed significant changes in arousal and dominance correspond to under challenging and over the challenging condition, respectively. The results of psychophysiological feature analysis showed significant differences only for the standard deviation of intervals between consecutive heartbeats.

Conclusion: The developed system is a low-cost smart solution that can be useful for upper limb neurological rehabilitation. Regulating difficulty parameters of the implemented game can be used to influence the motivation of users through rehabilitation procedures. It seems Photoplethysmogram is an appropriate psychophysiological indicator of mental states, but further studies are required.

Keywords: Virtual Reality; Serious Game; Psychophysiological Measures; Smart Hand Rehabilitation; Self-Assessment Manikin (SAM) Test.

Accepted Manuscript (Uncorrected Proof)

Introduction

Recovery of normal hand function has a considerable effect on individuals' sense of independence and quality of life. The functional and anatomical complexities of the human hand put some constraints on its rehabilitation. The current methods of neurological rehabilitation usually involve performing repetitive and intensive exercises based on specific regular tasks [1]. However, studies have shown that only about 30% of patients follow the recommended exercise routine by therapists [2]. Thus, one challenge in this process seems to be an increase in motivation levels in patients. A higher motivation level will increase patients' acceptance, intensity, and amount of exercise, leading to improved motor learning. [3]. Restrictions and challenges of rehabilitation have prompted rehabilitation based on virtual reality (VR) and serious games in recent years[4][5][6][7][8][9][10].

Maintaining motivation and commitment of patient are primary determinants of preventing boredom of rehabilitation procedure. This can be achieved by improving the patient experience by allowing them to have a challenge proportionate to their level of skills without it leading to disappointment [11]. Generally, serious games in VR-based rehabilitation system are including adaptive parameters could adjust the difficulty level of the given task[12]. If the system is appropriately designed, changing these parameters should change the person's psychological state. We also need to know how difficulty level regulation modulates various perceived cognitive states. Psychological dimensions are some criteria, such as dominance, arousal, and valance, to describe a person's response to events and situations. These dimensions usually measured using subjective questionnaire reports. However, self-reported measures are not an adequate solution, as they are objective and impose intervention to be interrupted. Psychophysiological measurements (originate from the autonomic nervous system) can be taken objectively and determined as an indirect method of estimating psychological state. One of the best known psychophysiological responses are the index extracted from heart activities[13].

This study aims to develop a VR-based Hand Rehabilitation System(VR-HRS) and investigate how it affects user's psychological states and motivation. We considered the following essential points in the design of this system: 1) measuring hand joints angels accurately, 2) providing meaningful exercises for hand, 3) using low-cost

Accepted Manuscript (Uncorrected Proof)

instrumentation, 4) maintaining motivation through the rehabilitation exercise.

In the first part, the VR-HRS set up revealed. We designed and implemented VR-HRS comprising different parts: a hand motion tracker, psychophysiological measurement unit and serious game scenarios in a VR environment. The hand motion tracker unit is developed based on Leap Motion (a new generation of marker-free hand visual-tracker technologies that have been introduced in recent years). It is low-cost and has sufficient accuracy, so these devices have attracted the attention of researchers in the rehabilitation field [14][15]. Photoplethysmography(PPG)-based heart activity monitoring was used as a cheap and feasible way to measure a person's psychophysiological indexes while performing a VR-based task. VR environments run two games were designed based on two common wrist mobility exercises, extension and ulnar-radial deviation.

In the latter part of this research, we carried out experiments on 20 healthy cases to measure subjective and objective participant's psychological states during the VR tasks. Each of them performs eight experimental sections (four different levels of difficulties in two scenarios). We examined the effect of changes in the difficulty level of tasks on the dominance, valance and arousal reported by its users. In the following step, we assessed whether these changes could be observed indirectly by objective psychophysiological measurements extracted from cardiovascular activity.

Accepted Manuscript (Uncorrected Proof)

Materials and methods

Hand Rehabilitation Hardware System

The developed system consists of a central unit and a subordinate system (Figure 1). The central unit task is the data acquisition and control of the other system compartments. This unit is connected to a hand tracking system (Leap Motion) and Photoplethysmogram (PPG) and carries out synchronization and input data analysis. The subordinate system received the wrist anatomical angles to control objects' position in the game and sent game information to the central unit.

Hand Movement Tracking

The movements are the main part of controlling the game. They have to be utilizable for rehabilitation intervention. There is a collection of hand rehabilitation movements in[16][17] for developing VR and gaming−based rehabilitation systems. Here we chose ulnar−radial deviation and extension of the wrist and designed two separate game scenarios for each of them. Figure 2 (a and b) shows a Schematic of the motion tracking system, in which Leap Motion was placed on the 30−cm distance above the hand. The forearm is fixed into the z−axis direction of the Leap Motion coordination system. We extracted the anatomical points using a dedicated Software Development Kit (SDK) of Leap Motion. The deviation and extension were defined as the angle between the middle finger metacarpal bone direction to the z-axis on the x-z plane and the y-axis on the y-z plane.

Psychophysiological Data Acquisition

It seems that mental and emotional produce somatic responses using the Autonomic Nervous System (ANS). These responses (e.g. ECG, GCR, and SKT) are more comfortable to record. Signals related to cardiac function have been a variety of these responses considered in previous studies [11][13]. This time series is affected by the sympathetic and parasympathetic nervous systems [13], and used as physical effort [18], as well as stress [19]measurements. In this study, we used PPG to consider psychophysiological features inputs of dynamic difficulty adaptation (DDA). PPG recording tools are inexpensive, easy to use, and contains information about cardiovascular function. We designed the data acquisition unit of PPG using Maxim MAX 30100 chip setup by SAM3X8E ARM CORTEX-M3 microcontroller with the sampling rate fixed to 100Hz. The performance and temporal accuracy of this sensor have been investigated [20][21].

Game Scenarios in Virtual Reality

The Unity game engine was used to fulfil the implementation of the VR environment of the game and the dynamic interplay of objects. We designed two games for performing hand movement tasks. The scenarios in both of the games are the same, and the only difference is in the direction of gun movement (horizontal for ulnar/radial deviation and vertical for extension) in the VR environment. During the game, spheres with random sizes (10 to 100 pixels) and in different positions appear in the game environment. The participants have to point at the sphere for a certain amount of time, (which is the control parameter of the game difficulty). This time alternates in the range of 0.5 to 2 seconds. Every time the participant explodes a sphere before the end of this period, he/she will gain 100 scores (lose 50 otherwise).

Accepted Manuscript (Uncorrected Proof)

Study Protocol

Twenty healthy subjects in the age range of 25 ±3 years participated in the experiment (12 males and eight females). All of them were right-handed. During the game, participants were sitting in front of the screen. They placed their dominant hand on a table so that it is in the Leap Motion field of view. We attached the pulse oximeter recording probe to the other hand (Figure 1). When the game was started, they experienced the VR environment and attempted to steer the gun's direction by changing their wrists' angle.

Participants played two different sessions for ulnar-radial deviation and extension games. Each session lasted about 30 minutes, including 5 minutes of warm-up and four games with different difficulty levels presented in random order. The running time of each game was about 5 minutes, depending on the speed of the person.

Self-Assessment Measures

At the end of each level, participants filled out the Self-Assessment Manikin (SAM) test questionnaire [22]. It is a non-verbal evaluation method to measure the psychological dimension directly. Dimensions represent by ordered figures arranged increasingly from the left to the right of paper (or screen) that indicates the level of personal response to experience. The validity and reliability of SAM for Persian speakers have been examined in [23] to assess the level of emotional dimensions include arousal, valance, and dominance. In rehabilitation research, this tool has been repeatedly used to record the individuals' subjective responses to their emotional situations while interacting with robotic or VR-based instruments [24].

Psychophysiological Measures

Heart rate variability signal (HRV) is a time series extracted from the intervals between two normal heartbeats. The sympathetic and parasympathetic nervous systems regulate the dynamic behaviour of HRV[13]. Related studies have used ECG-derived HRV through the interaction of participants in a virtual reality environment[25][26][11][27]. It has been previously shown that HRV extracted from PPG can be used instead of HRV extracted from ECG[28]. Feature extraction began by detecting Pulse Wave Systolic Peaks (PWSP) and calculating HRV from time intervals between Consecutive PWSP (NN intervals). There are some common measures used to quantify HRV signal: mean of NN intervals (MNN), the standard deviation of NN intervals (SDNN), number of intervals bigger than 50 ms (NN50) and the ratio of NN50 to total intervals (pNN50). Driven

Accepted Manuscript (Uncorrected Proof)

features were normalized to their baseline conditions' value (extracted from PPG data during the warm-up period).

Statistical analysis

VR-HRS has been developed based on two assumptions: increasing a person's motivation during exercise leads to adequate rehabilitation, and motivation can be controlled through the parameters of game scenarios in VR, such as the difficulty level. So for evaluation of the system performance, we investigate the difficulty level influence on psychological states. We needed to address a question: "Was the difference in difficulty level in the tests sufficient to cause a change in the scores of the questionnaires or psychophysiological indexes?". To answer it, we assessed the significance of differences in subjective (Enjoyment, Valence, and Arousal) and Psychophysiological objective measurements for four difficulty levels using the ANOVA test. If the null hypothesis of this test (i.e. equality of means in different groups) was rejected, then at least the index average in one of the difficulty levels would differ from the other levels. Kendall's W coefficient was reported to show concordance of measurements between subjects. Also we used multiple comparison tests to report the significant differences between each pair of difficulty levels [29]. All the statistical analyses were executed using Matlab statistical toolbox.

Results

Table 1 shows the outcomes achieved from statistical analysis for the self-reported SAM test (arousal, valence, and dominance) in different difficulty conditions. The results demonstrate a significant difference (at least for one of the difficulty levels) except the extension scenarios' valance dimension ($P<0.05$). We performed a multiple comparison test ($P<0.05$) to provide more information. The horizontal lines marked with a star in Figure 3 show the pairs of significantly different psychological measures. The results indicated that in the previous test, the significant change in valance in the deviation game was due to the higher quantity in the third level in comparison with the second and fourth levels, not due to the cohere increase or decrease of it. Also, we observed no noticeable changes in valence extension condition, but the maximum mean value of valence was observed at difficulty level 3 in both scenarios. Arousal and dominance matched to maximum pleasure during the extension task were obtained 7.10 ± 1.86 and 6.40 ± 1.35, respectively. A similar result was achieved for the deviation task scenario; mean arousal was 7.35 ± 1.46, and mean dominance was 6.45 ± 1.57 in proper challenging conditions.

Accepted Manuscript (Uncorrected Proof)

The paired comparison results clearly show an upward trend for arousal and a downward trend for dominance for increasing game difficulty (in both scenarios). Reported dominance for the over challenging situation (difficulty level 4) significantly decreased compared to other levels. Arousal was lower in the effortless condition (difficulty level 1) than the amount reported in the other levels.

An analysis of psychophysiological feature variations between difficulty levels found a meaningful difference only in SDNN measure (Table 2). Based on comparison of HRV extracted measures of the four difficulty levels (Figure 4), SDNN exhibited decreases during high difficulty level than low difficulty level.

Discussion

This work introduced a smart hand rehabilitation system that focuses on neural impairment patients using serious game and VR technology. We aim to exploit the inherent features of this technology to increase patient motivation and other capabilities such as guided therapy, enrichment environment, and real-time performance feedback to enhance the rehabilitation outcomes. Complications of these disorders have imposed a considerable expense, including hospitalization, long-term rehabilitation, and lifelong care on patients and healthcare systems in various countries [30]. Therefore, devising cost-benefit therapy strategies through minimizing human intervention becomes a matter of new technology solutions for smart rehabilitation. VR-based smart rehabilitation systems potentially reduce associated costs via increasing treatment speed, developing home-based therapy platforms, providing Task-Specific exercise, and prolonging training times[31]. These potentials were eliminated because current prices are still prohibitive for users[32]. We addressed this issue by using cost-efficient equipment for motion tracking units and psychophysiological signal recording instruments.

The cognitive load affects the cardiovascular system, and some physiological functions include modulating the Sinoatrial node's firing, decreasing the heart's muscle fibre length, and increasing the heart's contraction force. Also, the ECG time series is the most common signal used for evaluating the relationship of the mental and cognitive state with heart activity [33][34][35], here we investigate, the feasibility of using pulse oximetry and PPG signal for the goal mentioned above, due to its cost-effectiveness, and facility of use. Although a significant difference was reported only in one of the PPG

Accepted Manuscript (Uncorrected Proof)

extracted features (SDNN), but it is important to note that the observed change was repeated with a similar trend in both scenarios. Overall, this study strengthened the idea that the features extracted from the PPG signal are appropriate psychophysiological measurements to estimate psychological dimensions.

Data acquisition from motor behaviour is a vital component of a VR-based system. Rehabilitation motion tracking technologies can fall into three categories: visual tracking, non-visual tracking [36], and robot-aided tracking [37]. In our reviews, we concluded that Leap Motion (as a specialized visual tracker for the hand) is an acceptable option for our target application with low cost and reliable accuracy.

The results of the experimental phase indicate that the change of the difficulty significantly and monotonically changes the arousal and dominance (ascending and descending changes, respectively). This implies the proper design of the experiments so that the performing of the tasks arouses different emotional states in the participants. As expected, in more challenging situations, the person's arousal increases, and dominance decreases. Based on a closer inspection on Figure 3 and Table 1, we obtain a similarity between statistical results and overall psychological dimensions' changes. It confirms that the self-reported SAM test measures are independent of scenarios and physical motion used to control the game. Furthermore, it means that these observations are not accidental and repeated in two individual experiments.

We observed the peak mean valence (maximum pleasure) occurs at moderate levels of difficulty (level 3) in both scenarios. Having a more enjoyable experience in not too challenging nor too easy conditions is consistent with the basic idea of Flow theory [38] . Accordingly, pleasure maximized when the task is not under/over-challenged (Avoid boredom and anxiety). These findings present a potential mechanism to develop automatic difficulty adjustment for the introduced VR-based hand rehabilitation system.

Accepted Manuscript (Uncorrected Proof)

Conclusions

Maintaining motivation is known to be essential to the success of rehabilitation. Within the framework of this study, a VR-based smart hand rehabilitation system was proposed to improve patients' comportment. Game scenarios presented for wrist extension and radial-ulnar deviation exercises. Results of the experimental study demonstrated that the defined difficulty parameter (disappearance time of target objects in the game environment) is a good option for controlling the mental state of players.

Psychophysiological activity and perceived psychological states changed according to the task difficulty level in the games, so it seems that we could control these indexes through the game parameter regulation. Subjective measures analysis shows that selecting the appropriate level of difficulty (corresponds to optimal challenge/skill ratio) maximizes users' satisfaction when interacting with the rehabilitation system. Apathy or boredom states occurs when challenges are so low. It led to a meaningful decrease in arousal for this condition. On the other hand, the anxiety caused by experiencing very challenging tasks led to a reduction in the dominance perceived by the person compared to different levels.

The standard deviation of NN intervals extracted from the PPG signal is sensitive to changes in difficulties level; it would appear that this feature is relevant for objective quantification of patients psychological and emotional state when they intact with VR environment. There are many other methods for extracting information from the PPG signal. It is expected that Appropriate psychophysiological indicators would be funded using more precise signal processing techniques.

One concern about this study's conclusions was that all of the experiences were performed on healthy subjects. The performance of the system on cases with disabilities should also be evaluated. Using machine-learning methods to estimate subjective psychological states from psychophysiological activities directly could be an interesting topic as a future work of this study. This could allow closing feedback loop for dynamic difficulty adaptation of difficulty level in VR environments.

Accepted Manuscript (Uncorrected Proof)

References

[1] G. Alankus, A. Lazar, M. May, C. Kelleher, Towards customizable games for stroke rehabilitation, (2010) 2113. https://doi.org/10.1145/1753326.1753649.

[2] F. Benvenuti, M. Stuart, V. Cappena, S. Gabella, S. Corsi, A. Taviani, A. Albino, S. Scattareggia Marchese, M. Weinrich, Community-based exercise for upper limb paresis: A controlled trial with telerehabilitation, Neurorehabil. Neural Repair. 28 (2014) 611–620. https://doi.org/10.1177/1545968314521003.

[3] D. Novak, P[1] D. Novak, "Promoting motivation during robot-assisted rehabilitation," in Rehabilitation Robotics, Elsevier, 2018, pp. 149–158.romoting motivation during robot-assisted rehabilitation, in: Rehabil. Robot., Elsevier, 2018: pp. 149–158.

[4] E.V.D. Brown, B.J. Dudgeon, K. Gutman, C.T. Moritz, S.W. McCoy, Understanding upper extremity home programs and the use of gaming technology for persons after stroke, Disabil. Health J. 8 (2015) 507–513.

[5] F. Muri, C. Carbajal, A.M. Echenique, H. Fernández, N.M. López, Virtual reality upper limb model controlled by EMG signals, in: J. Phys. Conf. Ser., 2013.

[6] P.L. Weiss, E.A. Keshner, M.F. Levin, Virtual reality for physical and motor rehabilitation, Springer, 2014.

[7] A. Henderson, N. Korner-Bitensky, M. Levin, Virtual Reality in Stroke Rehabilitation: A Systematic Review of its Effectiveness for Upper Limb Motor Recovery, Top. Stroke Rehabil. 14 (2007) 52–61. https://doi.org/10.1310/tsr1402-52.

[8] P. Langhorne, F. Coupar, A. Pollock, Motor recovery after stroke: a systematic review, Lancet Neurol. 8 (2009) 741–754. https://doi.org/10.1016/S1474-4422(09)70150-4.

[9] C. Nissler, M. Nowak, M. Connan, S. Büttner, J. Vogel, I. Kossyk, Z.-C. Márton, C. Castellini, Vita—an everyday virtual reality setup for prosthetics and upper-limb rehabilitation, J. Neural Eng. 16 (2019) 26039.

[10] J. Omedes, A. Schwarz, G.R. Müller-Putz, L. Montesano, Factors that affect error potentials during a grasping task: toward a hybrid natural movement decoding BCI, J. Neural Eng. 15 (2018) 46023.

[11] D. Novak, M. Mihelj, J. Ziherl, A. Olenšek, M. Munih, Task difficulty adjustment

Accepted Manuscript (Unrorrected Proof)

in biocooperative rehabilitation using psychophysiological responses, IEEE Int. Conf. Rehabil. Robot. (2011) 381–386. https://doi.org/10.1109/ICORR.2011.5975380.

[12] F. Grimm, G. Naros, A. Gharabaghi, Closed-loop task difficulty adaptation during virtual reality reach-to-grasp training assisted with an exoskeleton for stroke rehabilitation, Front. Neurosci. 10 (2016) 518.

[13] L. Tiberio, A. Cesta, M. Olivetti Belardinelli, Psychophysiological Methods to Evaluate User's Response in Human Robot Interaction: A Review and Feasibility Study, Robotics. 2 (2013) 92–121. https://doi.org/10.3390/robotics2020092.

[14] I. Pastor, H.A. Hayes, S.J.M. Bamberg, A feasibility study of an upper limb rehabilitation system using kinect and computer games, Proc. Annu. Int. Conf. IEEE Eng. Med. Biol. Soc. EMBS. (2012) 1286–1289. https://doi.org/10.1109/EMBC.2012.6346173.

[15] A. Da Gama, P. Fallavollita, V. Teichrieb, N. Navab, Motor Rehabilitation Using Kinect: A Systematic Review, Games Health J. 4 (2015) 123–135. https://doi.org/10.1089/g4h.2014.0047.

[16] I. Grubišić, H.S. Kavanagh, S. Grazio, Novel approaches in hand rehabilitation, Period. Biol. 117 (2015) 139–145.

[17] A. Krukowski, D. Biswas, A. Cranny, J. Achner, J. Klemke, M. Jöbges, S. Ortmann, Evaluations with patients and lessons learned, in: Mod. Stroke Rehabil. through e-Health-Based Entertain., Springer, 2016: pp. 295–324.

[18] L. Bernardi, F. Valle, M. Coco, A. Calciati, P. Sleight, Physical activity influences heart rate variability and very-low-frequency components in Holter electrocardiograms, Cardiovasc. Res. 32 (1996) 234–237.

[19] P. Rani, J. Sims, R. Brackin, N. Sarkar, Online stress detection using psychophysiological signals for implicit human-robot cooperation, Robotica. 20 (2002) 673–685.

[20] C. Wu, I. Chen, W. Fang, An Implementation of Motion Artifacts Elimination for PPG Signal Processing Based on Recursive Least Squares Adaptive Filter, (2017) 0–3.

[21] P. Xuedan, Z. Kai, W. Lili, F. Yujie, C. Shufen, RESEARCH ON BLOOD OXYGEN SATURATION MEASUREMENT SYSTEM BASED ON REFLECTIVE SIGNAL, (2019) 2019–2020.

Accepted Manuscript (Uncorrected Proof)

[22] M.M. Bradley, P.J. Lang, Measuring emotion: the self-assessment manikin and the semantic differential, J. Behav. Ther. Exp. Psychiatry. 25 (1994) 49–59.

[23] Validity and Reliability of Self-Assessment Manikin , Rph YR - 2012. (n.d.) 52-61 K1-Self-Assessment Manikin (SAM) K1-V. http://rph.khu.ac.ir/article-1-94-fa.html.

[24] B.F. Villar, P.F. Viñas, J.P. Turiel, J.C.F. Marinero, A. Gordaliza, Influence on the user's emotional state of the graphic complexity level in virtual therapies based on a robot-assisted neuro-rehabilitation platform, Comput. Methods Programs Biomed. 190 (2020) 105359.

[25] D. Novak, M. Mihelj, J. Ziherl, A. Olensek, M. Munih, Psychophysiological measurements in a biocooperative feedback loop for upper extremity rehabilitation, IEEE Trans. Neural Syst. Rehabil. Eng. 19 (2011) 400–410.

[26] D. Novak, M. Mihelj, M. Munih, Psychophysiological responses to different levels of cognitive and physical workload in haptic interaction, Robotica. 29 (2011) 367–374. https://doi.org/10.1017/S0263574710000184.

[27] N. Goljar, M. Javh, J. Poje, J. Ocepek, D. Novak, J. Ziherl, A. Olenšek, M. Mihelj, M. Munih, Psychophysiological responses to robot training in different recovery phases after stroke, IEEE Int. Conf. Rehabil. Robot. (2011). https://doi.org/10.1109/ICORR.2011.5975498.

[28] W.-H. Lin, D. Wu, C. Li, H. Zhang, Y.-T. Zhang, Comparison of heart rate variability from PPG with that from ECG, in: Int. Conf. Heal. Informatics, Springer, 2014: pp. 213–215.

[29] Y. Hochberg, A.C. Tamhane, References in Multiple Comparison Procedures, (2008).

[30] C. Foerch, B. Misselwitz, M. Sitzer, H. Steinmetz, T. Neumann-Haefelin, MEDIZIN-Originalarbeit-Die Schlaganfallzahlen bis zum Jahr 2050, Dtsch. Arzteblatt-Arztliche Mitteilungen-Ausgabe A. 105 (2008) 467.

[31] D.E. Levac, H. Sveistrup, Motor learning and virtual reality, in: Virtual Real. Phys. Mot. Rehabil., Springer, 2014: pp. 25–46.

[32] G. Burdea, Keynote address: Virtual rehabilitation-benefits and challenges, in: 1st Int. Work. Virtual Real. Rehabil. (Mental Heal. Neurol. Phys. Vocat. VRMHR, sn, 2002.

[33] G. Valenza, P. Allegrini, A. Lanatà, E.P. Scilingo, Dominant Lyapunov exponent

Accepted Manuscript (Uncorrected Proof)

and approximate entropy in heart rate variability during emotional visual elicitation, 5 (2012) 1–7. https://doi.org/10.3389/fneng.2012.00003.

[34] F. Agrafioti, D. Hatzinakos, S. Member, A.K. Anderson, ECG Pattern Analysis for Emotion Detection, 3 (2012) 102–115.

[35] H.A.L. Scher, J.J. Furedy, Phasic T-Wave Amplitude and Heart Rate Changes as Indices of Mental Effort and Task Incentive, 21 (1979) 326–334.

[36] Y. Su, C.R. Allen, D. Geng, D. Burn, U. Brechany, G.D. Bell, R. Rowland, 3-D motion system ("data-gloves"): Application for Parkinson's disease, IEEE Trans. Instrum. Meas. 52 (2003) 662–674. https://doi.org/10.1109/TIM.2003.814702.

[37] N. Hogan, H.I. Krebs, J. Charnnarong, P. Srikrishna, A. Sharon, MIT-MANUS: a workstation for manual therapy and training. I, in: [1992] Proc. IEEE Int. Work. Robot Hum. Commun., IEEE, 1992: pp. 161–165.

[38] M. Csikszentmihalyi, Finding flow: The psychology of engagement with everyday life., Basic Books, 1997.

Accepted Manuscript (Uncorrected Proof)

Table 1. Significant differences and effect sizes for the psychological dimensions (Arousal, Dominance and Valence) between the difficulty levels. * shows Significant difference for $p < 0.05$, ** shows Significant difference for $p < 0.01$ and *** shows Significant difference for $p < 0.001$

	Extension		***Ulnar-Radial Deviation***	
	p-value	Effect size W	p-value	Effect size W
Arousal	**p=0.001****	W=0.146	**p=0.000*****	W=0.501
Dominance	**p=0.000*****	W=0.591	**p=0.000*****	W=0.335
Valence	**p=0.407**	W=0.000	**p=0.002****	W=0.139

Accepted Manuscript (Uncorrected Proof)

Table 2. Significant differences and effect sizes for the Psychophysiological Measures (MNN, SDNN, NN50 and pNN50) between the difficulty levels. * shows Significant difference for $p < 0.05$, ** shows Significant difference for $p < 0.01$ and *** shows Significant difference for $p < 0.001$

	Extension		***Ulnar-Radial Deviation***	
	p-value	Effect size W	p-value	Effect size W
MNN	p=0.930	W=0.032	p=0.988	W=0.037
SDNN	p=0.661	W=0.017	p=0.716	W=0.0.20
NN50	**p=0.000*** **	W=0.607	**p=0.000*** **	W=0.768
pNN50	p=0.535	W=0.010	p=0.948	W=0.034

Accepted Manuscript (Uncorrected Proof)

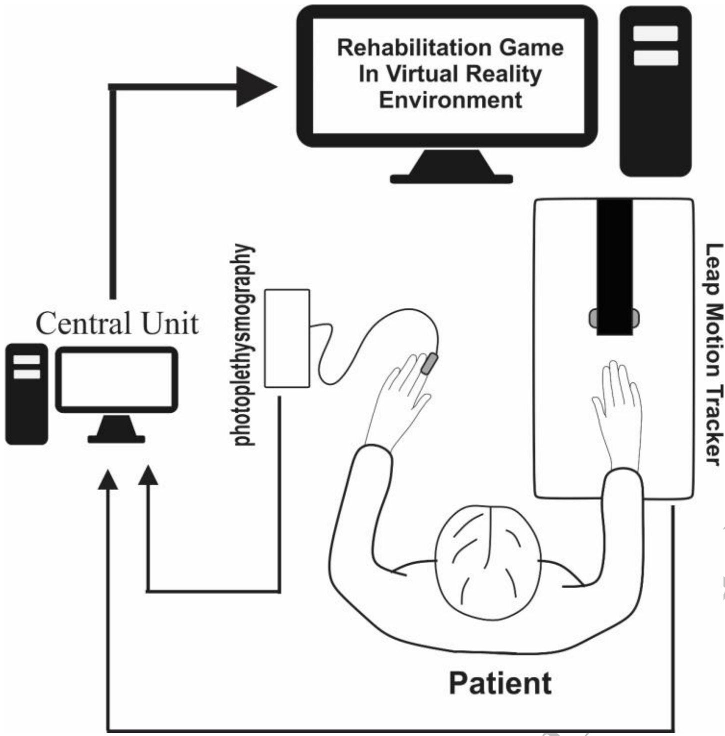

Figure 1. schematic of the developed hand rehabilitation system

Accepted Manuscript (Uncorrected Proof)

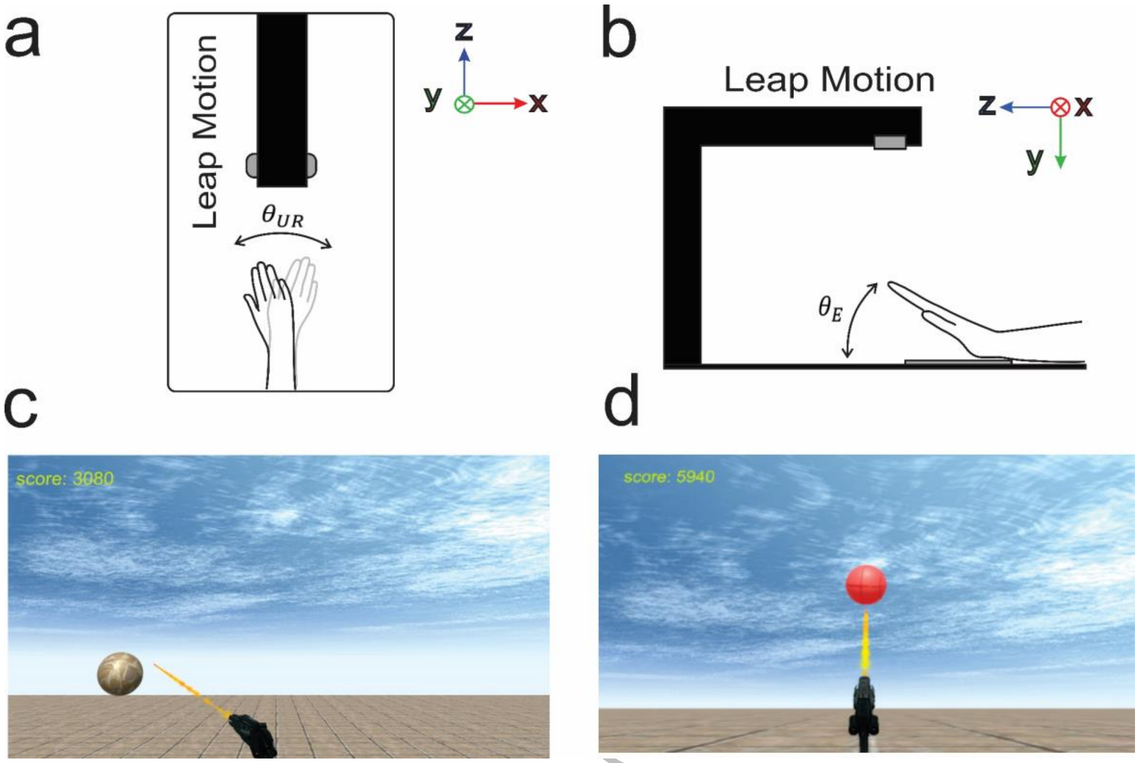

Figure 2. The structure of the hand tracking system and the controlling movements VR game environments, ulnar-radial deviation(a)(c) and extension(b)(d). The forearm is fixed using two straps to have the least movement in comparison to the Leap Motion coordination system.

Accepted Manuscript

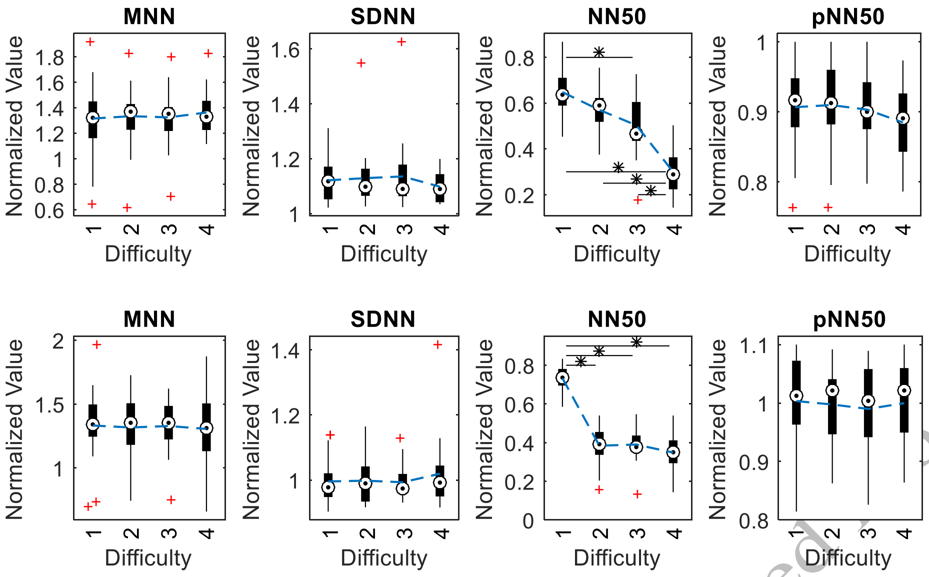

Figure 3. Changes on for Psychophysiological Measures (MNN, SDNN, NN50, and pNN50) for the four levels of difficulty in the extension (first row) and deviation (second row) game scenarios. Horizontal lines marked with a star show a significant difference between difficulty level pairs obtained by multiple comparison test (P <0.05).

Accepted Manuscript (Uncorrected Proof)

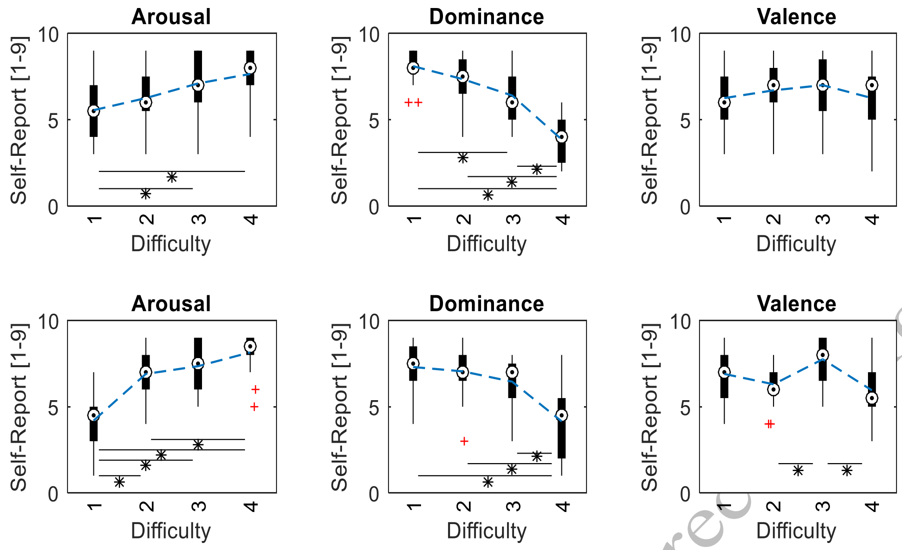

Figure 4. Changes on psychological dimensions (Arousal, Dominance, and Valence) for the four levels of difficulty in the extension (first row) and deviation (second row) game scenarios. Horizontal lines marked with a star show a significant difference between difficulty level pairs obtained by multiple comparison test (P <0.05).

Accepted Manuscript (Uncorrected Proof)