POST-STROKE REHABILITATION OF DISTAL UPPER LIMB USING VIRTUAL REALITY BASED TECHNOLOGY

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CENTRE FOR BIOMEDICAL ENGINEERING

INDIAN INSTITUTE OF TECHNOLOGY DELHI

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by

DEBASISH NATH

Submitted

in fulfillment of the requirements of the degree of Doctor of Philosophy

to the

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Dedicated to…

My Parents and the Almighty!

CERTIFICATE

This is to certify that the thesis entitled **"POST-STROKE REHABILITATION OF DISTAL UPPER LIMB USING VIRTUAL REALITY BASED TECHNOLOGY"**, submitted by **Mr. Debasish Nath** to the **Indian Institute of Technology Delhi** for the award of the degree of **Doctor of Philosophy** in **Biomedical Engineering**, is a record of the original, bona-fide research work carried out by him under my supervision and guidance. The thesis has reached the standards fulfilling the requirements of the regulations related to the award of the degree. The results contained in this thesis have not been submitted in part or in full to any other University or Institute for the award of any degree or diploma to the best of my knowledge.

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ABSTRACT

In recent years, Virtual Reality (VR) has been an emerging assistive technology for post-stroke rehabilitation. However, its clinical customization and standardization has been a research area of high importance. To facilitate post-stroke rehabilitation of distal upper limb (i.e., wrist and fingers) a VR-based task library has been developed. The tasks were developed with several factors of graded difficulty and in consideration of the required movements to perform the activities of daily living. The tasks were first validated in a cohort of healthy subjects (n=40) and two (n=2) patients with stroke. The benchmark values of three performance metrics i.e. time taken to complete the task, trajectory smoothness and relative error were established in a cohort of the healthy subjects to gauze the patients' performance. Based on the subjective feedback obtained from the healthy subjects and the patients, the therapeutic protocol was optimized. The optimized VR-based protocol was pilot-tested in a small sample of patients with chronic stroke (n=5) to observe the consistency in terms of clinical improvements. Further, the clinical effectiveness of the therapeutic protocol was evaluated in a cohort of patients with chronic stroke (n=9) in comparison with a dose-matched (20 therapy sessions of 45 min. each) patient group (n=9) receiving conventional physiotherapy. Statistically significant ($p < 0.05$) improvements at post-therapy were observed for VR-therapy group in terms of reduced spasticity, increased Modified Barthel Index and wrist active range of motion as compared to the conventional therapy group. Enhancement in cortical-excitability (in terms of increased Motor Evoked Potential and reduced Resting Motor Threshold) at post-therapy was observed for the VR-therapy group as compared to the conventional therapy group. A variable handle-resistance based hardware module to provide patient-centric customization was introduced, experimentally validated in a cohort of healthy subjects (n=15) and pilot tested with five (n=5) patients with stroke. The

cost-effective and portable version of the VR-based setup was developed to be used at low-resource home-based settings across different target platforms such as PC, smartphones etc. The setup was pilot-tested with five (n=5) healthy subjects to obtain feedback for further improvement.

Keywords: Virtual Reality, Stroke, Neuro-rehabilitation, Distal upper extremities, Neuroplasticity, Task performance metric

सार

हाल के वर्षों में, वर्चुअल रियलिटी (वीआर) स्ट्रोक के बाद पुनर्वास के लिए एक उभरती सहायक तकनीक रही है। हालाँकि, इसका नैदानिक अनुकूलन और मानकीकरण उच्च महत्व का अनुसंधान क्षेत्र रहा है। दूरस्थ ऊपरी अंग (यानी, कलाई और उंगलियों) के स्ट्रोक के बाद पुनर्वास की सुविधा के लिए एक वीआर-आधारित कार्य पुस्तकालय विकसित किया गया है। कार्यों को श्रेणीबद्ध कठिनाई के कई कारकों और दैनिक जीवन की गतिविधियों को करने के लिए आवश्यक गतिविधियों को ध्यान में रखते हुए विकसित किया गया था। कार्यों को सबसे पहले स्वस्थ प्रतिभागियों (संख्या = 40) और स्ट्रोक वाले दो (संख्या = 2) रोगियों के एक समूह में मान्य किया गया था। मरीजों के प्रदर्शन को मापने के लिए स्वस्थ प्रतिभागियों के एक समूह में तीन प्रदर्शन मेट्रिक्स के बेंचमार्क मान यानी कार्य को पूरा करने में लगने वाला समय, प्रक्षेपवक्र सुगमता और सापेक्ष त्रुटि स्थापित की गई थी। स्वस्थ प्रतिभागियों और रोगियों से प्राप्त व्यक्तिपरक प्रतिक्रिया के आधार पर, चिकित्सीय प्रोटोकॉल को अनुकूलित किया गया था। नैदानिक सुधार के संदर्भ में स्थिरता का निरीक्षण करने के लिए अनुकूलित वीआर-आधारित प्रोटोकॉल को क्रोनिक स्ट्रोक (संख्या = 5) वाले रोगियों के एक छोटे नमूने में पायलट-परीक्षण किया गया था। इसके अलावा, चिकित्सीय प्रोटोकॉल की नैदानिक प्रभावशीलता का मूल्यांकन क्रोनिक स्ट्रोक (संख्या = 9) वाले रोगियों के एक समूह में पारंपरिक खुराक प्राप्त करने वाले रोगी समूह (संख्या = 9) की खुराक-मिलान (प्रत्येक 45 मिनट के 20 थेरेपी सत्र) की तुलना में किया गया था। पारंपरिक थेरेपी समूह की तुलना में वीआर-थेरेपी समूह के लिए कम स्पास्टिसिटी, संशोधित बार्थेल इंडेक्स और कलाई की सक्रिय गति की सीमा के संदर्भ में पोस्ट-थेरेपी में सांख्यिकीय रूप से महत्वपूर्ण (पी <0.05) सुधार देखा गया। पारंपरिक थेरेपी समूह की तुलना में वीआर-थेरेपी समूह के लिए पोस्ट-थेरेपी में कॉर्टिकल-उत्तेजना (बढ़ी हुई मोटर इवोक्ड क्षमता और कम रेस्टिंग मोटर थ्रेशोल्ड के संदर्भ में) में वृद्धि देखी गई। रोगी-केंद्रित अनुकूलन प्रदान करने के लिए एक परिवर्तनीय हैंडल-

प्रतिरोध आधारित हार्डवेयर मॉड्यूल पेश किया गया था, जिसे प्रयोगात्मक रूप से स्वस्थ प्रतिभागियों (संख्या = 15) के एक समूह में मान्य किया गया था और स्ट्रोक वाले पांच (संख्या = 5) रोगियों के साथ पायलट परीक्षण किया गया था। वीआर-आधारित सेटअप का लागत प्रभावी और पोर्टेबल संस्करण पीसी, स्मार्टफोन इत्यादि जैसे विभिन्न प्लेटफार्मों पर कम संसाधन वाली घरेलू सेटिंग्स पर उपयोग करने के लिए विकसित किया गया था। सेटअप में सुधार के लिए पांच स्वस्थ प्रतिभागियों से प्रतिक्रिया प्राप्त की गई थी।

प्रमुख शब्द: आभासी वास्तविकता; स्ट्रोक; तंत्रिका पुनर्वास; दूरस्थ ऊपरी अंग; न्यूरोप्लास्टिसिटी; कार्य निष्पादन मापीय

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LIST OF ABBREVIATIONS

ACE-III	Addenbrooke's Cognitive Examination -III
ACS	Activity Card Sort
ADL	Activities of Daily Living
aFA	FA-asymmetry
ARAT	Action Research Arm Test
AROM	Active Range of Motion
BBT	Box and Block Test
BCI	Brain Computer Interface
BG	Basal Ganglia
BI	Barthel Index
BOLD-fMRI	Blood Oxygen Level Dependent- Functional Magnetic Resonance Imaging
BS	Brunnstrom Stage
CAHAI	Chedoke Arm and Hand Inventory
CE	Combined Environment
CG	Conventional Therapy Group
CGS	Commercial Gaming Systems
CST	Cortico-spinal Tract
CT	Computed Tomography
CV	Coefficients of Variation
DC	Digit Cancellation
DTI	Diffusion Tensor Imaging
EBI	Extended Barthel Index
ECG	Electrocardiogram
EDC	Extensor Digitorum Communis
EEG	Electroencephalogram
EMG	Electromyogram
FA	Functional Anisotropy
FIM	Functional Independence Measure
FMA-UE	Fugl-Meyer Assessment Upper-Extremity

fMRI	Functional Magnetic Resonance Imaging
FNT	Finger to Nose test
FOV	Field of View
FWE	Family-Wise Error
GBD	Global Burden of Diseases
GUI	Graphical User Interface
HMD	Head Mount Device
HPT	Hole Peg Test
HR-QoL	Health-related Quality-of-Life
HTS	Heel to Shin Test
IE	Individual Environment
LI	Laterality Index
MAL	Motor Activity Log
MAS	Modified Ashworth Scale
MBI	Modified Barthel Index
MCA	Montreal Cognitive Assessment
MCID	Minimum Clinically Important Difference
MEP	Motor Evoked Potential
MMSE	Mini-Mental Scale Examination
MMT	Manual Muscle Test
MNI	Montreal Neurological Institute
MoAS	Motor Assessment Score
MRA	Magnetic Resonance Angiography
MRI	Magnetic Resonance Imaging
MRS	Modifies Rankin Scale
MRV	Magnetic Resonance Venography
MSO	Maximum Stimulator Output
MT	Motor Threshold
NIHSS	National Institutes of Health Stroke Scale
NITRC	Neuroimaging Tools & Resources Collaboratory
OS	Operating System
OT	Occupational Therapy

PoG	Post-central Gyrus
PrG	Pre-central Gyrus
PT	Physiotherapy
RMT	Resting Motor Threshold
RPS	Reaching Performance Score
rTMS	Repetitive Transcranial Magnetic Stimulation
S.D.	Standard Deviation
SAH	Stroke Affected Hand
SIS	Stroke Impact Scale
SLC	Single Letter Cancellation
SMA	Supplementary Motor Area
SMC	Sensorimotor Cortex
SQF	Subjective Questionnaire Feedback
SUS	System Usability Scale
TCT	Time Taken to Complete the Task
tDCS	Transcranial Direct Current Stimulation
TIA	Transient Ischemic attack
TMS	Transcranial Magnetic Stimulation
VAS-F	Visual Analogue Scale-Fatigue
VR	Virtual Reality
VRG	VR-therapy Group
WHO	World Health Organization
WMFT	Wolf Motor Function Test
WSO	World Stroke Organization