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On Usage of EEG Brain Control for Rehabilitation of Stroke Patients

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Introduction

What is a stroke?

— a blood vessel bursts or is blocked by a clot
$\Rightarrow$ blood supply to brain is interrupted or reduced

— brain cells deprived of oxygen die
$\Rightarrow$ loss (paralysis) or impairment (paresis) of motor control

- quadriplegia/-paresis (legs and arms)
- paraplegia/-paresis (legs, lower part of body)
- monoplegia/-paresis (arms)
- hemiplegia/-paresis (one-sided paralysis/paresis)

— partially monoplegic patients with one paretic hand is common
$\Rightarrow$ potential for rehabilitation

Stroke rehabilitation

— 1950s (Twitchell): partial/full recovery is possible with rehabilitation

— 1960s (Brunnstrom): Brunnstrom approach for determinining stages of recovery

— 1970s (Fugl-Meyer): Fugl-Meyer assessment (performance-based impairment index)

— brain neuroplasticity enables structural and functional alterations of sensorimotor brain regions
$\Rightarrow$ adaptive brain reorganisation and cortical repair

— some rehabilitation methods for a paretic arm:

- exercise training
- impairment-oriented training
- functional electric stimulation
- robotic-assisted rehabiliation
- bilateral arm training
- mirror therapy
- game-stimulated rehabilitation

Common drawbacks with stroke rehabilitation

- labour intensive
- repetitive and boring exercises
- require personal interaction/instructions from trained personnel
- can last for many weeks/months
- equipment/systems are typically
  - expensive
  - non-portable
  - complex and difficult to operate
  - $\Rightarrow$ located in hospitals/institutions
  - $\Rightarrow$ required trained medical staff to operate
  - sessions must be booked, may have waiting time
- usually cannot be done at home at own pace

Mirror therapy

- simple, inexpensive, patient-directed rehabilitation method
- shown to improve hand/arm functioning after stroke, especially when used together with other conventional rehabilitation methods
- general paradigm:
  - patients simultaneously perform the same motor task with both paretical and normal hand/arm
  - paretic hand is hidden from sight
  - patients view mirror image of normal hand instead during task
    $\Rightarrow$ brain tricked into believing paretic hand functions well
    $\Rightarrow$ improves cortical reorganisation and repair

Example of mirror therapy

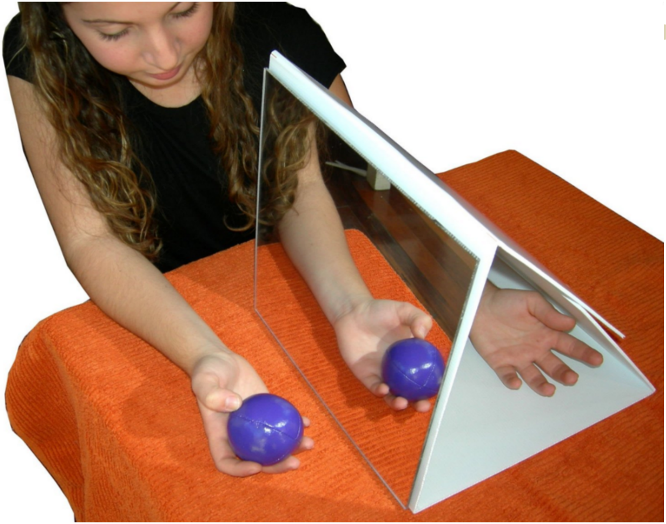

Figure: Commercial product Mirror Box by Neuro Orthopaedic Institute.

Game-stimulated rehabilitation

— 2000s: popularised, many studies

— effective stroke rehabilitation is intensive, repetitive, tiring
$\Rightarrow$ counteract using game-stimulated rehabilitation

— improve motivation, enjoyment, engagement, diversity

— may enable rehabilitation at home and adaptive training

— common platforms:

- Nintendo Wii
- PlayStation
- Microsoft Kinect
- Cyber Glove
- Leap Motion
- Unity 3D game engine
- Emotiv EPOC EEG

Electroencephalography (EEG)

— measurements of the natural electric potential on the scalp

— reflects number of synchronous neural discharges

— EEG frequency bands:

- delta (< 4 Hz)
- theta (4–7 Hz)
- alpha (8–15 Hz): alert and cognitive states
- beta (16–31 Hz): purposive movements
- gamma (> 32 Hz)

$\Rightarrow$ alpha and beta bands most relevant for stroke rehabilitation

— much good low-cost commercial-off-the-shelf (COTS) EEG equipment exists, e.g., Emotiv EPOC EEG

Motor-imagery brain-computer interface (MI-BCI)

— EEG-based MI-BCI can help paretic or paralysed stroke survivors to interact using brain waves instead of muscles

— reports on EEG-based MI-BCI combined with robotic feedback neurorehabilitation for stroke patients

— event-related desynchronization/synchronization in sensorimotor oscillatory rhythms associated with MI

— use rhythms/frequencies as inputs to BCI

— MI can replace actual physical task performance while still induce neural plasticity changes, e.g., brain wave control of a virtual arm in a computer game instead of one's physical arm

Steady-state visually evoked potential (SSVEP)

- EP: specific patterns in brain activity evoked by inputs to patients
- SSEP: input stimulus with steady frequency causes EEG activity at same frequency
- SSVEP: EEG frequency induced and synchronised with visual input frequency (e.g., flashing screen)
- can use SSVEP to increase EEG activity in desired frequency bands
- BCI with SSVEP can have higher information throughput and require shorter training
- may cause epileptic seizures and induce fatigue
- we hypothesise that adding SSVEP to BCI may improve stroke rehabilitation

Motivation and aim

— Most stroke rehabilitation require
  - expensive and complex equipment
  - trained medical staff
  - patients must travel to hospitals/institutions at given times
  - tasks that are repetitive and boring

  ⇒ Motivation: costly, time-consuming, stressful, unmotivating, not flexible or adaptable, ...

— mirror therapy and game-stimulated rehabilitation counteract drawbacks

  ⇒ Aim: combine the best of these methods

  + use Unity 3D virtual reality (VR) environment

  + interface Emotiv EPOC EEG headset for brain wave control

  = flexible and easy-to-use low COTS solution
  - can be used at home without medical staff
  - adaptable to user progression
  - motivational game environment
  - easy to extend to other interfaces/devices, e.g. robotic exoskeleton for manipulating the paretic hand

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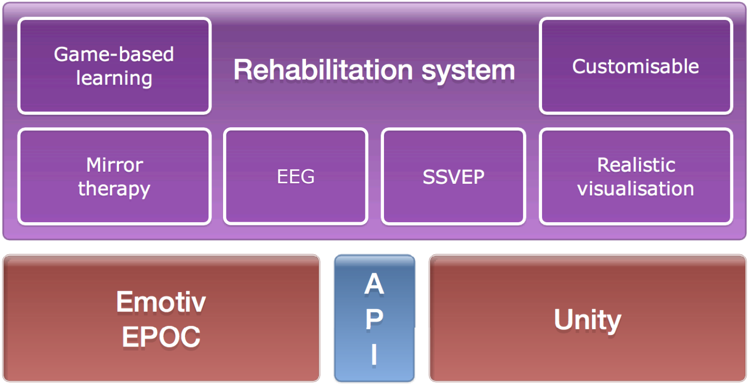
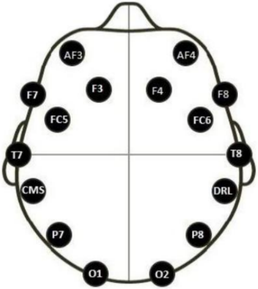
Overview of rehabilitation system



EEG data acquisition

— Use the Emotiv EPOC EEG headset
  - high-resolution, multi-channel, portable system
  - bluetooth wireless transmission to computer
  - 14 EEG channels placed as in 10-20 system:

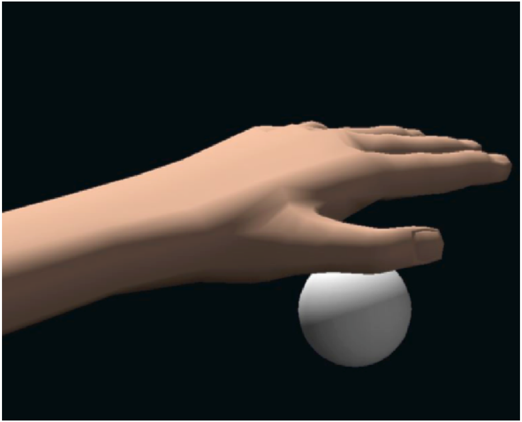


Training of mental commands

- use Emotiv software for EEG pattern recognition
- build up library of trained mental commands
- use Emotiv API to map commands into controls in Unity, e.g. control of virtual paretic hand in 2D horizontal plane (commands ’left’, ’right’, ’forward’, ’back’, ’open’, ’close’)
- we have integrated Emotiv’s own training environment into our virtual environment (VE) in Unity
- crucial: patients should try to move the paretic/nonparetic hands while training (like mirror therapy)
  $\Rightarrow$ link EEG patterns emerging from physical hand movements to brain control of virtual hand in Unity

3D model of the paretic hand

— brain must be tricked into believing paretic hand functions normally ⇒ realistic behaviour and looks
— use Blender for 3D model of paretic hand with internal set of finger joints
— program joints to move realistically and coordinated in synergy



Unity 3D application I

Main interactive scenes:

Main Menu: start scene and navigation to other scenes

Settings:
1. hand movement speed during reaching for object
2. hand close speed when grasping an object
3. target score for game level completion
4. SSVEP frequency

Training Environment:

— essentially the same as Emotiv's native but integrated in app

— train mental commands and store in calibrated profile for each user

Unity 3D application II

Game Rehabilitation Environment:

- current work: left paretic hand only, and only a single training exercise
- future versions: easily extend to right hand and more exercises
- reaching task:
  - top view of hand in xy-plane
  - EEG brain control using four commands ('left', 'right', 'forward', 'backward')
  - move hand towards target object
- grasping task:
  - close-up 3D view of hand and object
  - EEG brain control using two commands ('open', 'close')

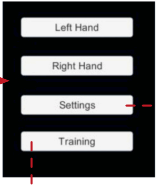
Unity 3D application III

- close command must last for a minimum duration for success $\Rightarrow$ increase score counter & reset game

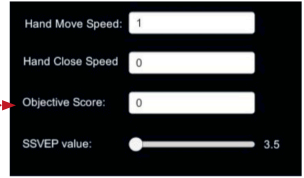
— important that patient tries to move paretic hand simultaneously while using EEG brain control of virtual hand

— SSVEP background colour flashes at set frequency (can be turned on/off)

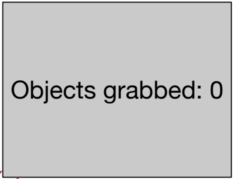
Screenshot of rehabilitation app



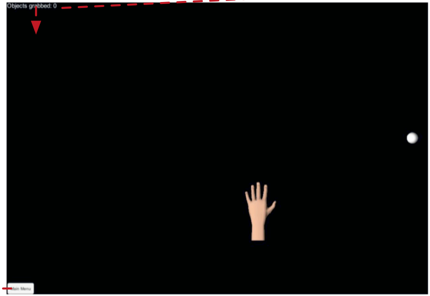
Main menu



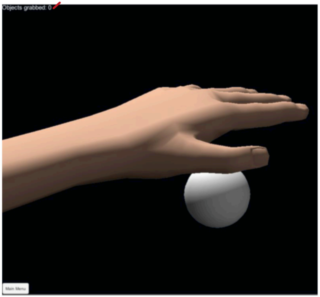
Settings



Score counter

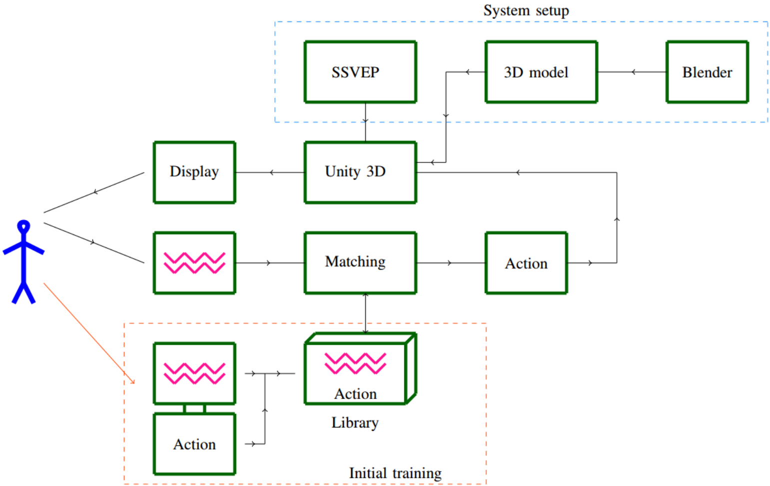


Left hand start view



Left hand close-up grasping view

Rehabilitation system diagram



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Proof-of-concept rehabilitation system

— complete but minimal system constructed (left hand + 1 exercise only)

— system can easily be extended to right hand and a library of exercises

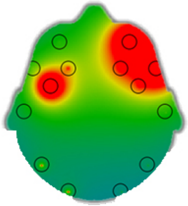
— no patients have yet tried the system

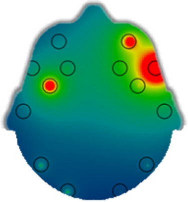
— healthy participants successfully able to complete exercise

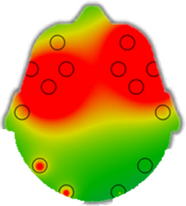
— tested several settings (reach and grasp speeds, SSVEP frequency), in particular the effect of SSVEP

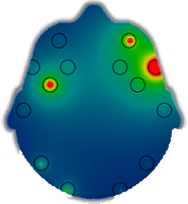
Effect of SSVEP on EEG activation

Much higher EEG activation with SSVEP in both alpha and beta bands:


Alpha waves with SSVEP


Alpha waves without SSVEP


Beta waves with SSVEP


Beta waves without SSVEP

Effect of SSVEP on game completion time

- game complete after four successful reach-and-grasps
- one exercise $\approx$ 30 sec $\Rightarrow$ game $\approx$ 2 mins
- participant completed game five times with/without SSVEP
- using SSVEP reduced completion time:
  average reduction in completion time 15 seconds (12%)
- results motivates a future thorough study with patients and healty participants

Trial	Without SSVEP (mm:ss)	With SSVEP (mm:ss)
1	02:04	01:43
2	01:58	01:46
3	02:34	02:06
4	02:16	01:55
5	01:52	01:59
Average	02:09	01:54
St. dev.	00:16	00:09

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Summary and conclusions

- demonstrated fast prototyping of low-cost COTS stroke rehabilitation system
- combines interactive 3D VR game environment (Unity) with EEG brain control (Emotiv EPOC EEG)
- proof-of-concept system is complete but minimal
- system inspired by mirror therapy and game-stimulated rehabilitation
- programmable exercises enables vast possibilities for motivational game-like rehabilitation
- potential advantages:
  - game-based and immersive training exercises
  - very customisable and extendable
  - adaptable and stand-alone at-home system without the need of personal instructor
  - low cost and flexible

Future work

- system must be refined, adjusted, and extended in close cooperation with medical experts and testing on real patients before clinical trial
- may be used alone or as supplement to conventional therapy
- may consider interfacing to external physical devices
  $\Rightarrow$ use Unity for virtual prototyping in early stages
  - hand exoskeleton or haptic glove with kinaestethic feedback
    $\Rightarrow$ guide patient with appropriate force feedback
  - use EEG brain waves to control prosthetic hand for fully paraplegic hand/arm patients

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Thank you for listening!

Questions?