NeuroRehabilitation – Virtual Rehabilitation

Instituto Nacional de Astrofísica, Optica y Electrónica

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Log

- 23-Mar-2018: Initial slides

Prerequisite slides

- Required;
  - NervousSystem_en
  - NeuroRehabilitation_Fundamentals_en
  - NeuroRehabilitation_Principles_en
    - ☞ At the time of writing this, I haven't yet "clean" my slides regarding the two above.
- Convenient:
  - Anatomy_JointsAndMovements_en

Recommended Bibliography

Contents

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VIRTUAL ENVIRONMENTS AND SERIOUS GAMES

Serious Games

- **Serious games** are those whose purpose is other than merely entertaining.

- Potential uses:
  - Eduational
  - Training
  - Motivational

- Industries benefiting from serious games:
  - Military
  - Education
  - Health
  - Social services (e.g. firemen)
  - Risk management (economy, natural disasters, etc)

Virtual environments

Figura 2.11 Entornos Virtuales en 2D y 3D implementados con tecnologías hápticas y realidad aumentada. Figura reproducida de (Gómez, 2015) y (Garfias, 2016).

Figure from [Hernandez-Castañón V (2016) MSc thesis]

Virtual Rehabilitation

- **Virtual rehabilitation** (VR) refers to the administration of motor rehabilitation enhanced by means of virtual environments (VE) [1].

[1] Sucar et al (2014) IEEE TNSRE 22(3):634-643

Rehabilitación virtual

¿Porqué debemos considerar la rehabilitación virtual (VR)?

- VR tiene el *potencial* de cumplir con todos los principios de rehabilitación requeridos para aprovechar la plasticidad dependiente de la experiencia, y además…
- La **motivación** y **apego** de los pacientes son factores importantes en un proceso de aprendizaje (como el que ocurre en neurorehabilitación) para favorecer los mecanismos plásticos, y VR ha demostrado ser exitosa en fomenter estos factores en diferentes dominios y a través de diferentes usuarios
- "...humans can learn motor skills in a virtual environment and that they can then transfer that motor learning to a real world environment. ...**proponents of VR believe that outcomes will be enhanced** following practice in VR because of the ability to make tasks easier, less dangerous, more customized, more fun, and of course easier to learn because of the salient feedback that can be provided during practice." [Holden 2005, CPB, 8(3) :187-211]

Rehabilitación virtual

¿Aporta algo nuevo a la neurorehabilitación?

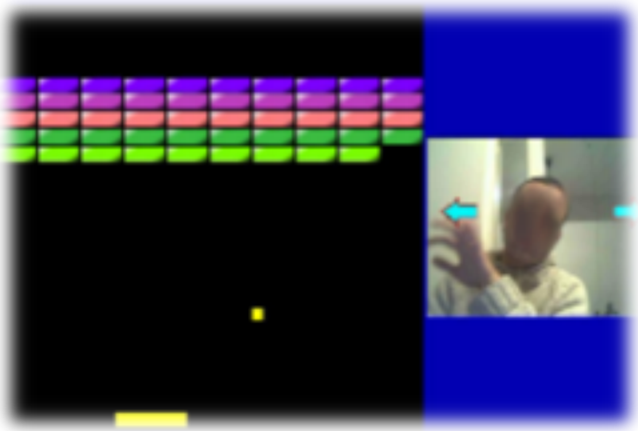
- "… virtual reality, allows us the opportunity to **manipulate the learning environment** and provide a more intensive learning experience" [Levin (2011) Expert Rev. Neurother. 11(2), 153–155] …esto es, más allá de lo que es posible con otras modalides de rehabilitación.
- Además, cada vez hay más evidencia de que es possible la **transferencia de conocimiento** desde entornos virtuales a reales, y que esta de puede modular de tal forma que tenga una major generalización a diferentes tareas [Hernández-Castañón, V (2017)]

Rehabilitación virtual

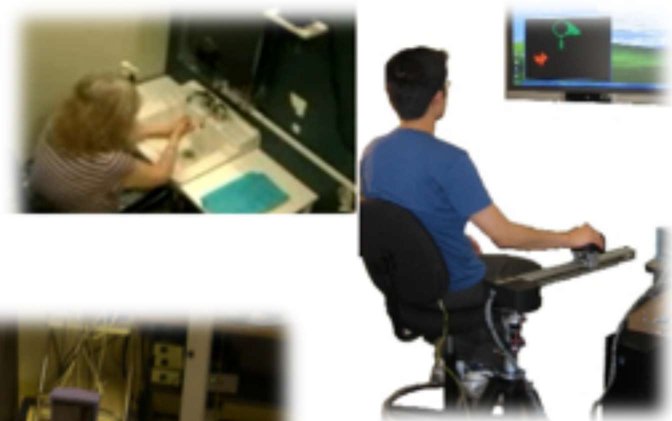
¿Es el "santo grial" de la neurorehabilitación o solo una tendencia novedosa?

- "We found **limited evidence** that the use of virtual reality and interactive video gaming may be beneficial in improving arm function and ADL function when compared with the same dose of conventional therapy." [Laver et al (2011) Cochrane Database of Systematic Reviews]
- "We are still at **the early stages of gathering evidence** of the effectiveness of various virtual reality applications in rehabilitation" [Levin (2011) Expert Rev. Neurother. 11(2), 153–155]
- En resumen; ni el santo grial ni una tendencia novedosa; una alternativa adicional que puede aportar algo nuevo en términos de motivación, apego y generalización de aprendizaje, y aún con margen de mejora.

Examples of Virtual Rehabilitation



Kizony R. , Weiss P. L., Shahar M. and Rand D(2006)



Hoey J., Monk A., and Mihailidis A. (2010)

Morrow K., Docan C., Burdea G., and Merians A. (2006)

Weiss P. L., Rand D., Katz N., and Kizony R. (2004)

Huber M., Rabin B., Docan C., Burdea G., Nwosu M. E., Abdelbaky M., and Golomb M. R. (2008)

Gesture therapy

Gesture Therapy

- Research highlights and platform features

Source: [SSNR2015_0002_FINAL.pptx]

Rehabilitación virtual

State of the art (more or less)

TABLE I

SUMMARY OF VIRTUAL REHABILITATION SOLUTIONS FOR THE UPPER LIMB BY YEAR OF PUBLICATION. PURELY ROBOTIC SOLUTIONS SUCH AS THAT IN [27] OR THE MIME SYSTEM [28] ARE NOT INCLUDED, BUT HYBRID SYSTEMS USING VIRTUAL REALITY ARE INCLUDED, e.g., MIT MANUS

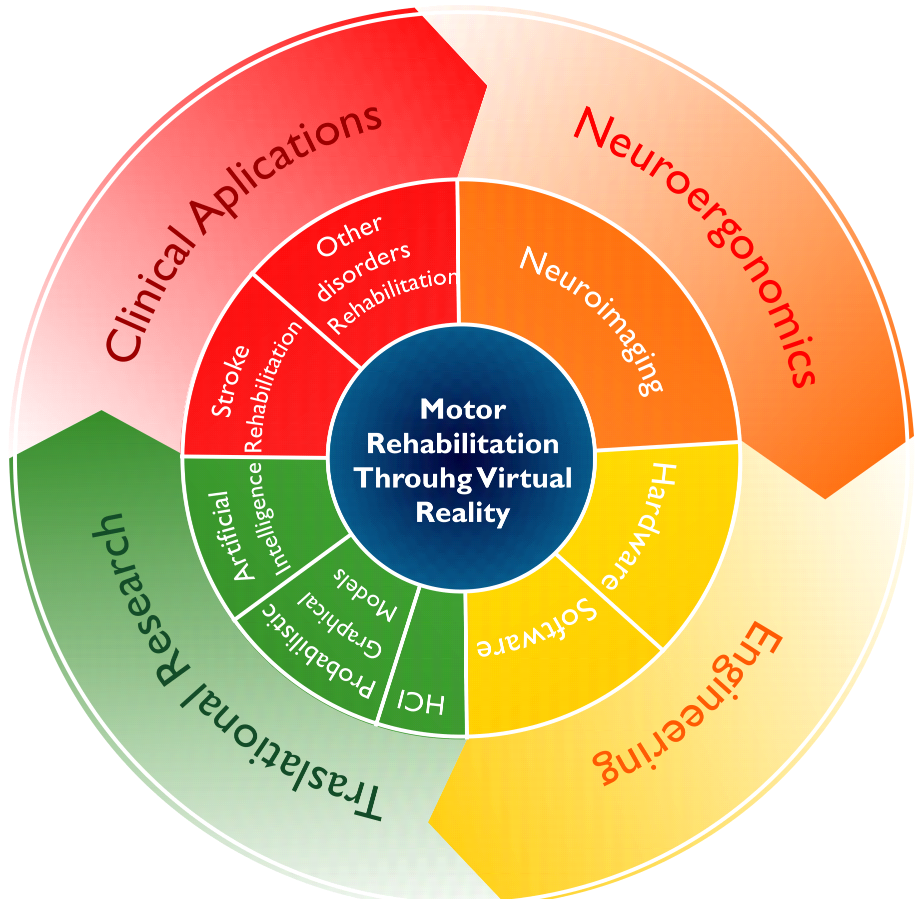
Name, Ref. & Year	Brief Description	Virtual Environments	Clinical Trials & Case studies
Driver's SEAT [29] (1999)	A 1 degrees of freedom (dof) steering wheel	Driving (rural, suburban and urban)	Not described
MIT Manus [30] (1998)	Robotic platform including a planar module (2 dof) and a wrist module (3 dof) with armrest	Drawing circles, stars, squares and diamonds, and navigating through windows	Robotic training additional to standard therapy improves motor recovery. The improved outcome was sustainable over 3 years
Rutgers orthopedic telerehabilitation system [16] (2000)	Input device is the "Rutgers Master" glove for the hand.	Games; Power putty, digikey, peg board, hand ball	It demonstrated improvements in terms of range of motion, velocity, fractionation and thumb strength in case studies
ARM Guide [31] (2000)	Passive linear constraint with 1 dof motor exoskeleton	Reaching task. Feedback is provided in video monitor.	Several case studies suggests increments in reach and velocity plus a reduction in tone.
Java Therapy [32] (2001)	Force feedback joystick with web based games. Requires armrest.	Games inc. Breakout, othello, torpedo and tail gunner	A case study is inconclusive [17]
Virtual Environment Training System [33] (2002)	A desktop display and electromagnetic motion-tracking devices	Putting envelope in mailbox. Reaching exercises.	A small cohort (n=9) exhibited improvements (15% in Fugl-Meyer and 31% in Wolf Motor Test) in 2 reaching movements.
TheraJoy [34] (2002)	Modified mass-marketed force feedback joystick	Games are used but no further details provided	Not described
Gentle/s [35] (2003)	Large screen with a 3 dof haptic interface.	Empty room, real room and detail room.	Requires elbow orthosis. The system was able to motivate people.
TheraDrive [36] (2004)	Force-feedback steering wheel	SmartDriver (Commercial driving videogame)	Clinical benefits in terms of motor performance and an edge on motivation
GestureTek's GX and IREX platforms [37] (2004)	Video capture VR system + gloves + large screen	Games inc. soccer, birds and balls and snowboard	Balance improvements similar to conventional therapy, but with increased enjoyment. IREX favours ipsilesional SM1 reactivation [38]
Sony PlayStation + EyeToy [37] (2004)	Off-the-shelf video capture virtual reality gaming platform	Games inc. Knockout, Do it yourself, Colors and Mr. Chef.	A case study showed improvements in motor dexterity mainly due to major sensory improvements
VR Physical Therapy [39] (2005)	Data glove and games system for telerehabilitation	Games; Puzzles inc. Merlin's revenge	Not described
TheraGame [40] (2006)	Video capture (Webcam) VR system	Games inc. Tetris, frog, color-Sok and motion music	Patient with neurological deficits found the system engaging.
T-WREX [41] (2006)	5 dof exoskeleton (WREX) used as 3D mouse + a grip sensor	JavaTherapy 2.0 (inc. shopping, washing, cracking eggs)	T-WREX is effective in enhancing UL motor recovery and patient motivation.
Xbox [42] (2006)	Modified Xbox + glove	2 games; Butterfly/UFO scaring and Clean up, shared with [43].	Not described
ARMeo (Hocoma) [31] (2000-6)	Passive linear constraint with 1 dof motor. This is the commercial version of [31] and [41]	Games inc. Rain mug, fruit shopping, egg cracking and reveal picture	Not described
Universities of Derby and Ulster's serious games [44] (2008)	Immersive head mounted display (HMD) and gloves	Games inc. Rabbit chase, arrow attack, orange catching, and whack-a-mouse	Small clinical trial suggested clinical benefits in terms of motor performance that was sustained 6 weeks after intervention
Play Station 3 [43] (2008)	PlayStation 3 + glove	2 games; Butterfly/UFO scaring and Clean up, shared with [42].	Pilot study in children suggests some improvements in ADL.
Wii [45] (2008)	Wii	Wii sports games inc. Boxing, tennis, bowling and golf	A case study of palsy resulted in augmented rehabilitation when complementing physical therapy.
Elinor Game Platform [46] (2009)	A game console controlled with 2 handles	15 games based on classical concepts	Case studies are not assessed clinically, but only claimed to exhibit gamers behaviour.
Virtual Piano Trainer [14] (2009)	Virtual piano with cyberglove, cybergrasp and two arm tracking sensors	Virtual piano	A pilot study suggested improvements in fractionation
iStretch [47] (2010)	1 dof robotic system for the early stages of physiotherapy	Reaching task	Not described
Adaptive Mixed Reality Rehabilitation system [48] (2010)	A table with 4 target buttons + large screen + 2 speakers	4 different training environments: Virtual, hybrid I and II and physical	A pilot (n=4) showed significant improvement in reaching and grasping performance compared to controls under traditional therapy.
None given [13] (2010)	Wii based + vision system	8 games inc. baseball catch, helicopter flying, frog Simon and under-the-sea	Results with case studies were encouraging
Hadassah University Hospital system [49] (2012)	A motion capture VR system integrating online self-face viewing and mirror visual feedback	Various game-like tasks; catch money and pick fruit among others	A study (n=6) demonstrated feasibility in terms of adherence and improvement in task performance
Art-empowered VR [50] (2013)	2 large displays, a tracking system of head and arm, and a pneumatically actuated glove	March Hare's cottage environment	Preliminary results (n=4 of 9) suggest grip and pinch improvements.
Spatial Augmented Reality [51] (2013)	Computer, webcam, projector and table for projection	4 tasks; reaching, holding and tilting, pointing and grasping	Two subjects feasibility pilot poorly described.
None given [52] (2013)	Hybrid; 7 dof passive robot (Trackhold), VR and 128 channels EEG	5 environments; sponge, bug hunt, grab 2D, grab 3D and Twirl	Pilot (n=2) demonstrated feasibility to monitor neuro-motor recovery. lateralization.

[Sucar et al, IEEE TNSRE 2013]

How is a VR solution developed?

- "…development of these platforms is a complex process which has **not yet reached maturity**" [Sucar et al, IEEE TNSRE 2013]

- From the point of viw of design, the work in this área is multidisciplinary, it requires considering knowlegde from hardware and software, human-computer interaction, virtual reality, and of course profound knowledge about neurology and psychology



Virtual Rehabilitation (VR)

- VR is a rehabilitation therapy exploiting virtual reality (serious games).
- VR adapts its activity to match;
  - Patient progress
  - Therapy demands

Motivation

- Several medical conditions can lead to motor impairment.
  - E.g. stroke, palsy, TBI
- To recover motor dexterity and functional ability, the affected people follow…
  - Expensive,
  - long and
  - Demotivating

VR is:
•Low cost,
•Facilitates treatment at home
•Motivating

- … rehabilitation treatments often resulting in abandonment of the therapy.

Adaptation

- Arguably the key element behind the VR capacity to fulfill intelligent personalization.

- Instead, adaptation should be guided by **non observable** the cognitive and emotional state of the patient,
  - Many processes concurrently conform the mind state of the patient.
  - **Attention** is the capacity to opt out one or several stimuli among potential distracters
    - [Chun et al (2011) Annual Review of Psychology 62, 73–101]

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FEEDBACK

Feedback

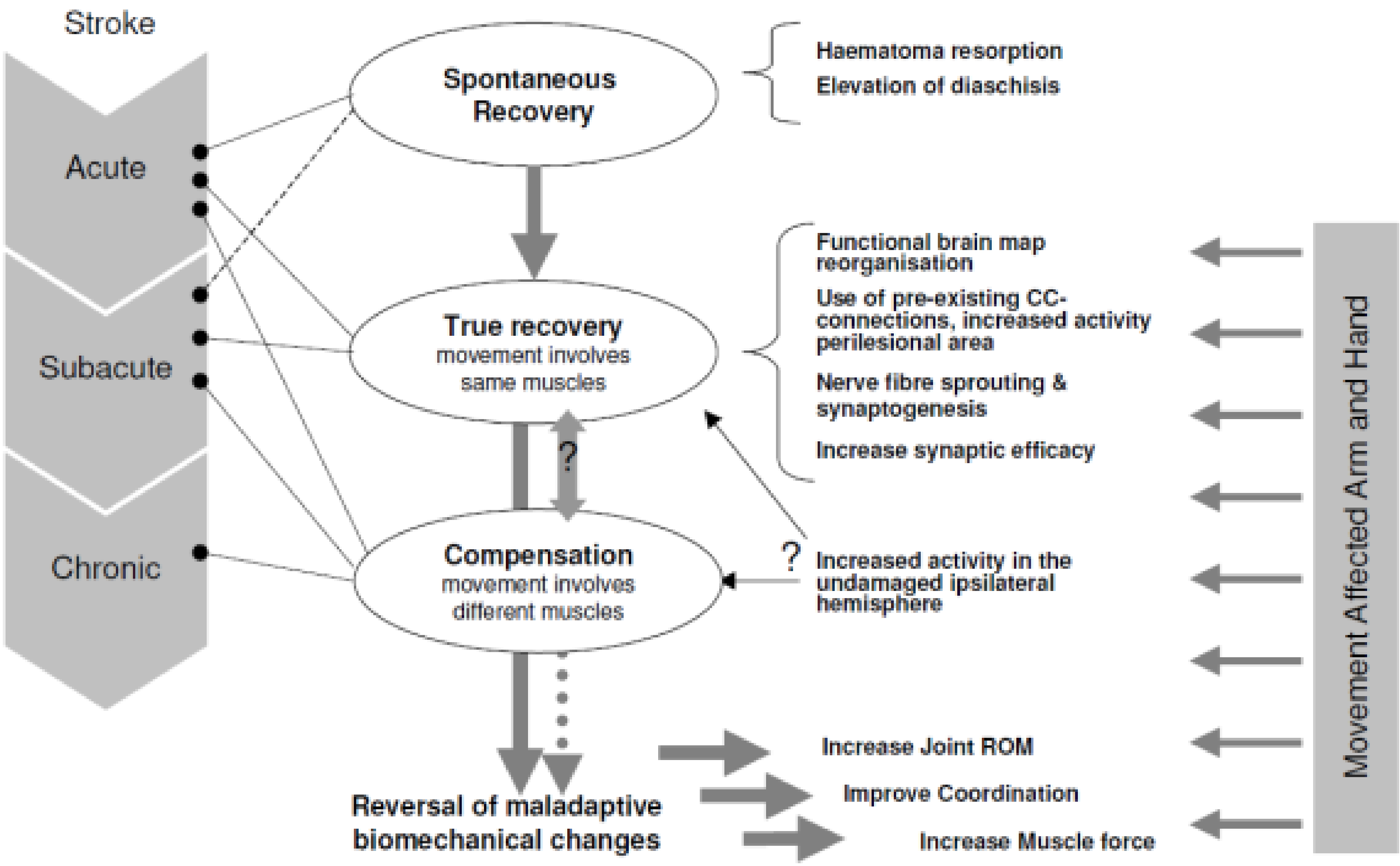

Figure 1
Declarative model of motor recovery after stroke. (CC = corticortical).

[Timermans et al (2009) JNER 6:1]

Feedback

- Feedback informs the patient about his performance and progress

- Feedback is known to:
  - Enhance motor learning [HoldenMK2005]
  - Enhance motivation [ColomboR2007]
  - Facilitate skill improvement [TimmermansAAA2009]

Feedback

- Feedback is acquired through:
  - Task-**intrinsic feedback** provided through visual, tactile, proprioceptive and auditory cues to a person who performs the task.
  - Task-**extrinsic feedback** or **augmented feedback** including verbal encouragement, charts, tones, video camera material, computer generated kinematic characteristics

[Timermans et al (2009) JNER 6:1]

Feedback

- Feedback is delivered through:
  - **Knowledge of performance**: information about movement characteristics that led to the performance.
    - Prescriptive or descriptive
    - Maybe delayed
  - **Knowledge of results**: outcome of skill performance or about goal achievement.
    - Quatitative, qualitative or subjective
    - Inmmediate

Feedback

Knowledge of results

Knowledge of performance

[GarciaMartinezS2015]

Feedback

- System feedback
  - Positive (reward) or
  - Negative (punishment)

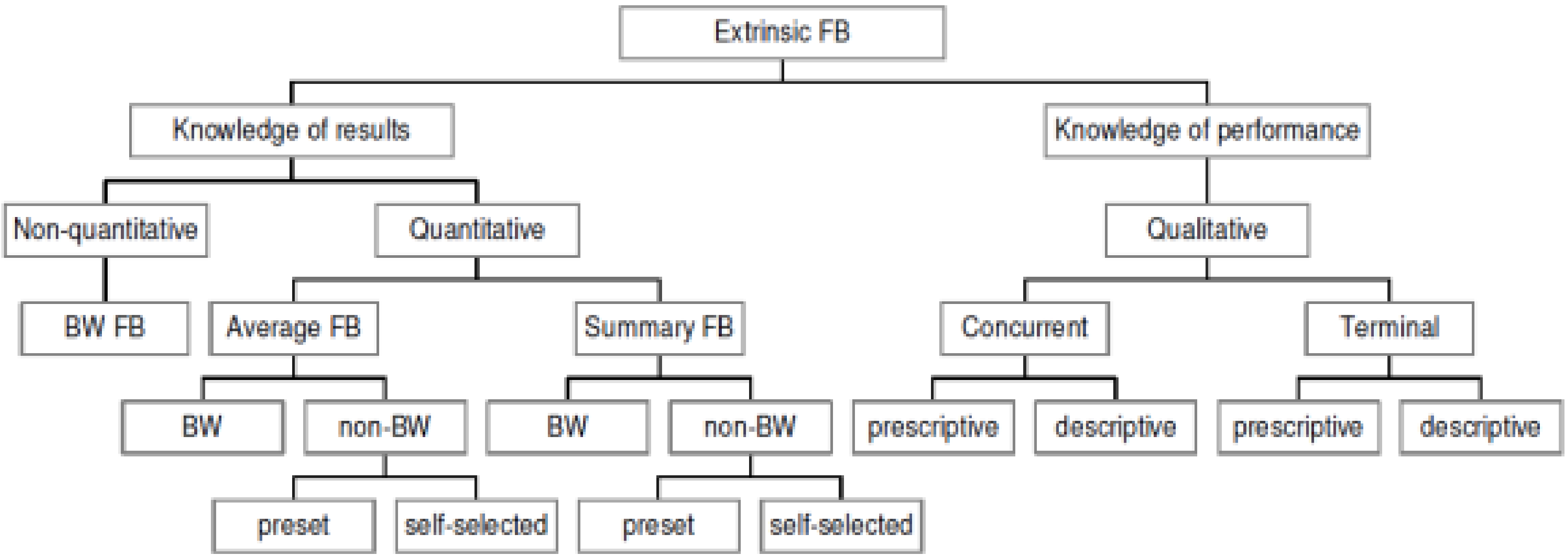

Figure 3
Schematic presentation of extrinsic feedback components for motor performance. (FB = feedback, BW = band-width).

[Timermans et al (2009) JNER 6:1]

Feedback

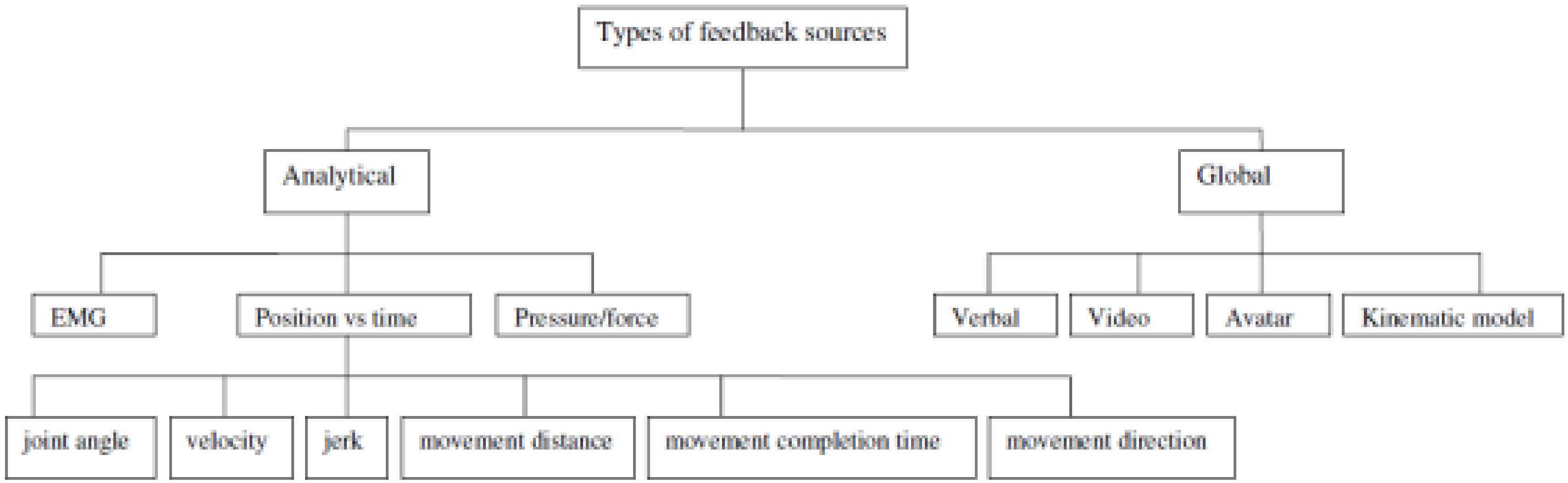

Figure 2
Schematic presentation of types of augmented feedback sources for motor performance.

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PERSONALIZATION, CUSTOMIZATION AND ADAPTATION

Personalization, customization and adaptation

- Controlling the learning environment is the key to provide a personalised and intensive learning experience in rehabilitation (Levin, 2011).

- The ultimate goal of this manipulation of the virtual rehabilitation environment is achieving optimal impact of the therapy (Rose et al., 1998, Levin, 2011, Burke et al., 2009a).
  - A collateral goal for those solutions design to be utilized at home is reducing dependency on clinical expert supervision.

Personalization, customization and adaptation

- Tailoring of the virtual environment can be achieved by;
  - Manipulation of the appearance of the environment itself keeping the environment response coupled to the background of the patient, often referred to as customization;
    - ☞ This is also sometimes referred as **personalization**, but here we shall reserve personalization for the hardware component to avoid ambiguity.
  - Affecting the environment's response to patient actions and behaviour and mind status as these evolve throughout therapy, which is often referred to as adaptation.
  - Personalization of the hardware platform as complementing that of the virtual environment itself.
    - ☞ We won't see this here.

[OrihuelaEspina and Sucar (2016)]

Customization and Adaptation

- Customization and adaptation
  - …do not necessarily differ in:
    - what they change in the environment,
    - when they do apply the changes or
    - on the expected impact,

[OrihuelaEspina and Sucar (2016)]

Customization and Adaptation

- Customization and adaptation
  - …but they do depart on the etiology for proposing those changes.
    - evolution of the patient profile (customization) vs
    - behavioural performance progress (adaptation).

[OrihuelaEspina and Sucar (2016)]

Customization and Adaptation

- Customization is more often seen as a static alteration of the environment,

- Adaptation being more often seen as the one responsible for dynamic changes.

  - However, strict adherence to this static vs dynamic separation of these concepts is only a partial view of these two concepts.

[OrihuelaEspina and Sucar (2016)]

Customization and Adaptation

- Control of the environment dynamics:
  - Three dimensions adjust the way in which the adaptation and customization decisions are delivered to transform the environment
    - Decision making actuator
    - Decision making time
    - Decision making scope

[OrihuelaEspina and Sucar (2016)]

Customization and Adaptation

- Control of the environment dynamics: **Actuator**
  - The actuator is the VR platform's component permitting manipulation of the environment whether through customization and adaptation.
  - Its responsibility is to provide sufficient flexibility and to ensure the human's decision is respected.
  - It senses the scenario scrutinizing the patient profile and behaviour as well as his interaction with the virtual environment, together with keeping track of additional medical decisions and recommendations, and from the combined information, taking the optimal decision in some sense.

[OrihuelaEspina and Sucar (2016)]

Customization and Adaptation

- Control of the environment dynamics: **Actuator**
  - The actuating force may be:
    - Human driven (Holden and Dyar, 2002, Loureiro et al., 2003, Kizony et al., 2006),
    - AI driven (Kan et al., 2008, Avilés-Arriaga et al., 2011, Ávila-Sansores et al., 2013), or
    - Hybrid (Ma and Bechkoum, 2008, Burke et al., 2009b).

[OrihuelaEspina and Sucar (2016)]

Customization and Adaptation

- Control of the environment dynamics: **Actuator**
  - The actuator can be:
    - A single component combining both types of manipulation (customization and adaptation) (e.g. (Burke et al., 2009b)), or
    - Individual components each one taking care of one type of manipulation (e.g. (Sucar et al., 2014)), whether customization or adaptation.
    - Many platforms only support one type of manipulation.

[OrihuelaEspina and Sucar (2016)]

Customization and Adaptation

- Control of the environment dynamics: **Time**
  - Manipulation processes can occur:
    - Synchronous a.k.a. on-line: subsequent to the arrival of new information about the patient profile and status,
      - Provide immediate adjustment of the environment, but are more likely to be computationally demanding and can lead to overfitting to particular instantaneous circumstances.
    - Asynchronous a.k.a. off-line: temporally detached from the arrival of such information.
      - Less likely to overfit and low computational demand, but sacrifices immediacy of response.
    - Both on-line and off-line strategies can be combined to obtain a seamless modification of the rehabilitation environment with the evolving pattern of patient status and therapy demands.

[OrihuelaEspina and Sucar (2016)]

Customization and Adaptation

- Control of the environment dynamics: **Scope**
  - Guarantee adequate challenge at all times, whilst boosting the chances of a better long term outcome.
  - It must ensure sufficient flexibility to take quick local decisions, without decreasing therapeutic effectiveness, and
  - …analogously, they can help to maintain high therapeutic value without being confined to a predefined schedule

[OrihuelaEspina and Sucar (2016)]

Customization and Adaptation

- Control of the environment dynamics: **Scope**
  - Intra game: Changes the challenge of a single game or task to maintain arousal and skill development.
    - E.g. increase/decrease difficulty
  - Inter-game: Dynamically schedules tasks for improving long term outcome
    - Must compromise between local goals (e.g. ensuring patient safety, avoidance of fatigue and pain) and therapy goals (e.g. optimal patient recovery)
    - e.g. choose next game
  - Therapy-wide: Affect the therapy until overruled by another contradicting decision
    - e.g. ensures compatibility with co-morbilities

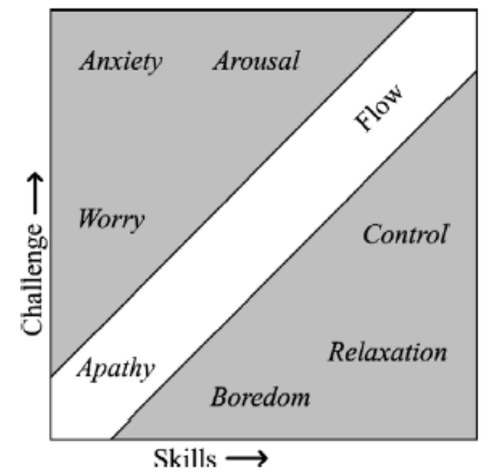


Figure from: [Nijholt et al, Entertainment Computing 1 (2009) 85-94]

[OrihuelaEspina and Sucar (2016)]

Customization and Adaptation

Table 1 Summary of some relevant virtual rehabilitation platforms incorporating customization and adaptation elements. Model and Policy: (S)tatic, (D)ynamic; Actuator: (AI) –Artificial Intelligence; Timing: (S)ynchronous, (A)synchronous. Scope: Intra-task (IT), Inter- o Between task (BT), Therapy Wide (TW); Driving Force: Personalized Feedback (PF), Challenge Maintenance (CM), Compensation Control (CC), Increasing Engagement (IE)

Reference	Author and year	Brief description	Customization / Adaptation	Model	Decision Policy	Actua-tor	Timing	Scope	Driving force	Impact of customization and adaptation
Virtual piano trainer (Adamovich et al., 2009)	Adamovich S et al (2009)	Cyberglove + Cybergrasp + two arm tracking sensors combined with a virtual piano.	Two adaptive algorithms control the haptic assistance. A target fractionation decreases steadily until actual fractionation exceeds target fractionation.	S	D	AI	S	IT	PF	Adaptive algorithm affects degree of fractionation.
MIT Manus (Krebs et al., 1998, Krebs et al., 1999)	Krebs HI et al (1998, 1999)	Robotic platform including 2 modules; planar module (2 dof) and wrist module (3 dof) with armrest.	Assistance only provided if the patient is unable to perform task.	S	D	AI	S	IT	CM	Active assisted learning tested on small cohort (n=8). Effect of assisted learning control not dissociated.
Virtual Environment Training System (Holden and Dyar, 2002)	Holden MK and Diar T (2002)	A desktop display and electromagnetic motion-tracking devices.	May accept different displays and/or tracking devices. Over a hundred settings to tailor feedback.	S	S	Human	A	IT, BT and TW	PF	Platform tested on 2 individuals. Effect of customization not dissociated.
Gentle/s (Loureiro et al., 2003)	Loureiro R et al (2003)	Large computer screen with a 3 DOF haptic interface. Requires elbow orthosis.	Different levels of guidance and correction can be programmed.	S	S	Human	A	IT, BT and TW	CM	Clinical trial (n=31) highlighted motivation. Specific contribution of customized level of guidance not reported.
TheraGame (Kizony et al., 2006)	Kizony R et al (2006)	Video capture (Webcam) VR system	Level of games may be graded to patient's level.	S	S	Human	A	IT	IE	Small pilot suggest high levels of enjoyment. Effect of customization not dissociated.
Universities of Derby and Ulster (Ma and Bechkoum, 2008, Burke et al., 2009b)	Ma M et al (2008) and Burke et al (2009)	Immersive head mounted display (HMD) and gloves.	Difficulty increases as games progresses. The platform supports user profiling, but it is not reported how it is used for customization.	S	D	Hybrid	S/A[1].	IT	CM	Pilot study (n=10) revealed good acceptance but adaptivity requires improvement "so that it is not as aggressive".
Reaching robot (Kan et al., 2008, Kan et al., 2011)	Kan P et al (2008, 2011)	A 1 DOF robot accompanied of a virtual scenario for reaching tasks .	A POMDP regulates required stretch.	S	D	AI	S	IT	CM and CC	Evaluated on a case study. 65% agreement with expert decision.
Gesture Therapy; 1st prototype (Sucar et al., 2010, Avilés-Arriaga et al., 2011)	Sucar LE et al (2009) and Aviles-Arriaga HH et al (2011)	Gesture Therapy (see section about the platform).	Game challenge adjusted by balancing speed and control. Menu based choices allow further customization.	S	D	Hybrid	Custom.: A Adapt.: S	IT	CM	Lab test show challenge adjustment with varying input.
Gesture Therapy; 2nd prototype (Ávila-Sansores et al., 2012, Ávila-Sansores et al., 2013)	Avila-Sansores et al (2012, 2013)	Gesture Therapy (see section about the platform).	Game challenge is adjusted by balancing speed and control, and decision policy regularly updated.	D	D	AI	S	IT	CM	Lab test show high agreement with expert decision.

[1] Depending on game.

[OrihuelaEspina and Sucar (2016)]

Customization and Adaptation

- Current solutions include:
  - Thresholding (e.g. (Kizony et al., 2006))
  - Initial calibration (see Calibration section)
  - Manual adjustment
  - AI based dynamic adjustment
    - Partially observable Markov decision process (POMDP) (e.g. (Kan et al., 2008))

Customization

- **Customization** is the alignment of the environment to the patients' profile [OrihuelaEspina and Sucar (2016)]

  - Under customization, the environment's response against an input action is preserved.

Customization

- Customization is more of aesthetical nature but it goes beyond the obvious modification of the graphical rendering.

  - It includes aspects such as demographical, psychological, ethnographical and even individual taste, as well as long-term clinical and therapeutic goals.

  - It also involves control of the abstraction level at which the task is presented to match the learning capabilities of the user, and it may even affect the physics and behaviour of the environment, e.g. by alighting the virtual weight of the virtual object to oppose less resistance for children, but it does so deterministically; under customization the same patient always observes the same weight until his/her profile changes, e.g. by growing older.

Adaptation

- **Adaptation** is the alignment of the environment to the patient changing physical and cognitive function and present circumstances, and to her short-term clinical and therapeutic demands. [OrihuelaEspina and Sucar (2016)]
  - It will most times involve a change in the response of the environment to the same input.

Adaptation

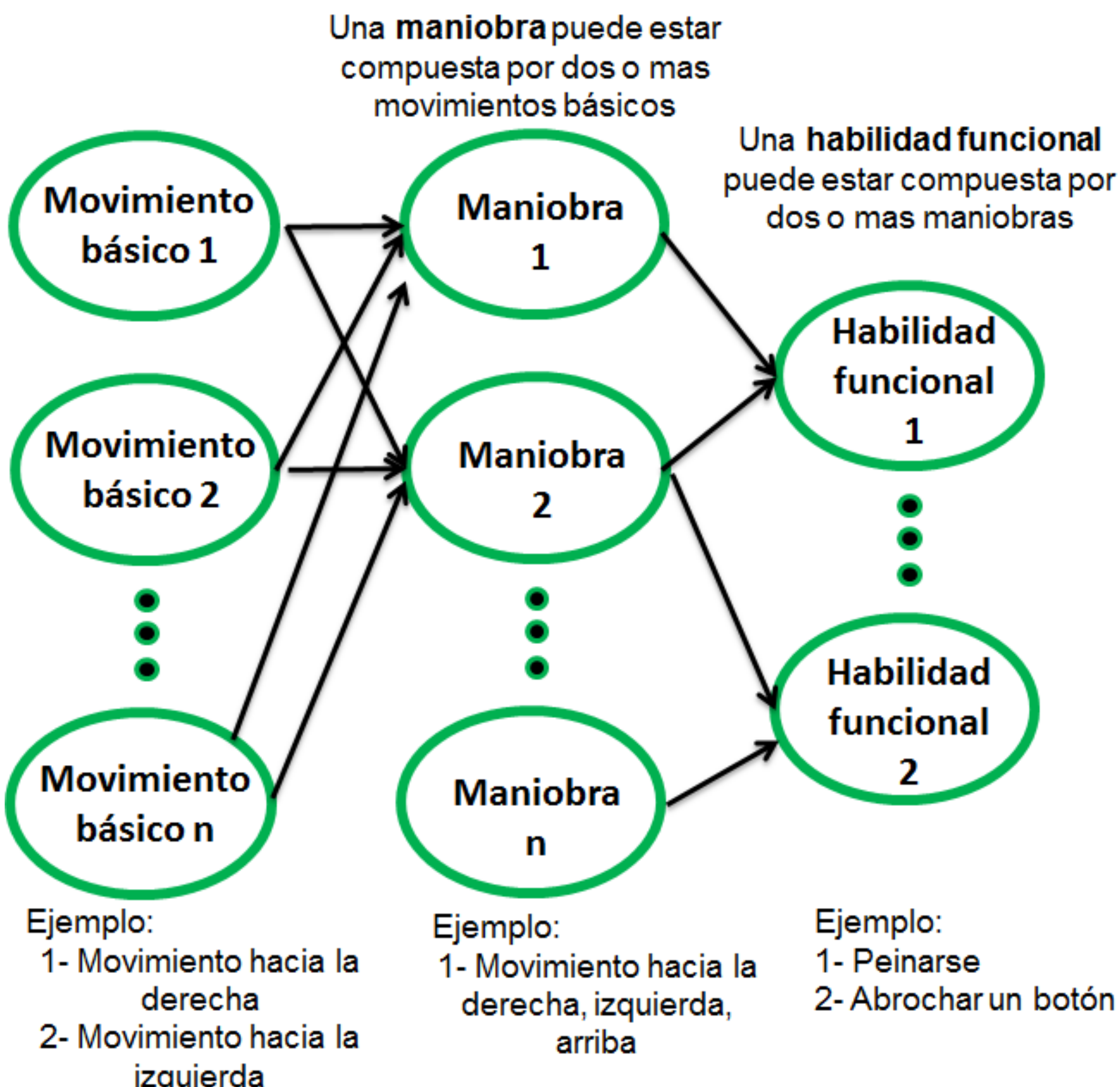
- Adaptation affects task abstraction, aesthetics, and physics

  - Challenge of the task is altered to match
    - the new skills,
    - the present physical status, e.g. fatigue or pain, or
    - the current mind status, e.g. frustration.

Adaptation

- Different ways for incorporating adaptation to VR
  - AI engine for challenge adjustment
  - Affective computing for mining emotional state
  - Understanding postural cues to decipher attention

AI engine for challenge adjustment



[AvilaSansores SM (2013) MSc thesis]

AI engine for challenge adjustment

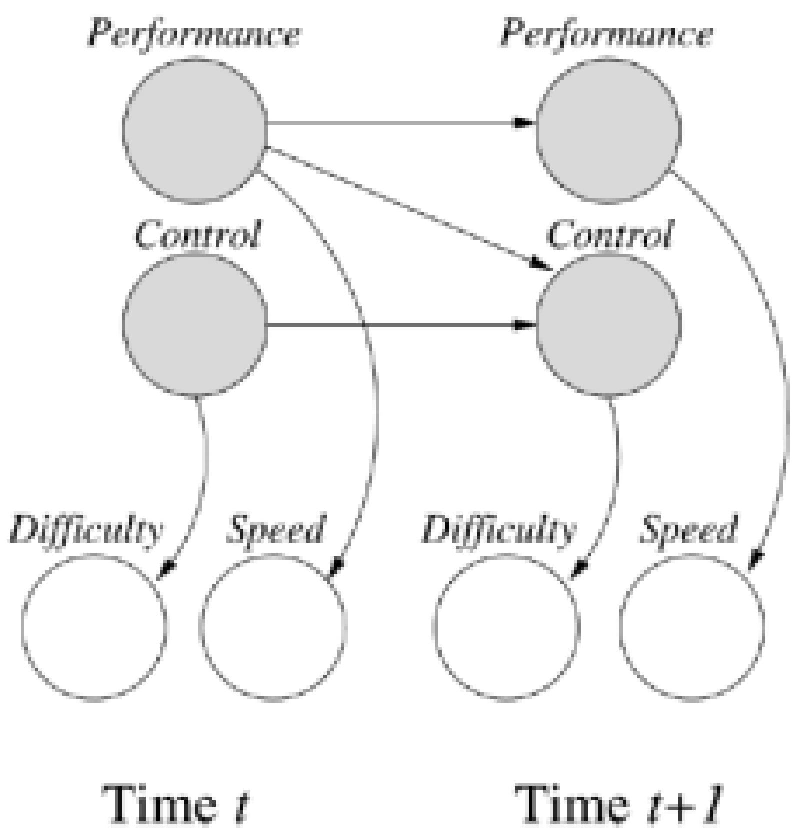


Figure 3 The structure of the first adaptation module of the Gesture Therapy platform. Figure reproduced from (Avilés-Arriaga et al., 2011). Hidden state variables (shaded circles) are inferred from observable variables (white circles) which are assumed to be consequence of the former along the temporal sequence of observations.

[AvilesArriaga et al (2011)]

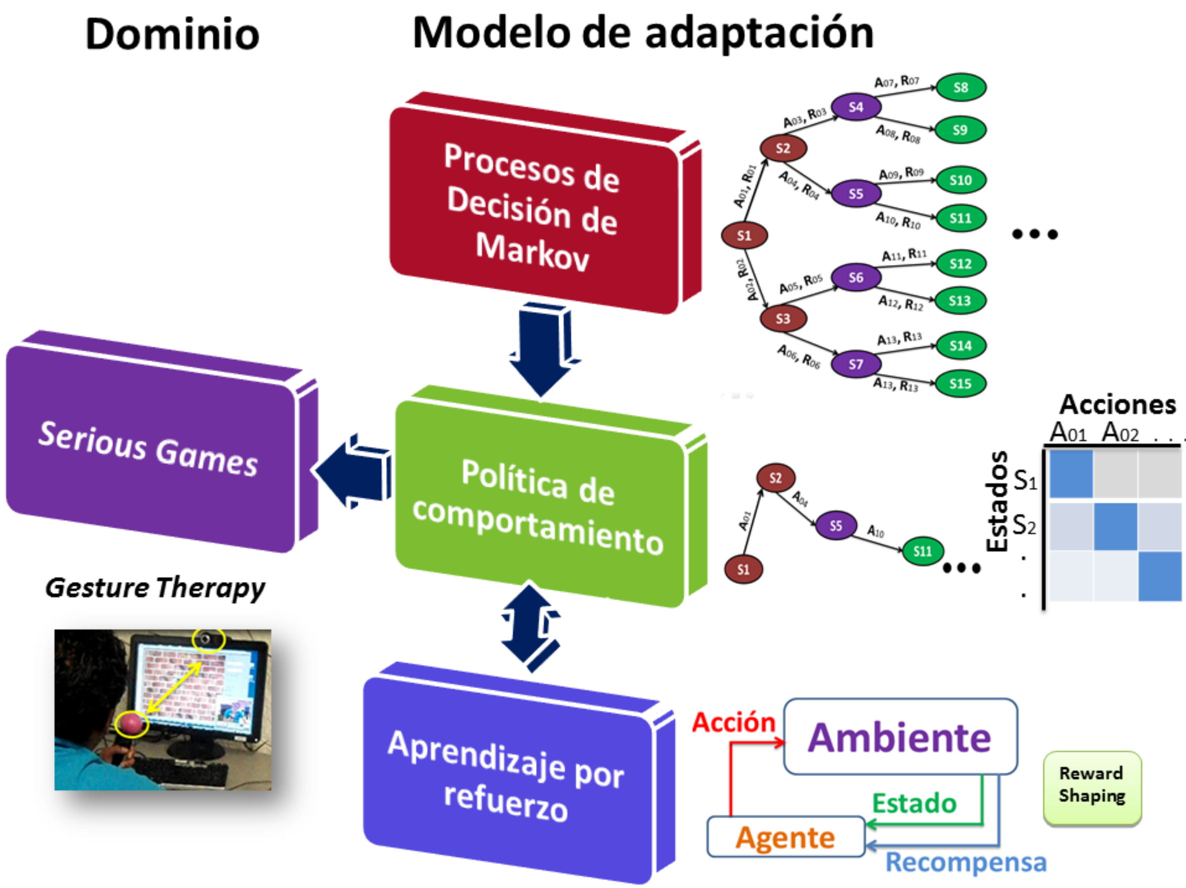
AI engine for challenge adjustment

- The case of GT

[AvilaSansores SM (2013) MSc thesis]

AI engine for challenge adjustment

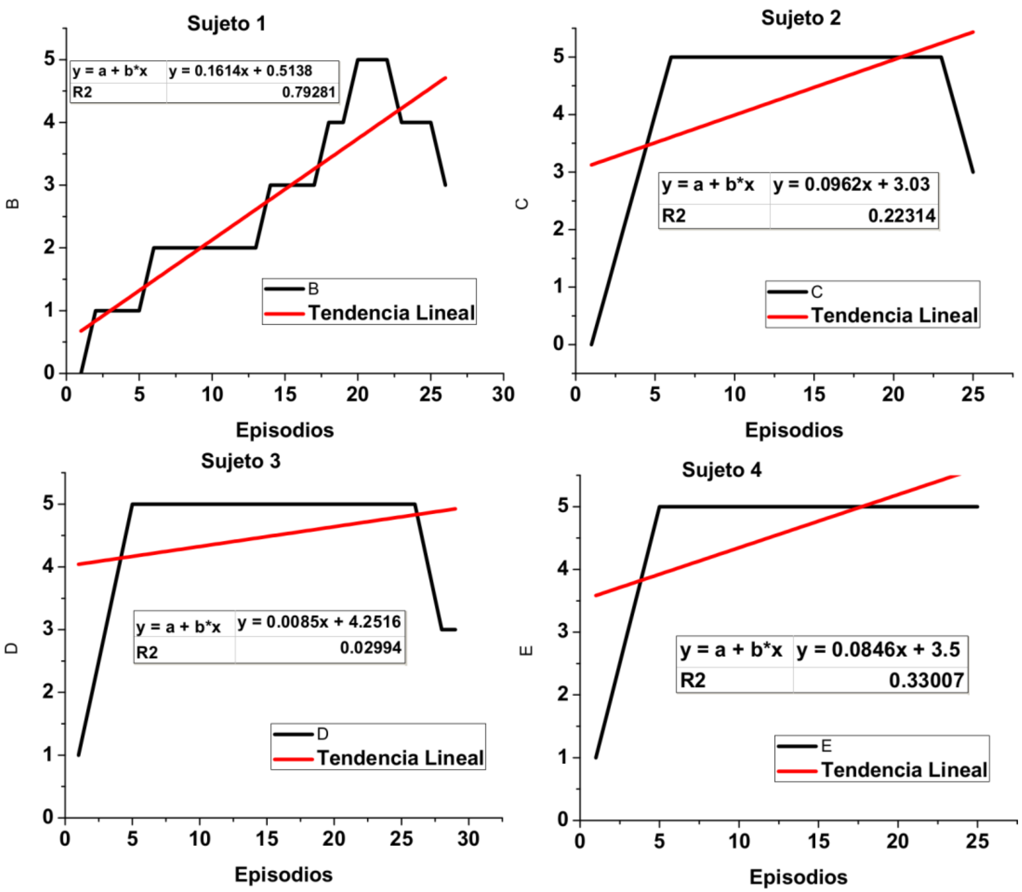
- The case of GT



[AvilaSansores SM (2013) MSc thesis]

AI engine for challenge adjustment

- The case of GT



- Matching between the AI and the experts decisions

sujeto	Porcentajes de congruencia
1	56 %
2	92 %
3	96 %
4	100 %

[AvilaSansores SM (2013) MSc thesis]

Affective Computing (AC)

- Affective Computing is the branch of computing related to encoding and decoding emotions [Picard (2003) IJHCS, 59:55-64].

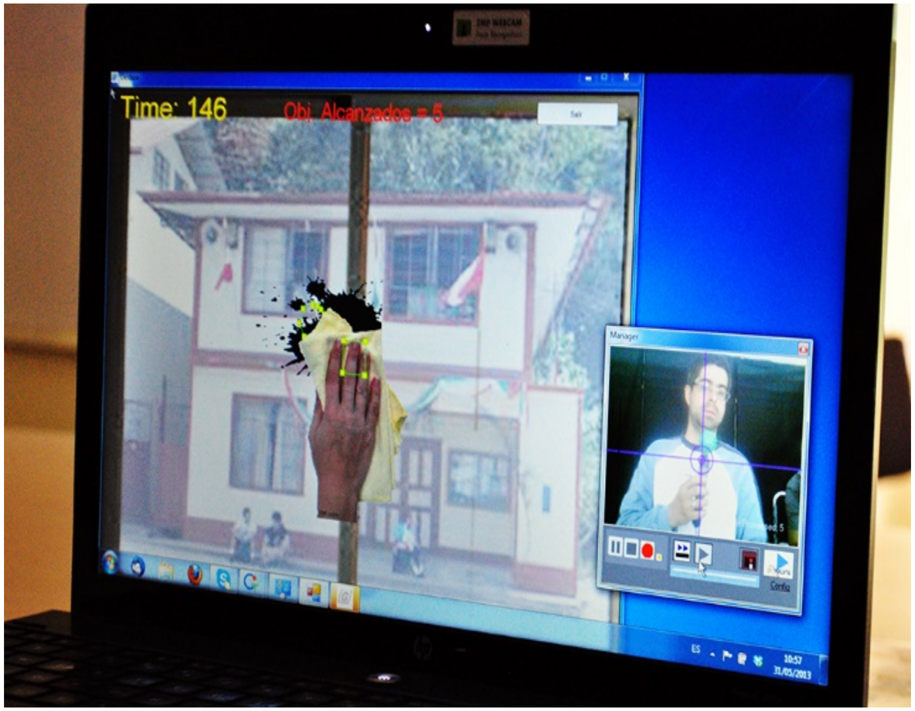
- Three channels to express emotions:
  1. audio (speech)
  2. face and body gestures/movements (visual)
  3. internal physiological changes (heart beat rate, respiration, etc).

Adaptation through Affective computing

- Mining the affective state of the user can be exploited to design motivating VR sessions.
- Our behavioural gestures may convey information about our affective state.
- Gesture Therapy (GT) is a virtual rehabilitation platform that incorporates a physical controller or gripper.

Adaptation through Affective computing

- Thus far adaptation in VR has been based on observable behaviour, e.g. speed and control.
- Now, starting to incorporate **affective computing**.
  - Supplementing adaptation strategies with cognitive and emotional inputs



Adaptation through Affective computing

- Research in affective computing has dedicated strong efforts to decode some user affective states through facial expressions, generally using the FACS (Facial Action Coding System) code [10-12], linguistic expressions [12, 13] and non-linguistic, such as laughter, sigh, cough, among others [10], tracking and monitoring human body while walking, talking, etc. [14-17].

- Many experiments focus on recognizing a set of six universal basic emotions: happiness, sadness, surprise, fear, anger and repugnance [10].

Adaptation through Affective computing

- Other efforts have been made to detect boredom, fatigue and pain from the face in recorded videos when the person has spontaneous facial expressions [19, 20].

- Aung et al. [20] studied the level of chronic pain in the lower back. In this work, experts labelled the presence of pain by observing the face of 21 patients. Then using Support Vector Machine (SVM) as the classification method, they report a ROC (Receiver Operating Characteristics) Area Under the Curve (AUC) of 0.658.

Adaptation through Affective computing

- Partially observable Markov decision process (POMDP) have been used in rehabilitation of the upper extremity in stroke patients to modify exercise parameters so that the system adapts to the patient specific needs; the patient fatigue was included in the model [21].

- In Bonarini et al. [22], the authors studied 5 levels of stress in rehabilitation protocols, from biological signals, such as blood pressure, skin conductance, electrocardiogram (EKG), respiratory rate, electrical activity of muscles (electromyogram: EMG) and temperature; with the classification algorithm k-NN (k-Nearest Neighbor) with k = 11, testing with 6 healthy people and achieving a precision (accuracy) of 88%.

Adaptation through Affective computing

- Meanwhile, for Gesture Therapy, S. Avila et al. [23] built a module based on a Markov decision process (MDP) and reinforcement learning (RL) to adapt the therapy using 2 variables: the patient speed to achieve the games targets and the control of his/her upper limb while moving to those targets. The adaptation consists in optimizing game challenge (adjust game difficulty) according to patient's performance [5]. The authors suggested as part of future work, taking into account the patient's frustration or fatigue to improve the adaptation module [23]. A difference of this work with previous research is that we are using only motion and pressure from the affected limb to infer the affective state, as we want to avoid additional sensors not already available in Gesture Therapy.

Incorporation of affective state

- Adaptation can be enriched with the consideration of emotional variables.
- Potentially (no hard evidence yet);
  - Increases motivation, and
  - Optimizes explotation of plastic changes.

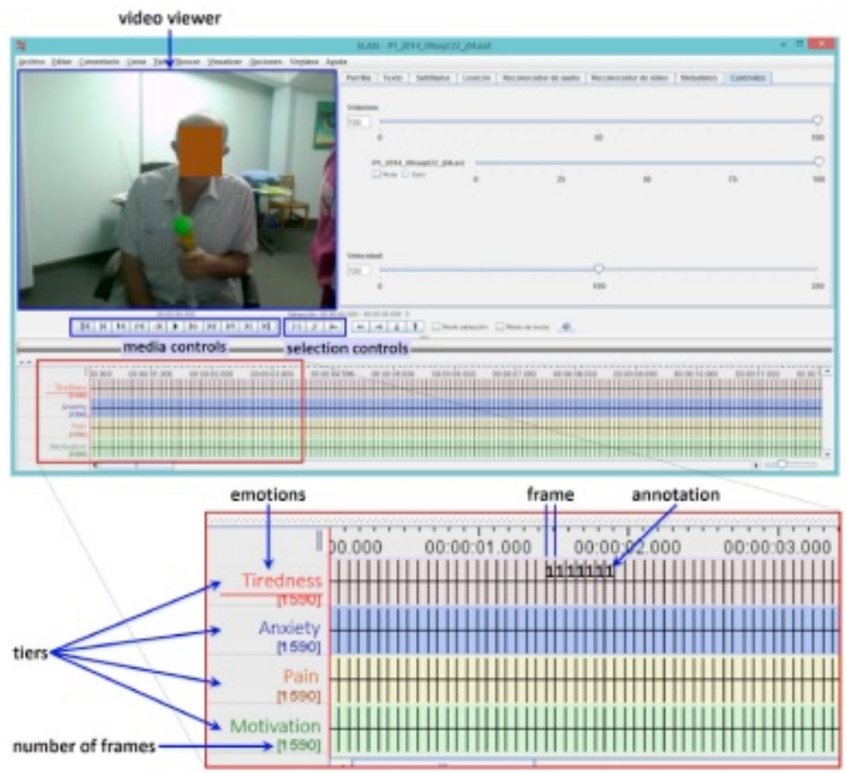


Fig. 3. Raters used ELAN to tag the interval of frames where he/she considered the patient showed an affective state: tiredness, anxiety, pain and motivation. The videos were displayed in the upper left side (in the video viewer) and the rater had the media control buttons to play, stop, go backward or forward one frame, etc. The label lines or tiers are located in the whole lower side. A coloured tier identifies each affective state and these tiers were synchronized with video frames.

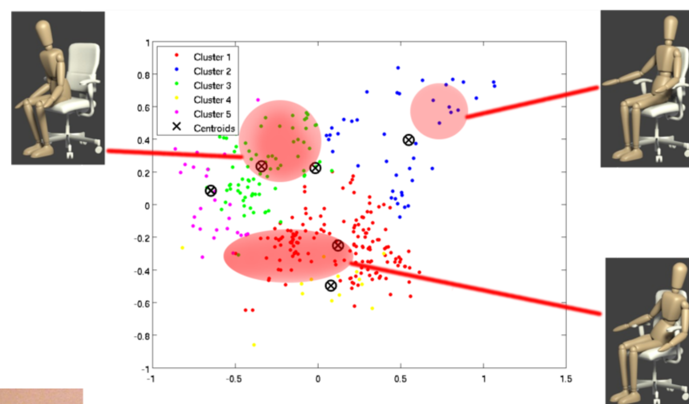
Figura de [RivasJJ2017, Submitted to IEEE TAC]

63

Understanding patient posture

- Permits modulating feedback
- Unacted posture conveys cues about people's attentional disposition
  - Body posture is an important form of human communication which tends to reflect the emotive state.
  - Static body postures can be mined for regulators communicating the attentional and affective state of subjects [EkmanP1969].

Head tilting a strong predictor of attention



[Heyer P et al (2013) PSIVT]

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CALIBRATION

Calibration

- **Calibration** refers to the ability of the system to match patient's skills (e.g. range of motion) to the virtual environment demands

- It may involve;
  - Matching patient's range of motion to maximal on-game motion range
  - Maximizing transfer from virtual to real environment

Automatic motor dexterity assessment

- Highly benefitial for home deployment
- Reduces dependency on exhaustive supervision from the medical team
- Increases objectivity in patient progress evaluation.

Figure 5.2.: Sample data capture sessions from patients at different clinical settings. Pictures blinded to mantain participants privacy

Figure from [Heyer P (2017)]

Automatic motor dexterity assessment

	Not Obtrusive	Sensor	On demand Assessment	Clinical Interpretation	Representation
Bento (I) 2011		Accel		Wolf	Time
Hester (II) 2006		Accel		FMA	Time-Vel
Quintana (III) 2008	X	Stereo camera	X	FMA, MI	HMM
Allin (IV) 2010	X	6 camera setup		Wolf	Angles
Heyer MSc thesis	**X**	**Kinect Camera Accelerometer**	**X**	**FMA**	**Unnamed**

Graph 1. Comparison table of different methods of Motor Dexterity Assessment.

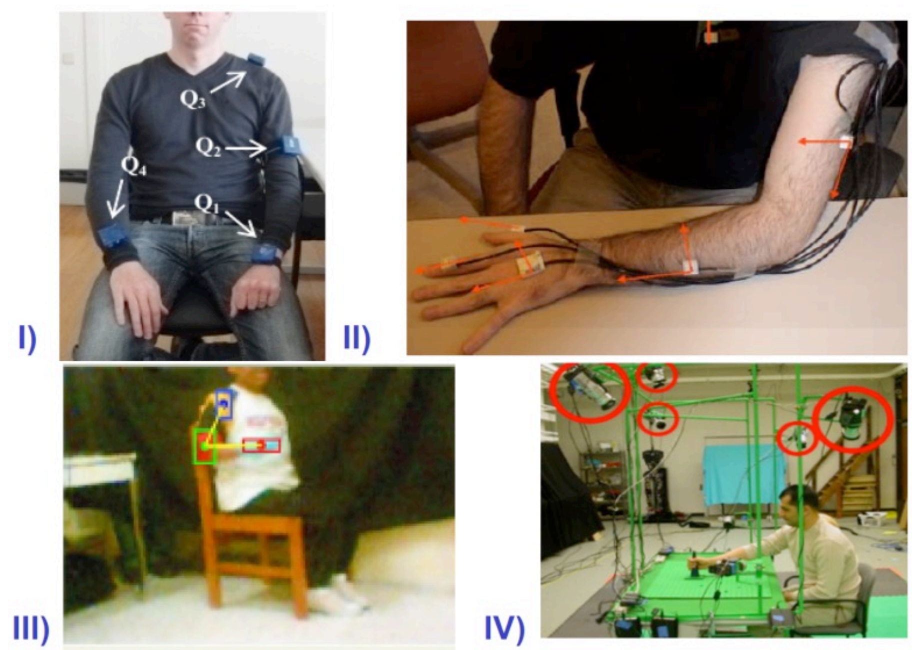


Figure 2. I) Bento setup, **II)** Hester setup, **III)** Quintana setup, **IV)** Allin setup

Figure from [Heyer P (2016) MSc thesis]

Automatic motor dexterity assessment

$$R = h \circ g \circ f(S)$$

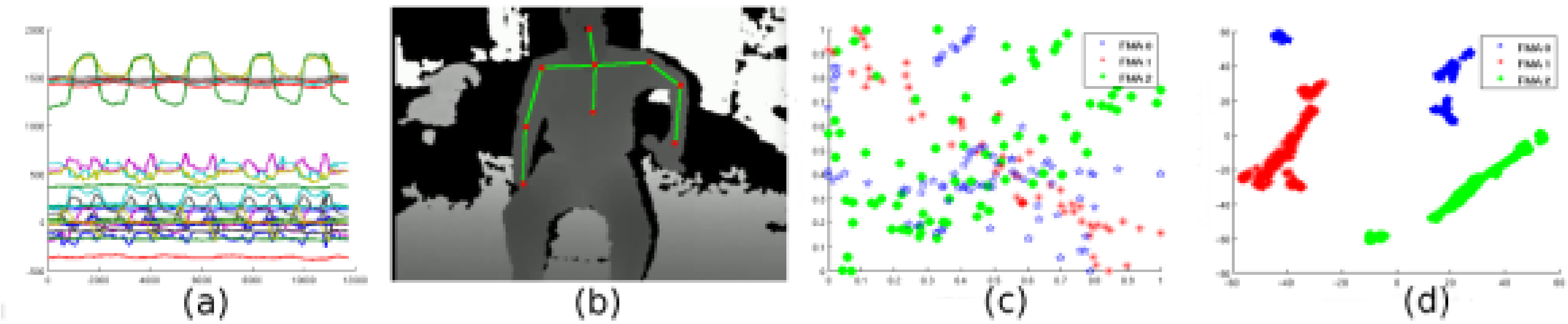


Figure 3: Function composition where: S is the sensor output, f is the transformation to project from sensor output limb-segment orientation space, g is the transformation to nullify dimensional differences in variance, h is the transformation to project to a space of salient components, R is the n-dimensional representation.

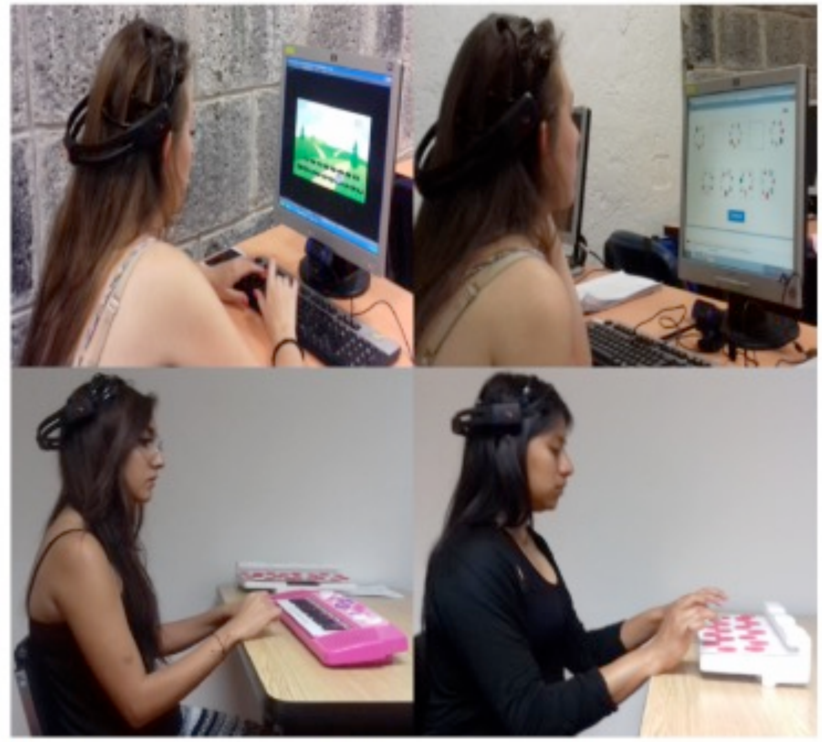
Figure from [Heyer P (2016) MSc thesis]

Autocalibration

- **PENDING**

Transfer of Knowledge

- Increase effectiveness of the VR solution
- Research on game elements adding an effective transfer
- Reduction of excessive and premature demand of clinical trials
- Reduction of development times and reuse of solutions.



(b) Entrenamiento en EVs y ER en el nivel de abstracción bajo y alto.

Figure from [Hernandez-Castañón V (2016) MSc thesis]

Transfer of Knowledge

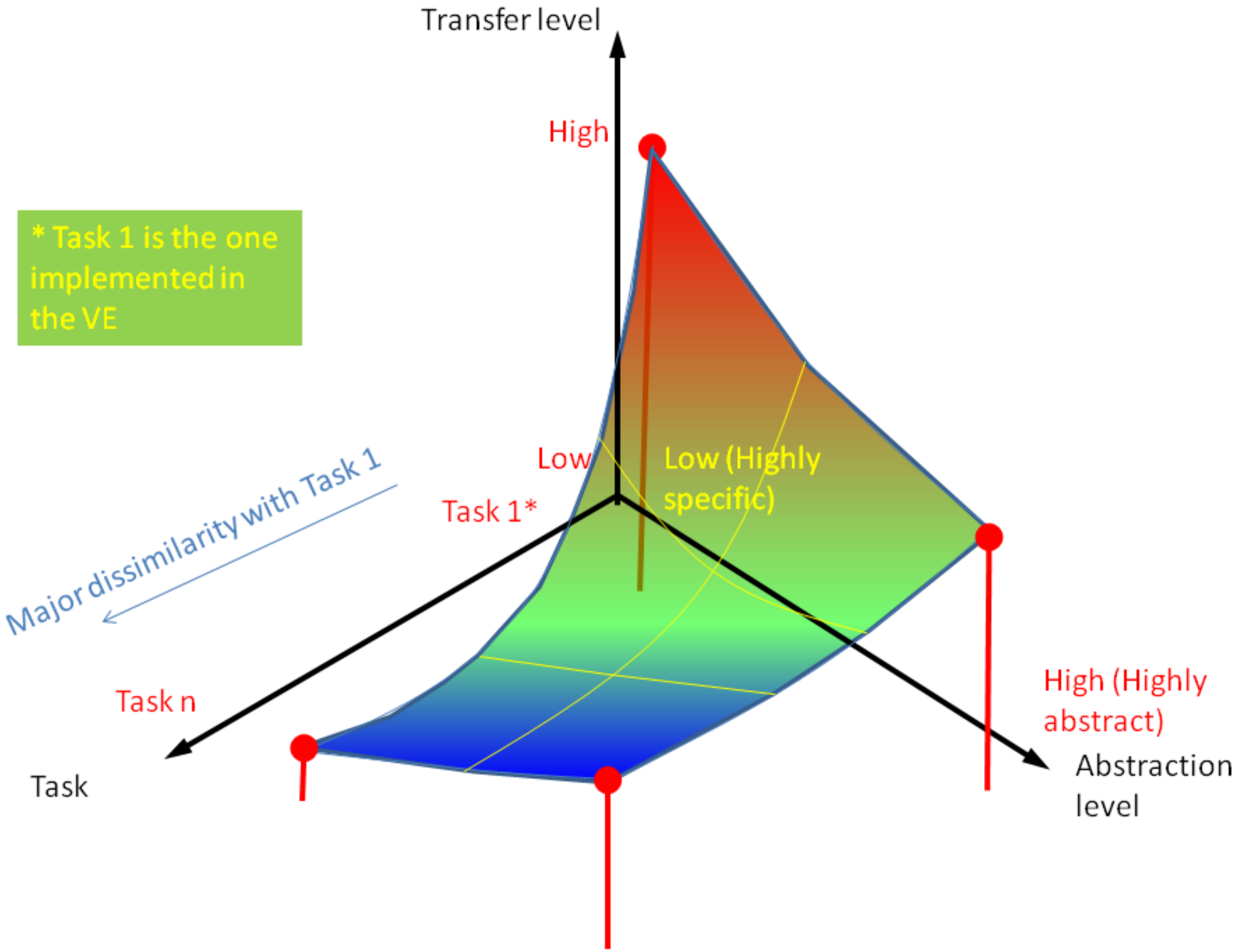


Figure from [Hernandez-Castañón V (2016) MSc thesis]

Transfer of knwoledge

Tabla 3.1 Análisis de la transferencia de conocimiento desde entornos virtuales.

REFERENCIA	EV	PROPÓSITO DE APRENDIZAJE	MEDIDA	TRANSFE-RENCIA
(Kozak et al., 1993)	Pick and place	Motora, requiere percepción, analizan repetición.	- Tiempos de respuesta - Cuestionario	Baja
(Rose et al., 2000)	Pasar arillo en alambre	Motora, coordinación en el movimiento, analizan retroalimentación visual.	-Número de errores	Alta
(Webber et al., 2001)	Baghera	Cognitiva, solución de problemas en geometría, analizan retroalimentación auditiva.	-Puntaje de éxito	Alta
(Popovici et al., 2004)	EVE para niños	Cognitiva, lectura colaborativa, analizan motivación.	- Puntaje de éxito	Rica
(Kiper et al., 2014)	Tomar objetos	Motora, realizar movimiento articulares, analizan retroalimentación reforzada.	- Escala Fugl-Meyer - Escala FIM -Velocidad y tiempos	Rica

Table from [Hernandez-Castañón V (2016) MSc thesis]

Transfer of Knowledge

EXPERIMENTAL DESIGN BETWEEN SUBJECTS

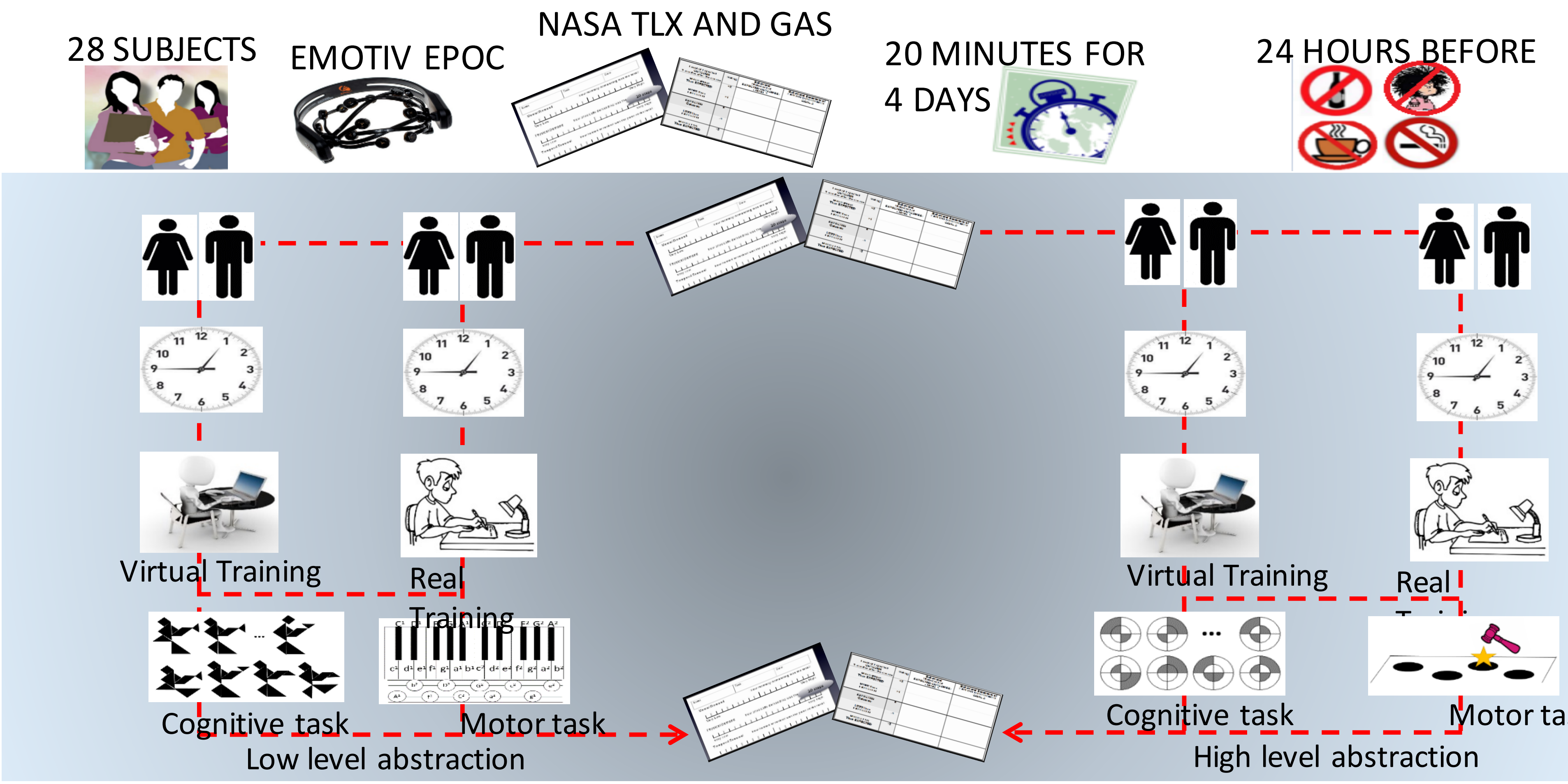
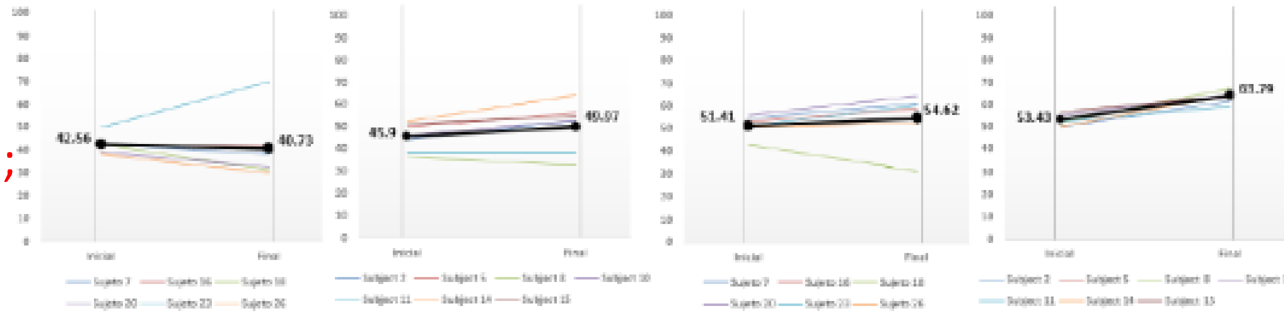


Figure from [Hernandez-Castañón V (2016) MSc thesis]

Transfer of Knowledge

Entrenamiento **virtual**; ejecución *real*



(a) Tarea cognitiva con abstracción alta.

(b) Tarea cognitiva con abstracción baja.

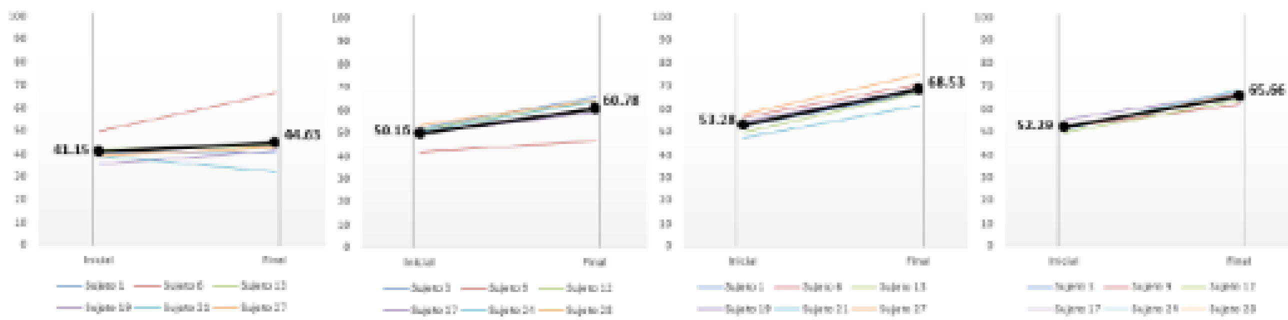
(c) Tarea motora con abstracción alta.

(d) Tarea motora con abstracción baja.

Figura 5.7 Logro de objetivos (GAS) para el grupo con entrenamiento virtual y ejecución real de la tarea cognitiva y motora a diferentes niveles de abstracción. Las líneas de color indican rendimientos individuales y la negra el promedio del grupo.

Similar trends in 3 out of 4 plots. Amplitude differs indicative of some but not full transfer

Entrenamiento **real**; ejecución *real*



(a) Tarea cognitiva con abstracción alta.

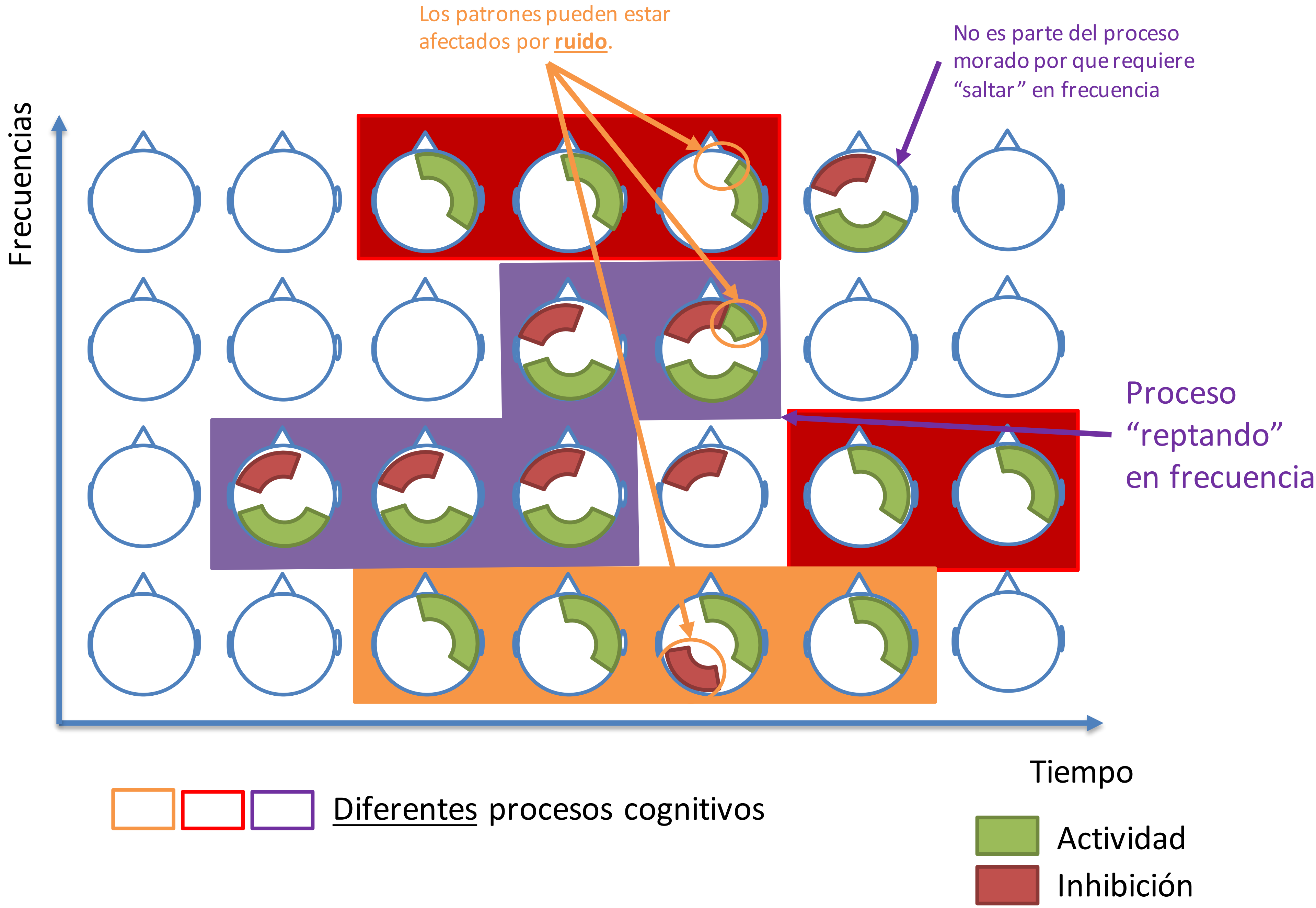
(b) Tarea cognitiva con abstracción baja.

(c) Tarea motora con abstracción alta.

(d) Tarea motora con abstracción baja.

Figura 5.8 Logro de objetivos (GAS) para el grupo con entrenamiento y ejecución real de la tarea cognitiva y motora a diferentes niveles de abstracción. Las líneas de color indican rendimientos individuales y la negra el promedio del grupo.

Ejemplo de patrones de procesos cognitivos



Transfer of Knowledge

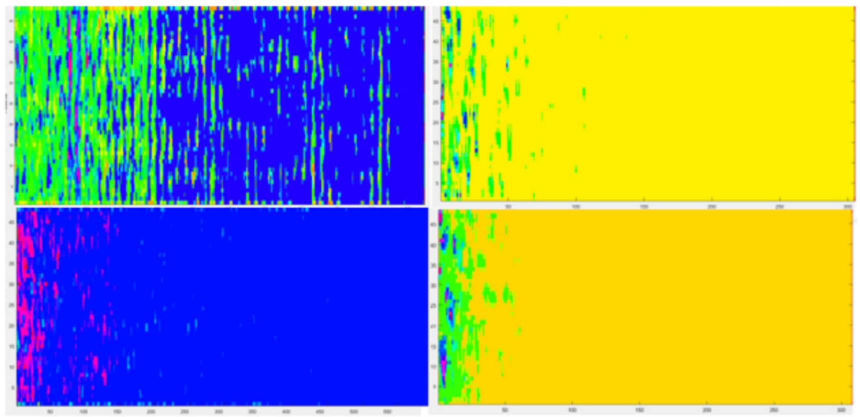


Figura 5.16 Segmentaciones de las señales de EEG en el entrenamiento con EVs. Los mapas superiores corresponden a los procesos cognitivos de la tarea cognitiva con alta abstracción y los mapas inferiores a los de la tarea con baja abstracción. Del lado izquierdo están los mapas del primer dia de entrenamiento y del lado derecho la ejecución (ER) de la tarea (después de tres días de entrenamiento). Los colores identifican diferentes regiones frecuencia-tiempo donde se han localizado los diferentes procesos cognitivos detectados. No obstante la diferencia de colores es arbitraria y no representan alguna característica, siendo el único objetivo del color resaltar la presencia y la magnitud de los procesos cognitivos. Además, grupos de patrones poco extendidos en tiempo y/o frecuencia se han filtrado (filtro de la mediana) para facilitar la interpretación. Es posible que estos grupos de patrones más compactos puedan estar asociados a regiones frecuencia-tiempo no utilizadas por el cerebro bajo la estimulación dada.

Figure from [Hernandez-Castañón V (2016) MSc thesis]

BALANCE

Balance

- **Balance** is concerned with handicapping players playing together so to ensure fair level of challenge.
  - e.g. A healthy relative playing an impaired subject
  - Balancing [Gerling et al (2014). CHI pgs 2201-2210] is a mechanism to automatically adjust players' handicap to promote fair playing.
    - Balacing assists weaker players

Balance

Figure 2. Study setup for able-bodied players and players in wheelchairs (left) and able-bodied dyads (right).

[Gerling et al (2014). CHI pgs 2201-2210]

Balance

- Balanced competitions increases fun [Bateman et al (2011) in Gerling2014]

- Balancing machanisms [Gerling2014];
  - Handicapping – players abilities are estimated and scored adjusted accordinggly (e.g. golf, chess)

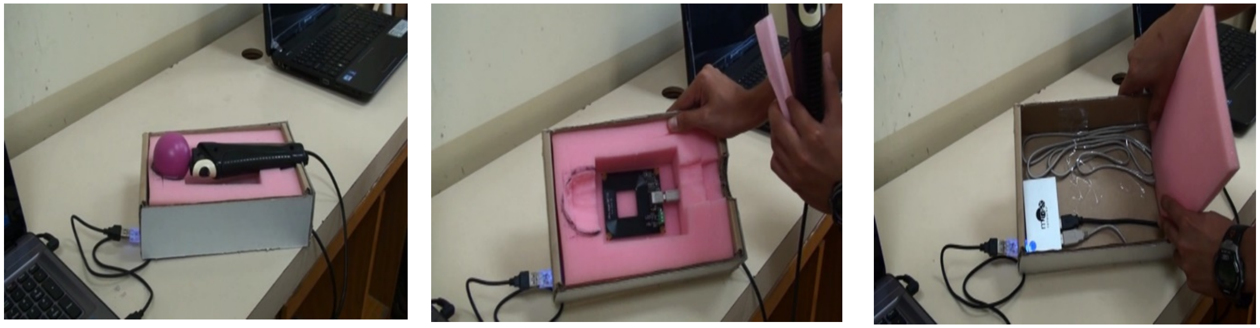
  - Dynamic difficulty adjustments – enforcing of maximal differences (e.g. mario karts). In turn, can be implemented by:
    - Step count – e.g. varying the necessary number of hits for success
    - Hit Interval – e.g. allowing different sized targets (spatial) or less precise timings (temporal)
    - Score multiplier – e.g. affording different scoring scales
    - Others?

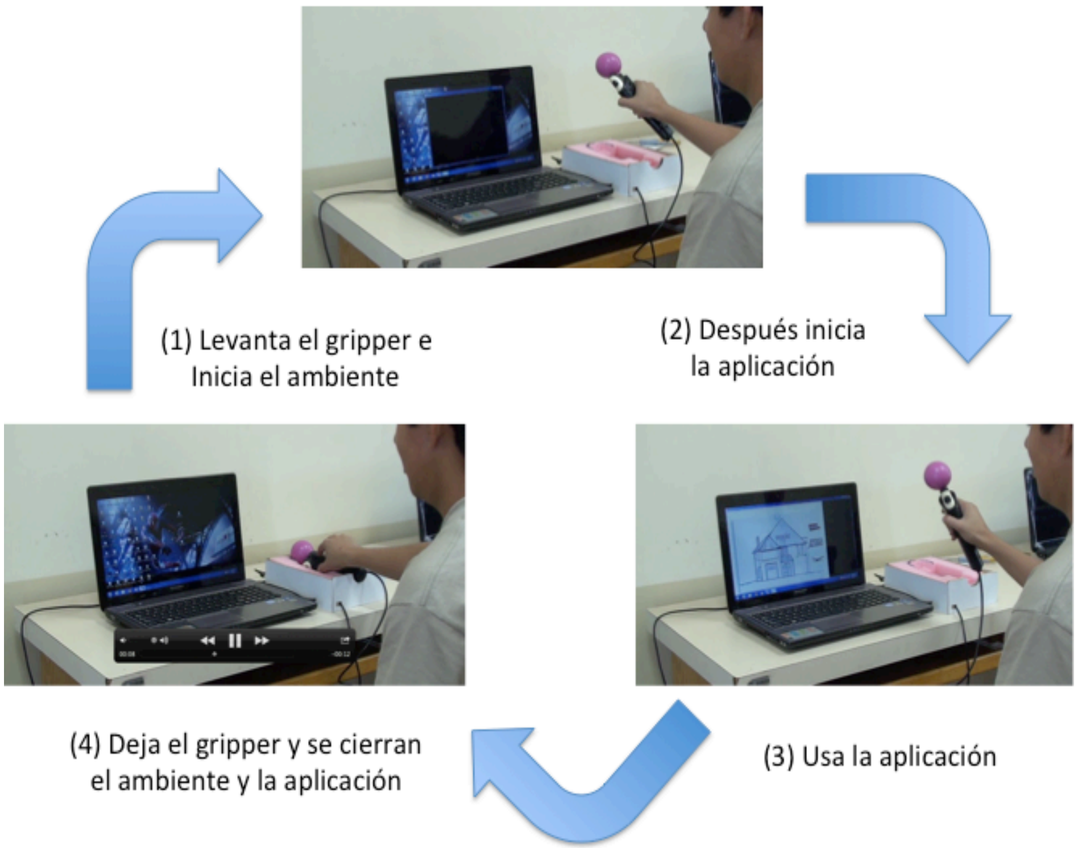
Balance

- Challenges in balancing games;
  - Innate ability of players
  - Differences in practice or fitness levels (e.g. profesional vs amateur)
  - Stigma (e.g. height differences in basketball)
  - Ability (e.g. able bodied vs impaired bodied)

[Gerling et al (2014). CHI pgs 2201-2210]

Automatic recognition of user identity





Automatic recognition of patient using RFID technology

Instituto Nacional de Astrofísica, Optica y Electrónica

DESIGN OF ENVIRONMENTS

Design Factors of Virtual Rehabilitation

Table 1: Checklist of criteria/guidelines for robotic and sensor rehabilitation technology, based on motor learning principles

Criteria related to therapy approaches

- Training should address function, activity and participation levels by offering strength training, task-oriented/CIMT training, bilateral training.
- Training should happen in the natural environmental context.
- Frequent movement repetition should be included.
- Training load should be patient and goal-tailored (differentiating strength, endurance, co-ordination).
- Exercise variability should be on offer.
- Distributed and random practise should be included.

Criteria related to motivational aspects

- Training should include fun & gaming, should be engaging
- The active role of the patient in rehabilitation should be stimulated by:
  - m therapist independence on system use.
  - m individual goal setting that is guided to be realistic.
  - m self-control on delivery time of exercise instructions and by feedback that is guided to support motor learning.
  - m control in training protocol: exercise, exercise material, etc.

Criteria related to feedback on exercise performance

- KR (average & summary feedback) and KP should be available (objective standardized assessment of exercise performance is necessity).
- Progress Components:
  - m fading frequency schedule (from short to long summary/average lengths)
  - m from prescriptive to descriptive feedback
  - m from general (e.g. sequencing right components) to more specific feedback (range of movement, force application, etc)
  - m from simple to more complex feedback (according to cognitive level).
- Empty time slot for performance evaluation before and after giving feedback.
- Guided self-control on timing delivery feedback.
- Feedback on error and correct performance.

[Timmermans et al (2009), JNER 6:1]

Design Factors of Virtual Environments for Upper Limb Motor Rehabilitation of Stroke Patients

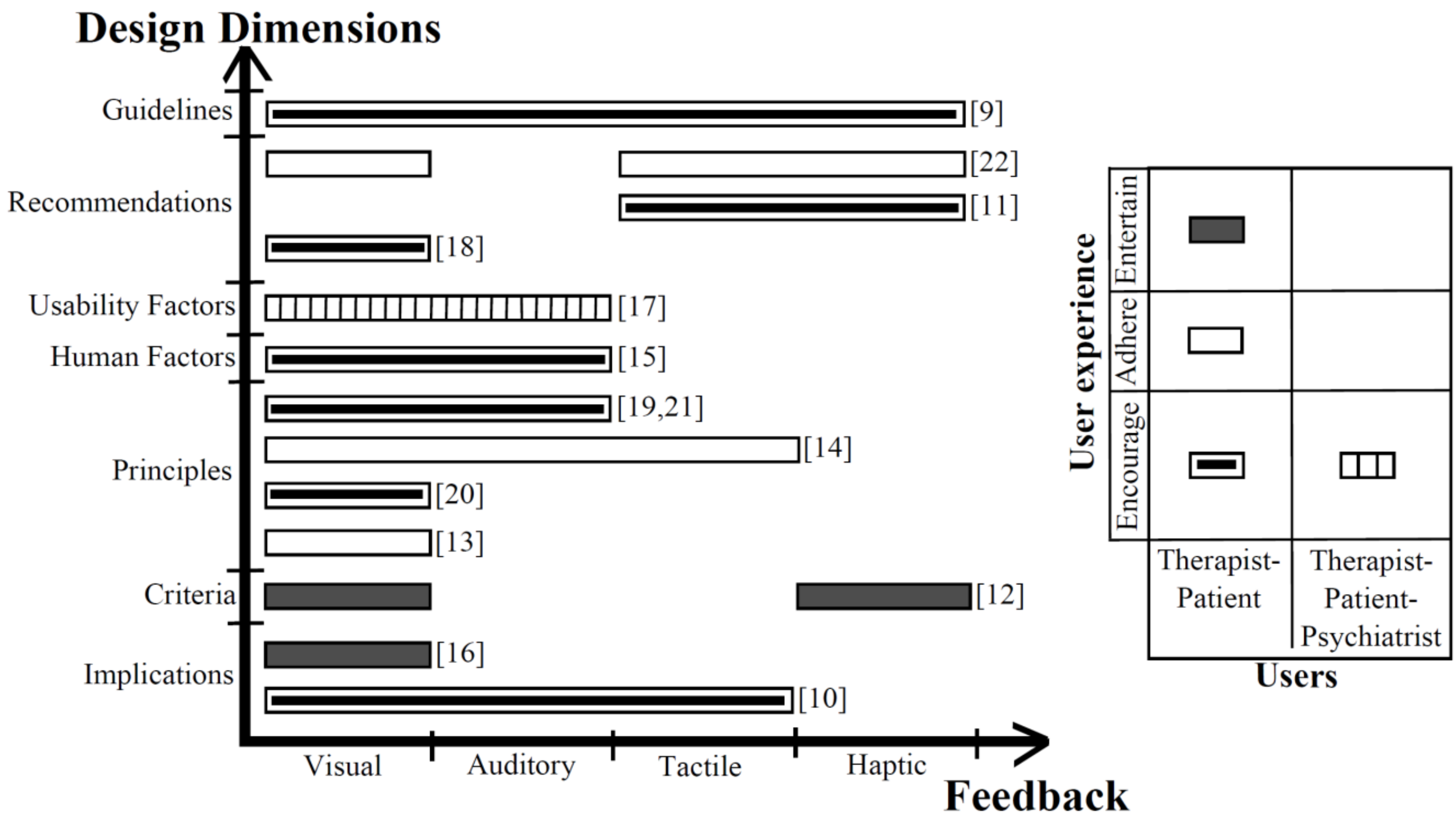


Figure 1: Design recommendations for upper limb motor therapy.

[RamirezFernandez C et al (2014) MexIHC]

Design Factors of Virtual Environments for Upper Limb Motor Rehabilitation of Stroke Patients

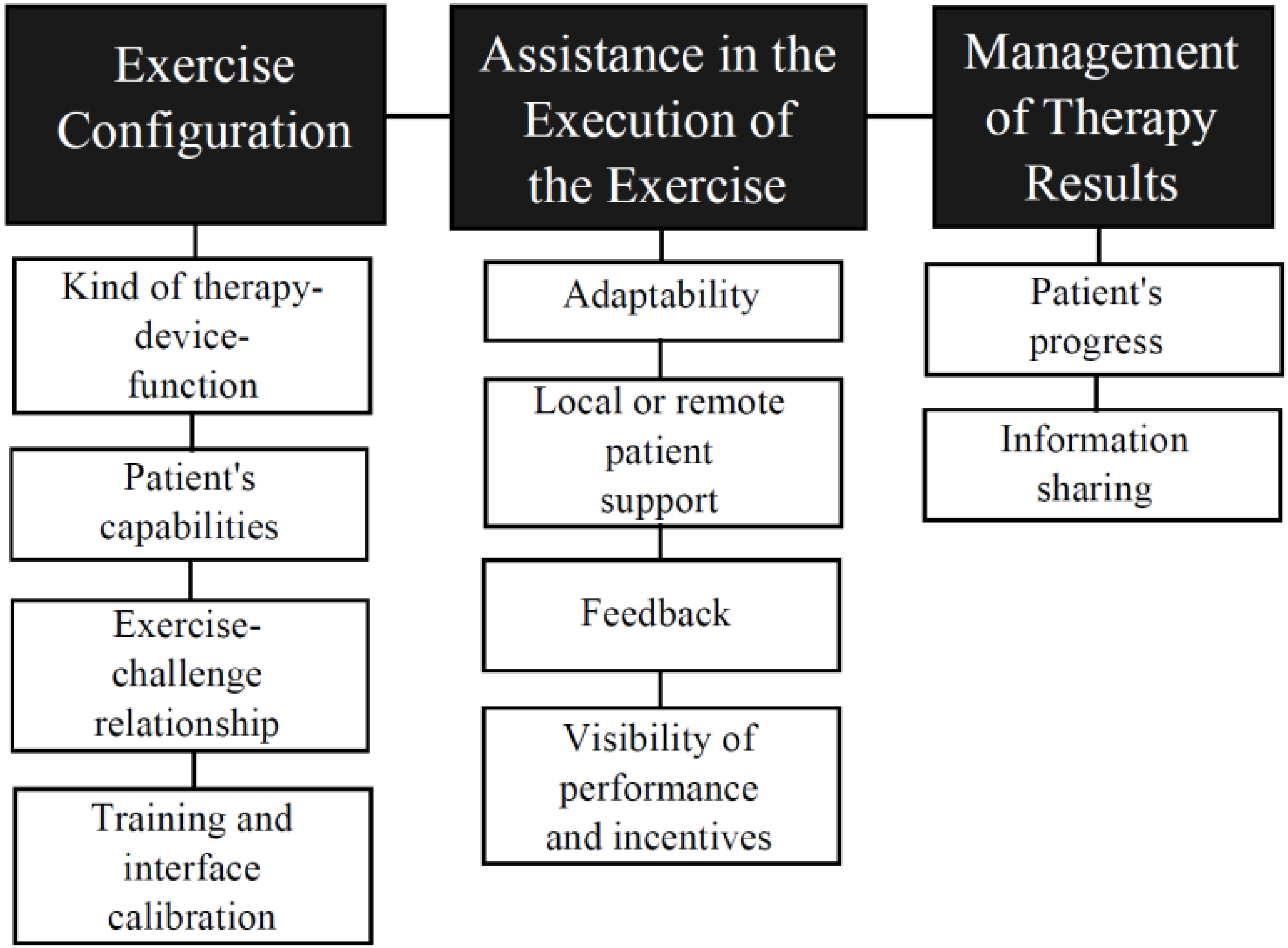


Figure 2: Taxonomy of factors for the design of VEs for upper limb motor rehabilitation.

[RamirezFernandez C et al (2014) MexIHC]

Virtual Rehabilitation

- Tens of solutions in literature by now
- Differences in games, controllers, feedback, adaptive elements, etc

Figure from: [http://compassmag.3ds.com/1/Research/IMMERSIVE-VIRTUAL-REALITY]

Motivation

- VR has not yet fully achieved its potential; possible factors include:
  - Poor understanding of the neurorehabilitation process itself
  - Poor knowledge of the mechanism behind transfer of knowledge
  - Poor integration between multidisciplinar (additive) and transdisciplinar (holistic) elements

- Because of the above; game development for virtual rehabilitation still not a smooth process.
  - Need of designing consistent, reusable and clinically valid games for rehabilitation in a faster, simpler, and more efficient manner.

- Design frameworks can
  - speed up the development process,
  - Improve integration: facilitate communication between technicians and clinicians, and
  - Maximize transfer of knowledge: boost chances of clinical effectiveness.

State of the art (not comprehensive)

Reference	Demands covered	Comments
[Flores et al (2004)]	User demands	Centered on elder
[Weiss et al (2006)]	Platform demands	Focus on enhancing presence
[Timmermans et al (2009)]	Therapy, motivational and feedback demands	Focus on robotics rehab.
[Aviles Arriaga et al (2011)]	Social and user demands	
[Saini S et al (2012)]	Technical demands	Structural requirements for low cost platforms
[Oropeza Salas (2012)]	Social, clinical and user demands	Separation of demands unclear
[Ramírez Fernández et al (2014)]	Usability demands	Separation of usability stages. Focus on upper limb.

State of the art summary

- Demands from medical, technical and user centered perspectives have thus far guided the development of these systems.

- Designing a single game complying with all the suggested principles remains unsolved

- Demostration of gains/improvements obtained by using design guidelines/frameworks whether for the
  - Engineering team e.g. reduction in developing time, reduced errors
  - Clinical team e.g. reduced supervision demands
  - Patient e.g. higher therapeutic value,

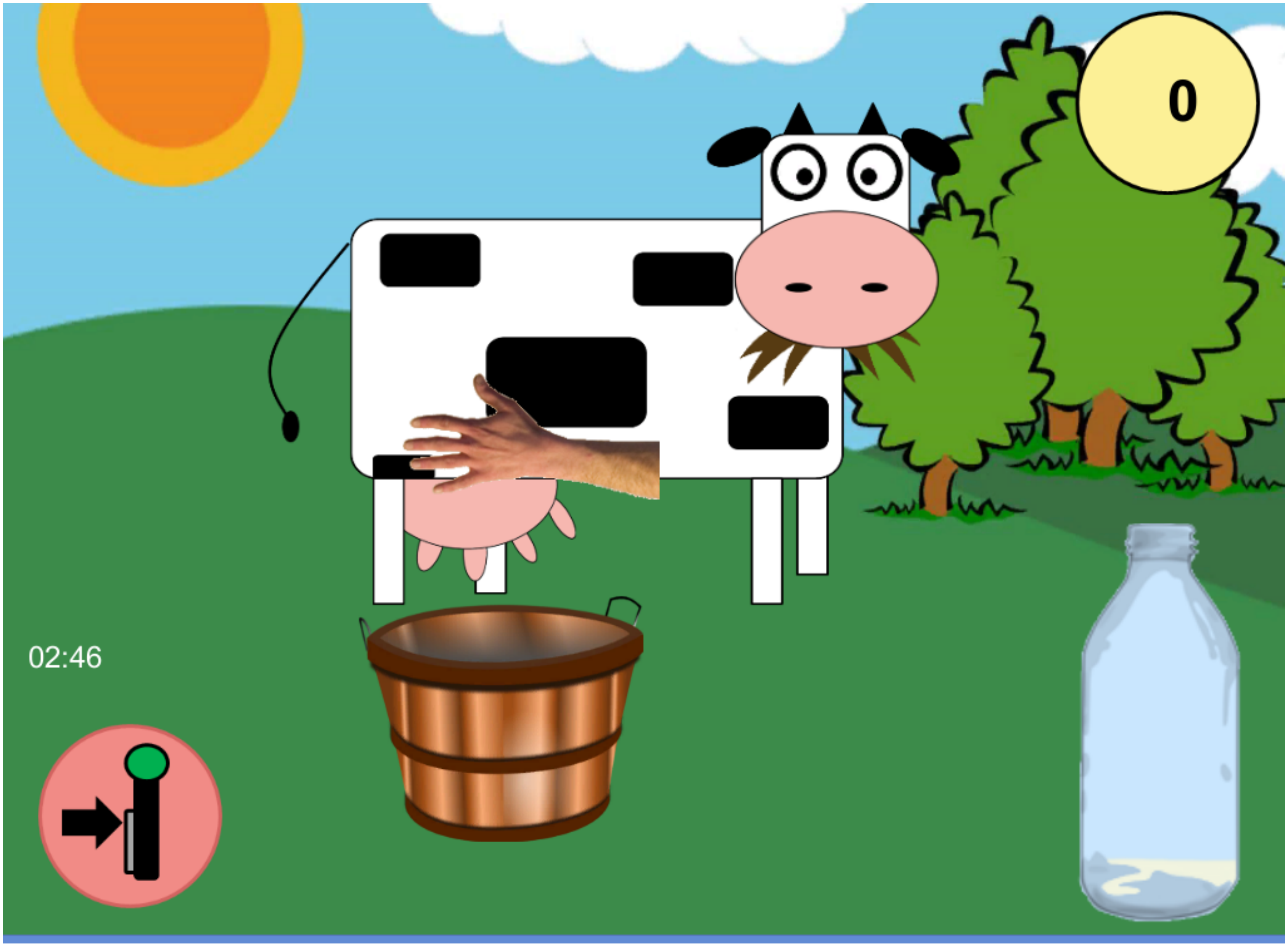
…remains uncharted territory

Concepts, Objects, Mechanics, Feedback and DYnamics

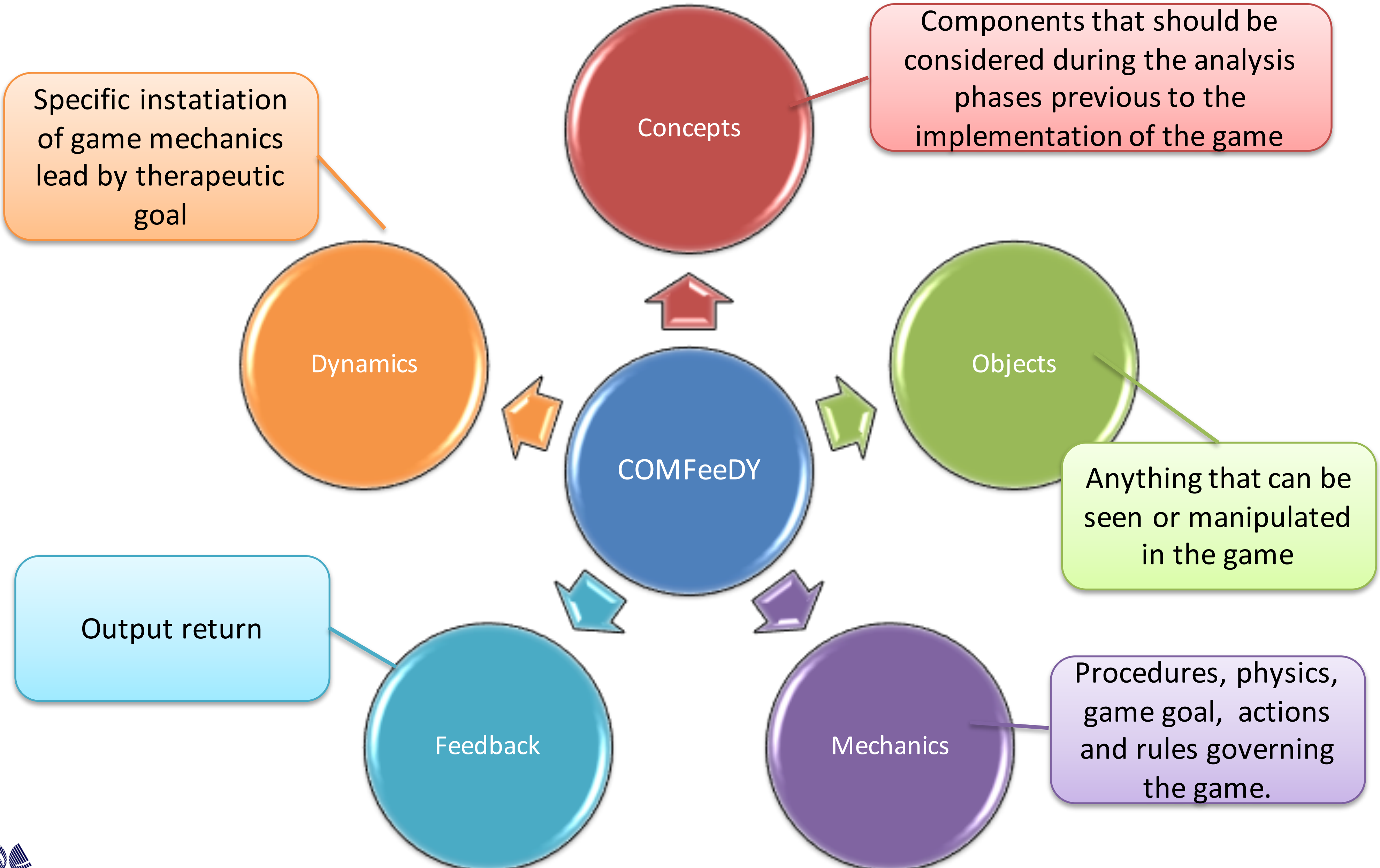
THE COMFEEDY FRAMEWORK

[GarciaMartinez S et al (2015) ICVR]

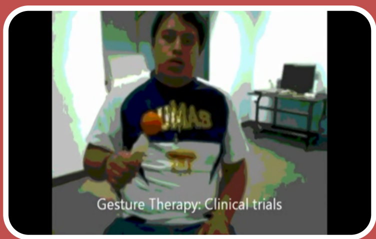
The working example



The framework in a nutshell



Concepts

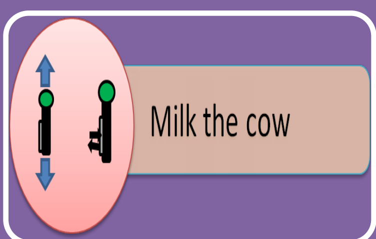


Patient / Player

- Demographics, Cultural and etnographical, Medical condition, Gaming preferences, Interests

Movements and their virtual mapping

- Depends on input device



Game goals and Value

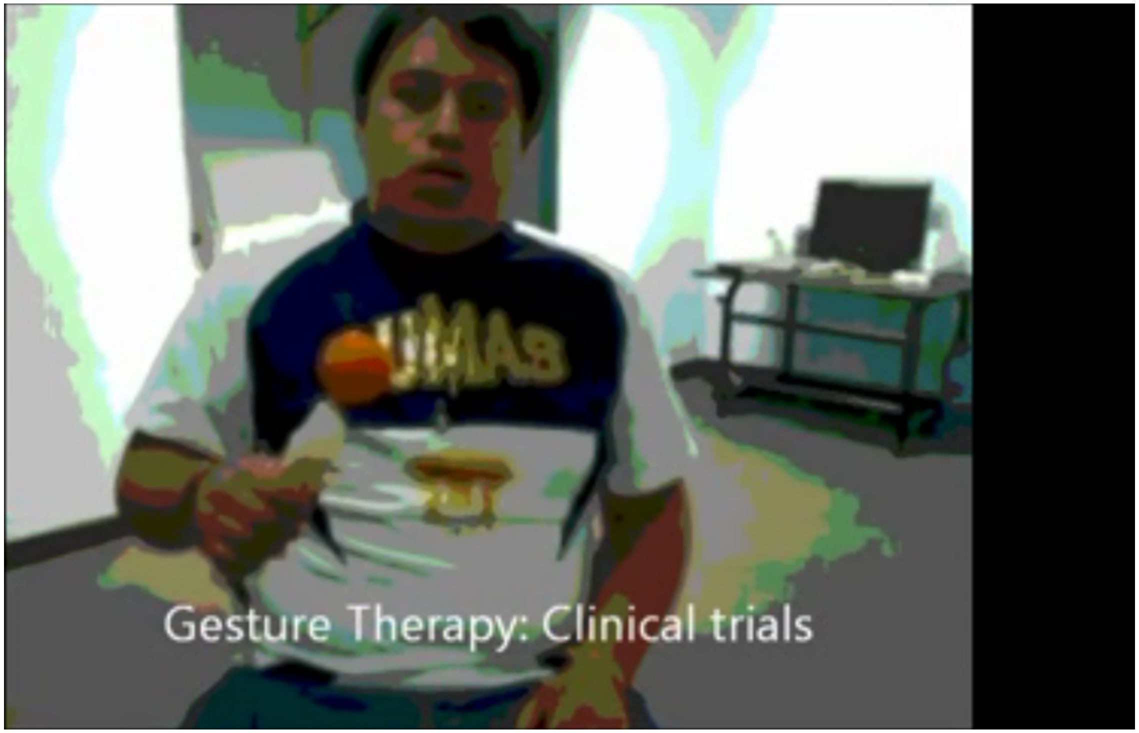
- Two perspectives;
  - Rehabilitation: Aims for therapeutic value
  - Implementation: Aims for simple, clear, concrete, well balanced, achievable and rewarding gamification of tasks

Story

- Sequence of events that unfold in the game
- Games "tell a story"
- Summarized in the storyboard

Concepts

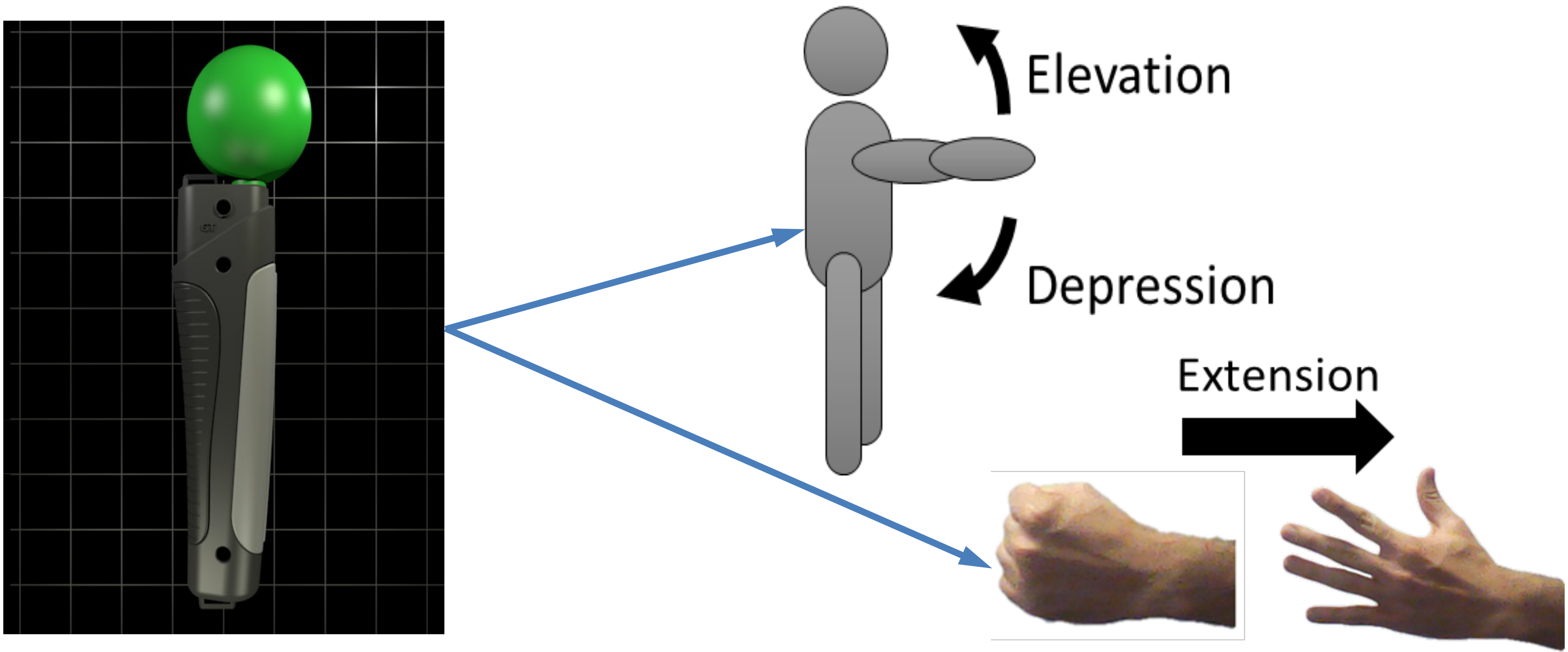
- **Player / Patient**



- Demographics
- Cultural and etnographical
  Medical condition
  Gaming preferences
  Interests

Concepts

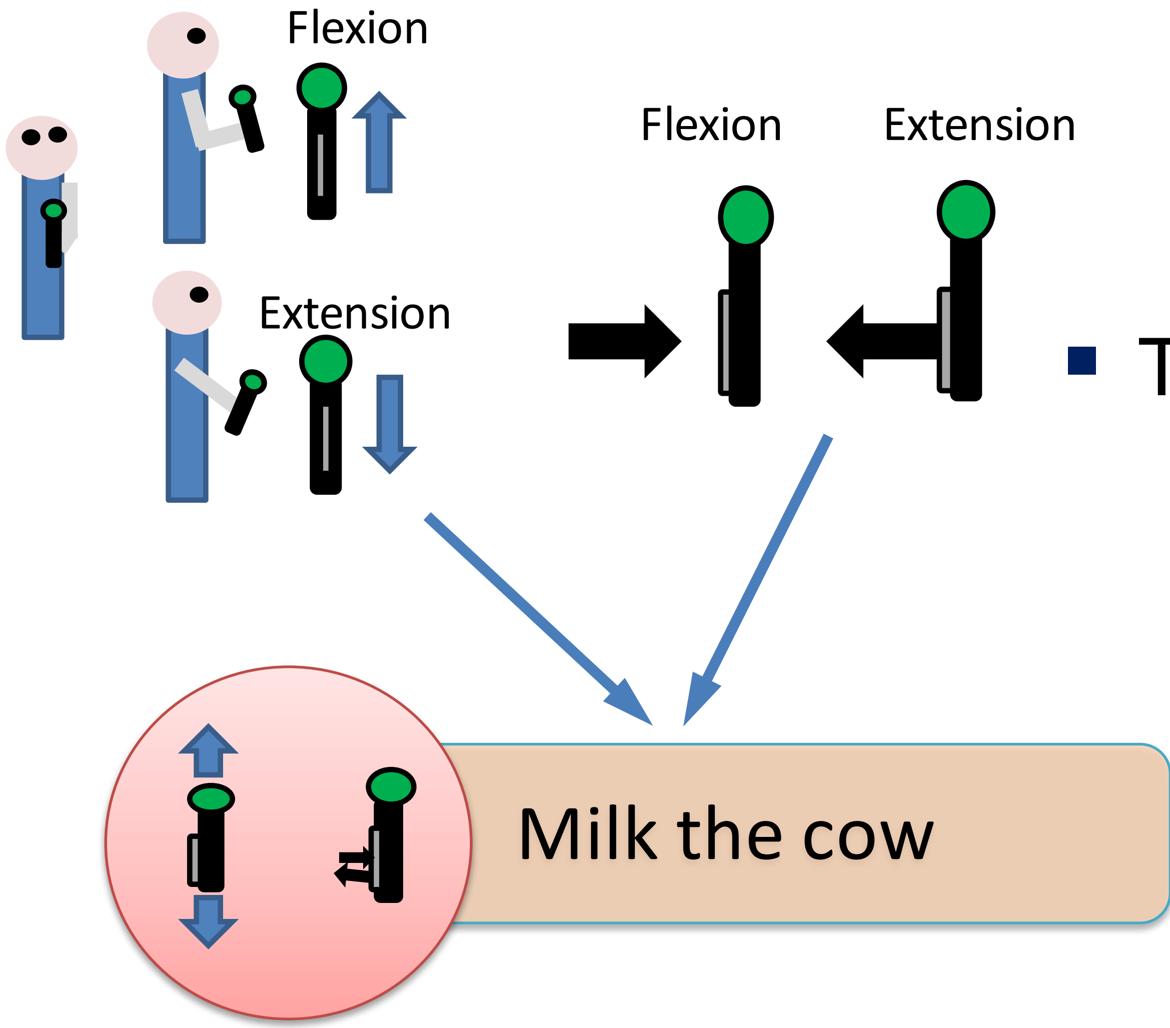
- **Movements and their virtual mapping**



  - Depends on input device

Concepts

- **Game goals and Value**

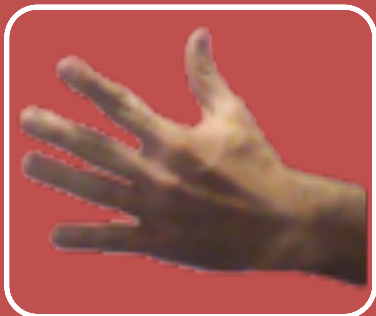


- Two perspectives;
  - Rehabilitation (therapeutic value)
  - Implementation (gamification of tasks)

Concepts

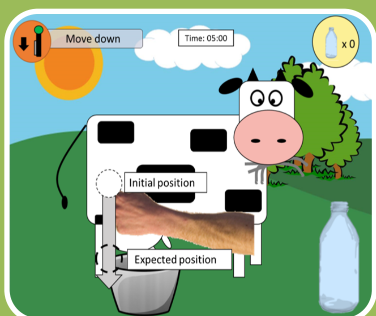
- **Story**
  - Sequence of events that unfold in the game

Objects



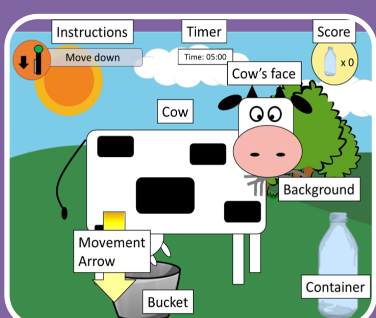
Avatars

- Representation of the player in the game
- Player's identity
- Visual connection and meaningful experience



Targets

- The aim of actions from the user
- Static or moving
- Initial location fixed or random



Distractors

- Elements not interacting with the user
- May affect the game mechanics or be purely decorative.
- Some may be informative e.g. scoreboards

Objects

- **Avatars**

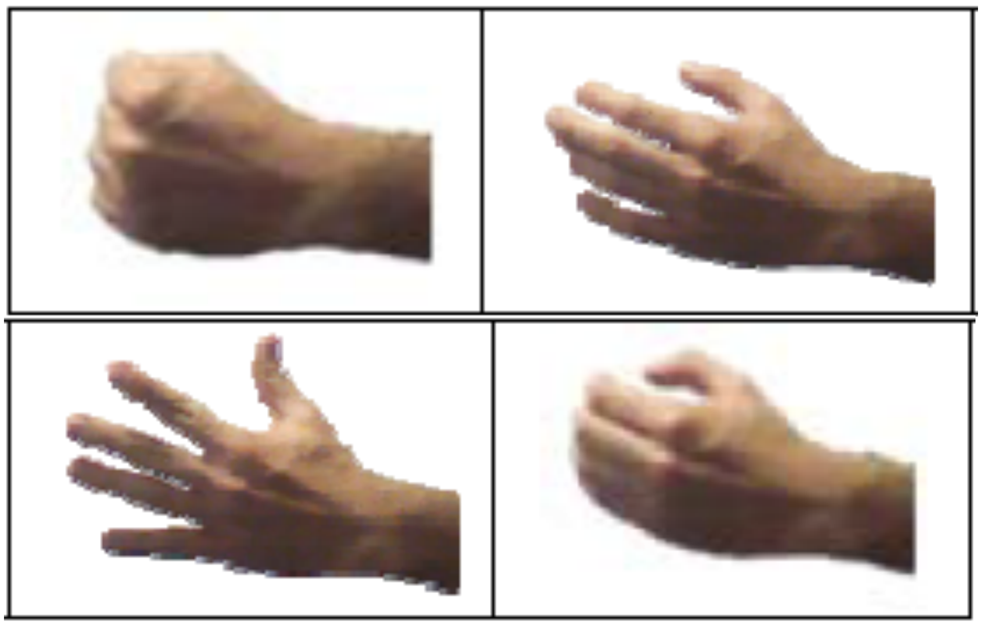
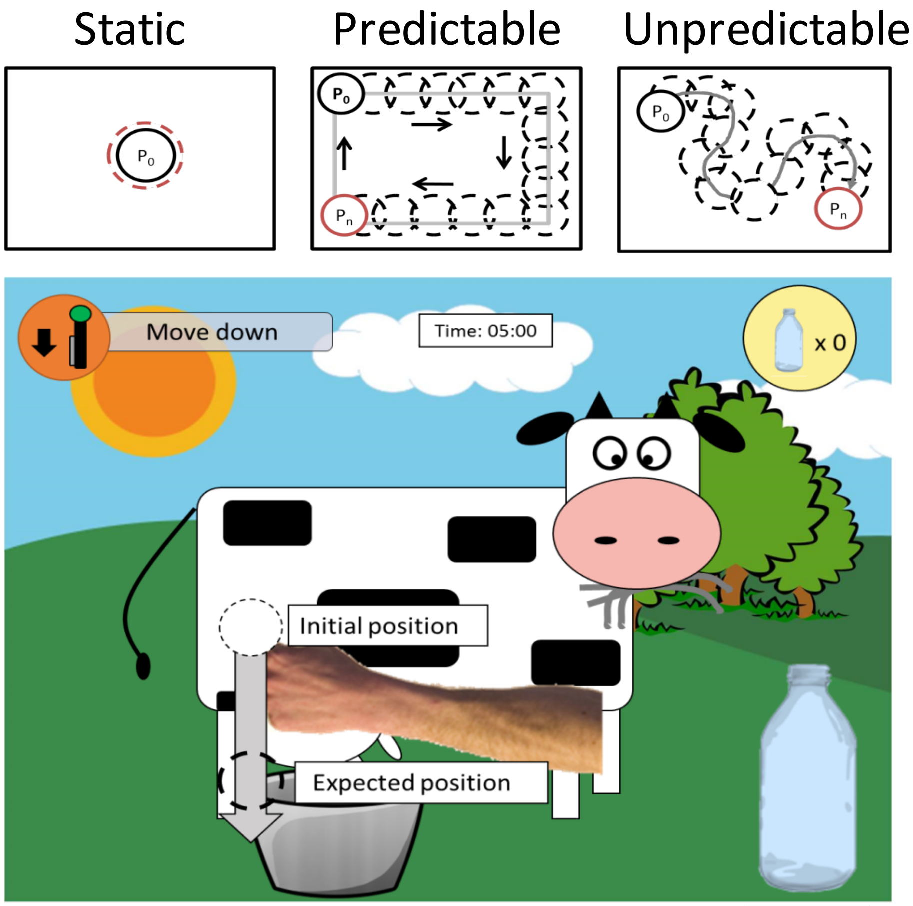


Figure 4. Avatar animation for opening and closing grip.

- Representation of the player in the game
- Player's identity
- Visual connection and meaningful experience

Objects

- **Targets**

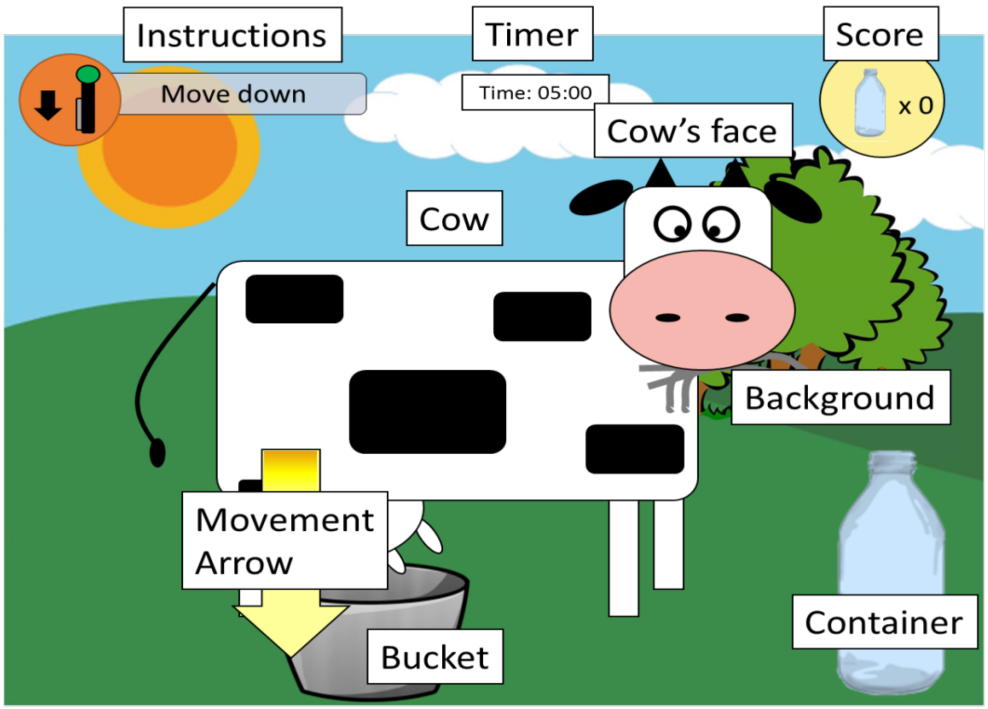


- The aim of actions from the user
- Static or moving
- Initial location fixed or random

Use of a static target in the Milk the cow game example. a static target is used. However, the target location changes depending on the stage of the milking maneuver.

Objects

- **Distractors**



- Elements not interacting with the user
- May affect the game mechanics or be purely decorative.
- Some may be informative e.g. scoreboards

Mechanics

Actions

Action	Movements
Reach top of the teat	Move avatar towards the initial target.
Grasp teat	Close hand within predefined pressure limits.
Reach the bottom of the teat	Move avatar towards the end target.
Release teat (getting milk)	Open hand until reaching the desired extension degree

Table 1. Actions in the Milk the Cow game

- Verbs of the game
- In Rehabilitation: Reach, Grasp, Release, Manipulate, Coordination

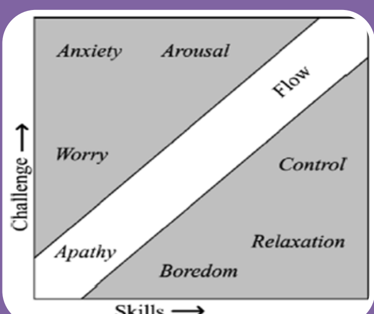
Rules

Rule	Description
Milking	A milking maneuver requires; the user has to reach the top of the teat, grasp it, move the avatar to the bottom of the teat while pressing it and, finally, to release it.
Fill a bottle.	To fill a bottle, it is necessary to execute the milking maneuver five times.
Time	The session lasts 3 minutes by default (although this is a configurable parameter).
Game over	The game ends after the time is over.
Cow's Mood	If the user is not milking the cow properly, she gets angry. Otherwise, she is happy.

Table 2. Milk the Cow - Rules

- Responsible for physics, behaviour, and association of outcomes to player actions

Challenge and progress



- Responsible for matching player skills, needs and limitations
- Maybe artificial intelligently guided

Mechanics

- **Actions**

Action	Movements
Reach top of the teat	Move avatar towards the initial target.
Grasp teat	Close hand within predefined pressure limits.
Reach the bottom of the teat	Move avatar towards the end target.
Release teat (getting milk)	Open hand until reaching the desired extension degree

Table 1. Actions in the Milk the Cow game

- Verbs of the game
- In Rehabilitation:
  - Reach
  - Grasp
  - Release
  - Manipulate
  - Coordination

Mechanics

- **Rules**

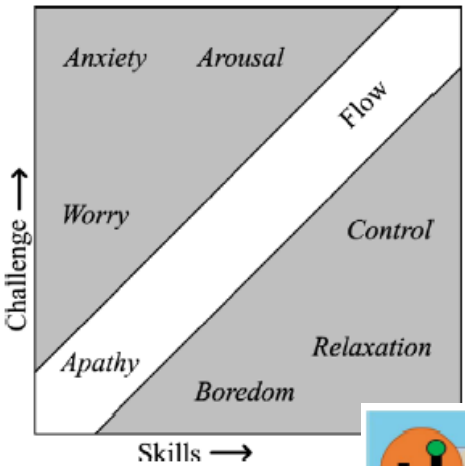
Rule	Description
Milking	A milking maneuver requires; the user has to reach the top of the teat, grasp it, move the avatar to the bottom of the teat while pressing it and, finally, to release it.
Fill a bottle.	To fill a bottle, it is necessary to execute the milking maneuver five times.
Time	The session lasts 3 minutes by default (although this is a configurable parameter).
Game over	The game ends after the time is over.
Cow's Mood	If the user is not milking the cow properly, she gets angry. Otherwise, she is happy.

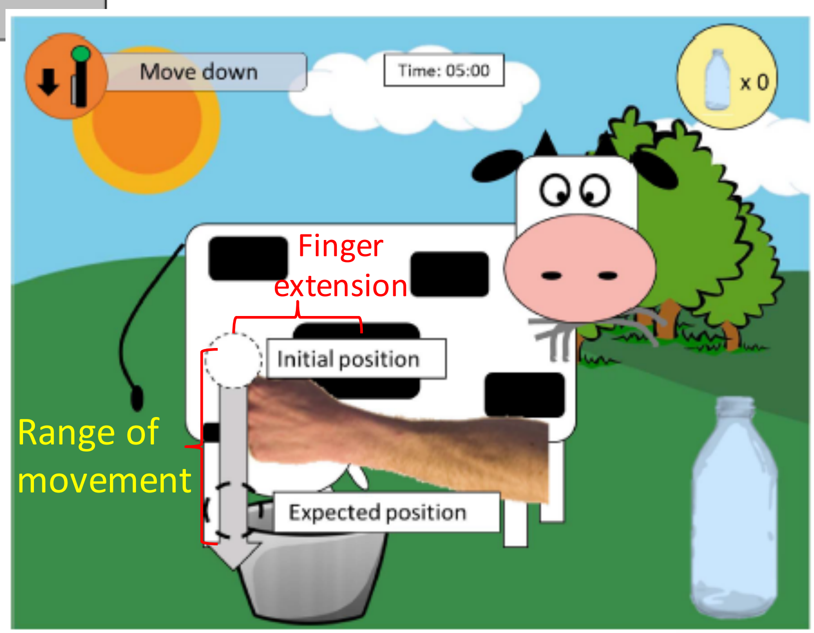
Table 2. Milk the Cow - Rules

- Responsible for physics, behaviour, and association of outcomes to player actions

Mechanics

- **Challenge and progress**



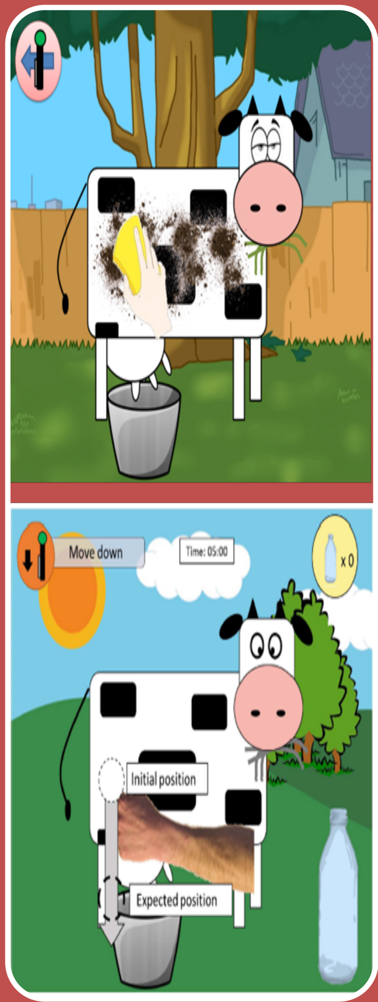


- Responsible for matching player skills, needs and limitations
- Maybe artificial intelligently guided

Top figure from: [Nijholt et al, Entertainment Computing 1 (2009) 85-94]

Dynamics

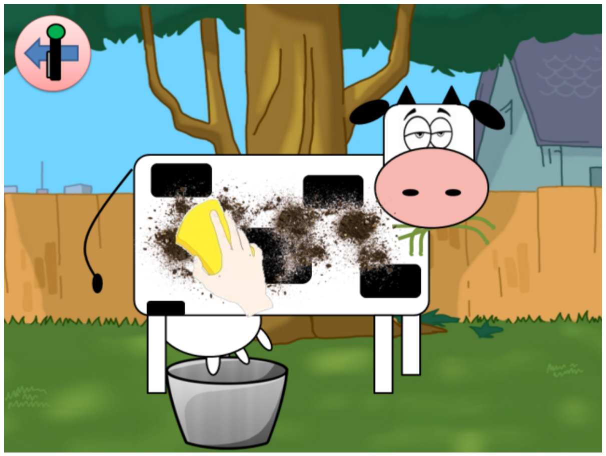
Game instantiation



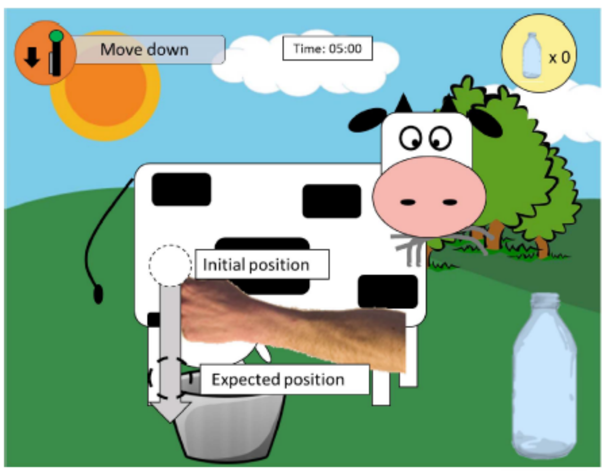
- Arise from the mechanics after the game is set in motion.
- Some examples include:
  - Free movement
  - Touch the target
  - Catch the target
  - Follow the path
  - Move the target
  - Point and shoot
  - Race to the end
  - Territorial acquisition

Dynamics

- **Game instantiation**



Touch target



Follow path

- Arise from the mechanics after the game is set in motion.
- Some examples include:
  - Free movement
  - Touch the target
  - Catch the target
  - Follow path
  - Move the target
  - Point and shoot
  - Race to the end
  - Territorial acquisition

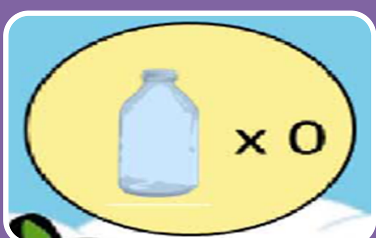
Feedback

User interface feedback

- Triggers following players actions
  - Spatiotemporal dynamics of feedback
- In rehabilitation, patient physical and mind constraints dictates interface behaviour (e.g. slow reaction time)

System feedback

- Modification of game elements following players actions
- Positive (reward) or negative (punishment)



Game feedback

- Information about game status
- Control feedback output channel: Visual, Auditive, Haptic, etc

Therapy feedback (a.k.a. extrinsic feedback)

- Information about the treatment status
- Knowledge of performance and Knowledge of results

Feedback

- **User interface feedback**

•Triggers game commence
•The user expects this behaviour
•A count down may give the patient extra time to get ready

- Triggers following players actions
  - Spatiotemporal dynamics of feedback
- In rehabilitation, patient physical and mind constraints dictates interface behaviour (e.g. slow reaction time)

Feedback

- **System feedback**

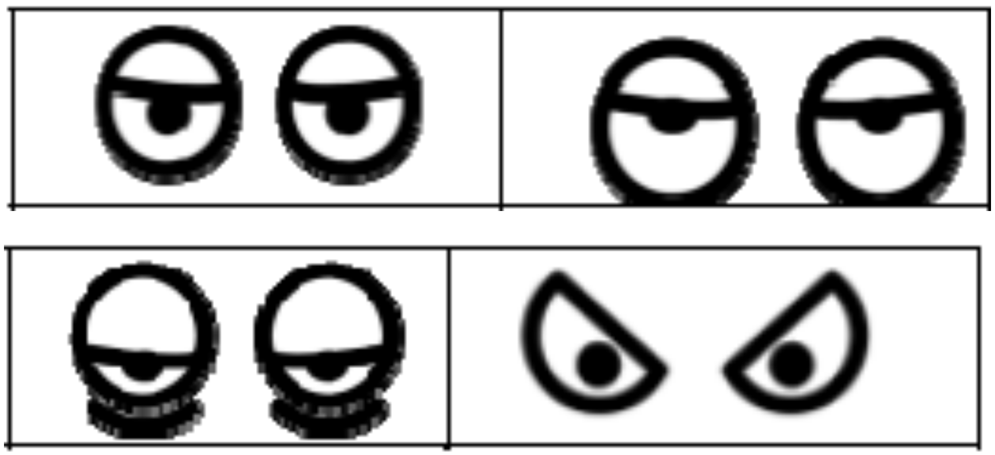
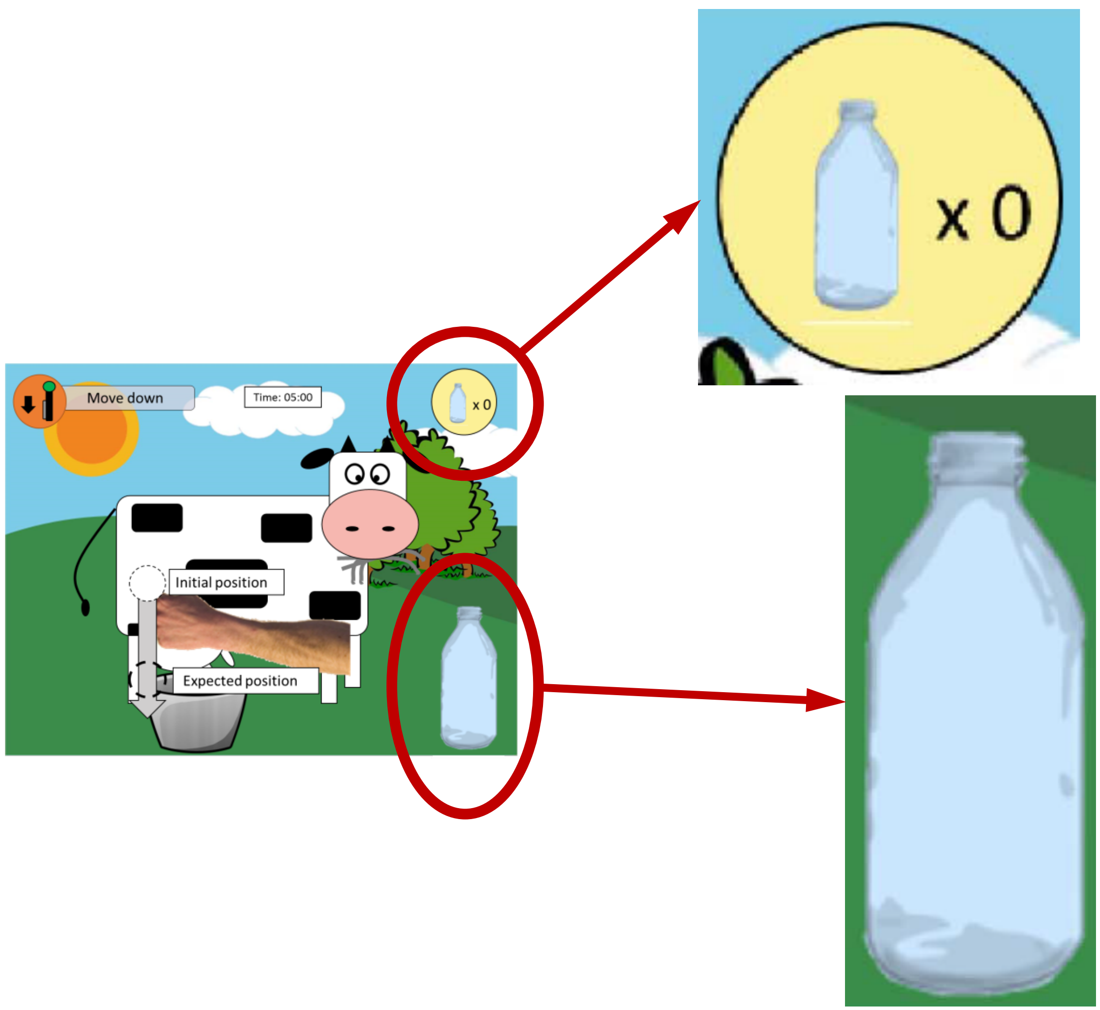


Figure 6. Suggestion of different moods by modification of visual elements; in this case the eyes of the cow.

- Modification of game elements following players actions
- Positive (reward) or negative (punishment)

Feedback

- **Game feedback**

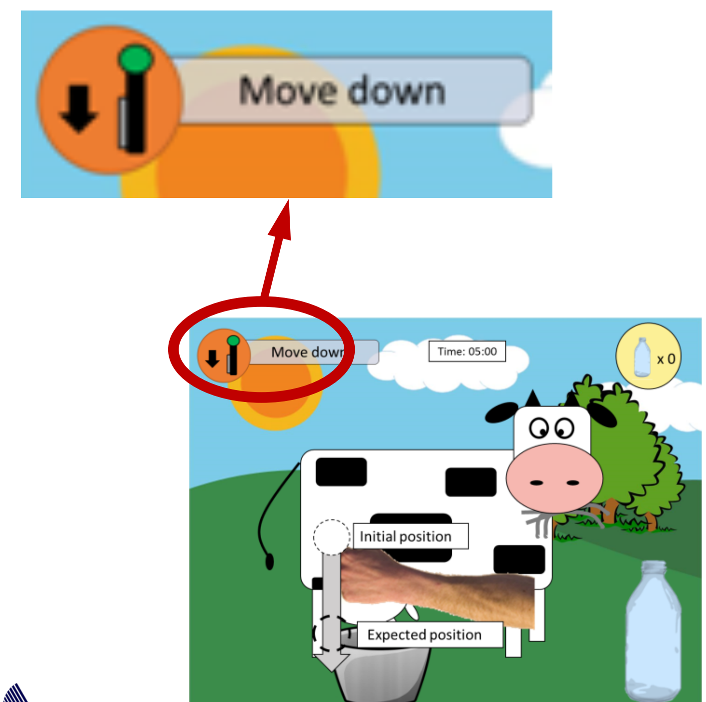


- Information about game status
- Control feedback output channel:
  - Visual
  - Auditive
  - Haptic
  - etc

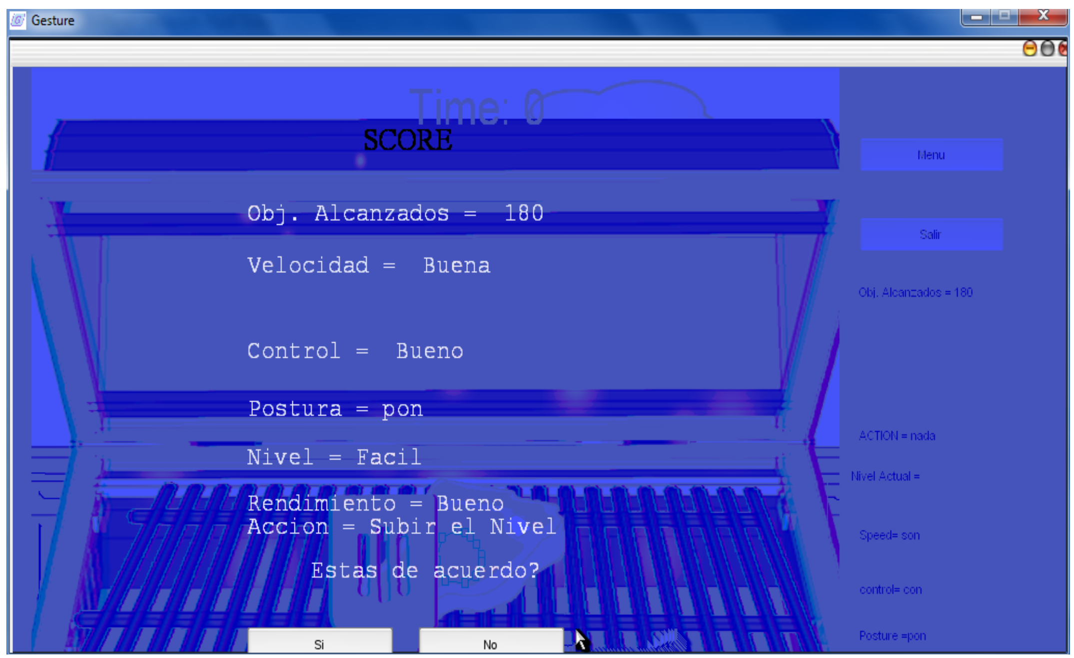
Feedback

- **Therapy feedback** (a.k.a. **extrinsic feedback**)
  - Information about treatment and progress status

Knowledge of results



Knowledge of performance



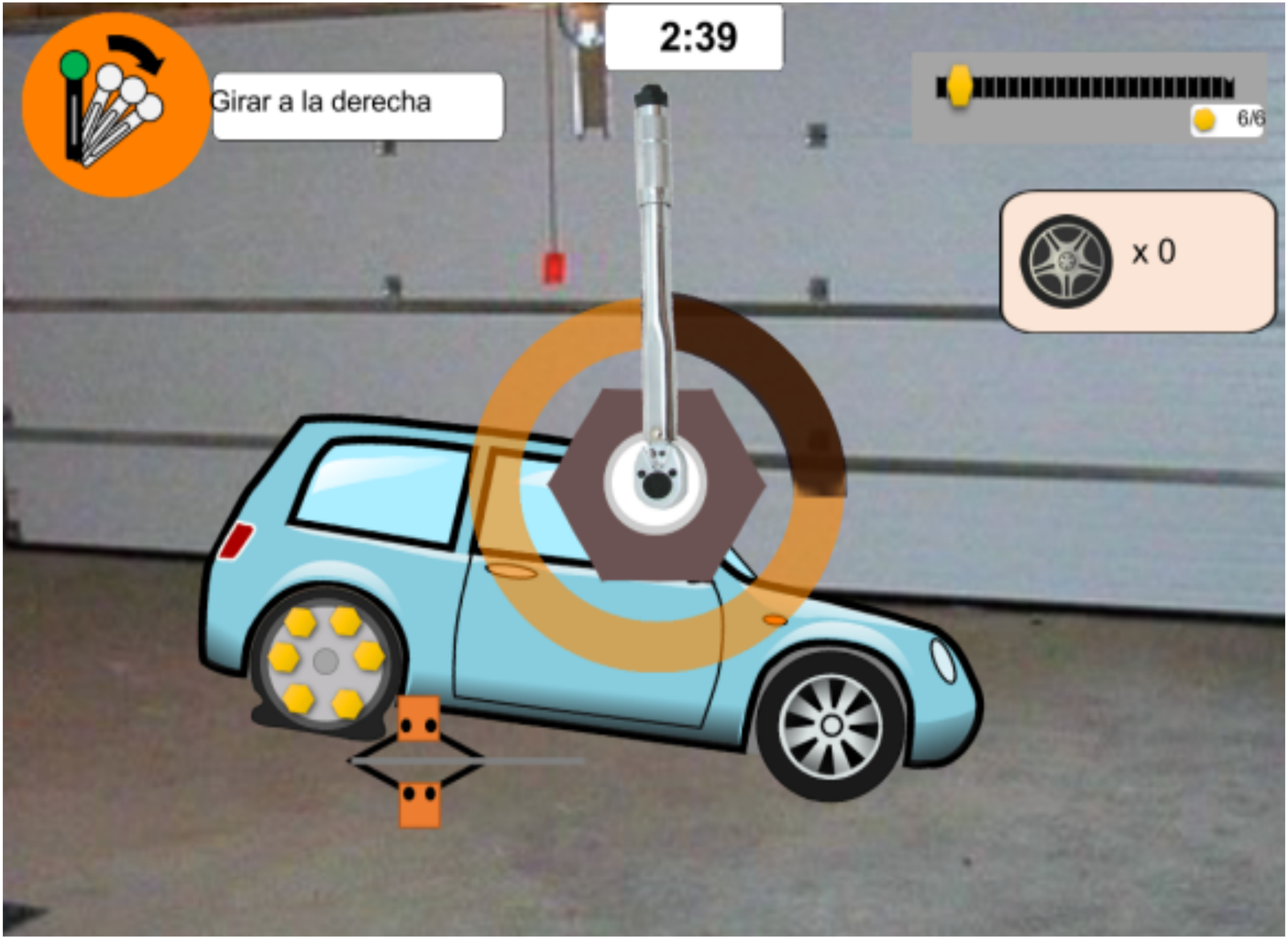
Games developed with COMFeeDY

- 4 new games developed with the COMFeeDY framework
- 1 single designer; 3 programmers in 3 different institutions (INAOE, UABC and ProBayes)
- Development time < 3 months
  - None of the programmers has any previous expertise with game engine Unity, or game development at all.
- Clinical evaluation now in progress (patient recruitment stage)

Games developed with COMFeeDY

Games developed with COMFeeDY

Games developed with COMFeeDY



Conclusions

- Design frameworks may help designing consistent and reusable games for rehabilitation in a faster, simpler, and more efficient manner.
  - …hopefully helping VR to reach its potential
  - …unfortunately, design frameworks themselves are still far from robust or validated

- The COMFeeDY framework incorporates user and technical demands.

Future work

- Quantifying gain due to developing under the framework.
- Increasing game (task) variety
- Attending some of the framework limitations e.g. cognitive aspects, medical aspects, social aspects, better feedback description, intergame interactions, etc

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OPEN CHALLENGES

Open challenges

- Improve game design criteria taxonomy
  - By better understanding the necessities of rehabilitation games, specific aspects of the development process of serious games for rehabilitation can be streamlined

ESTADO INICIAL	PARÁMETROS CLINICOS DE LA TERAPIA	MOTIVACIÓN / COMPROMISO.	REPETICIÓN DE MOVIMIENTOS	SENTIDO / TAREAS SIGNIFICATIVAS.
• Edad. • Destreza Motora. • Depresión post-ictus / Fisiológica. 1. Nivel de fatiga. 2. Nivel de depresión. • Estilo de vida. • Grupos de apoyo (familia, etc.). • Estado de comorbilidad	• Ventana de oportunidad. • Adaptación al paciente. • Sesión. 1. Agentes activos. 2. Intensidad, Frecuencia y repetición. 3. Nivel de capacidad (carga de trabajo). 4. Duración. 5. Retroalimentación adecuada. 6. Tareas.	• Inmersión en el juego. 1. Representación de sí mismo (Avatar gráfico). 2. Sentimiento de control. 3. Representación de sus movimientos en el juego. 4. Interfaz simple y objetivos claros. • Interés. • Autosuficiencia / Tolerancia. • Cumplimiento / compromiso. • Tolerancia.	• Tipo de movimientos cubiertos. • Reducción de compensación de movimientos. • Rango de movimiento.	• Actividades de la vida cotidiana. • Actividades funcionales.

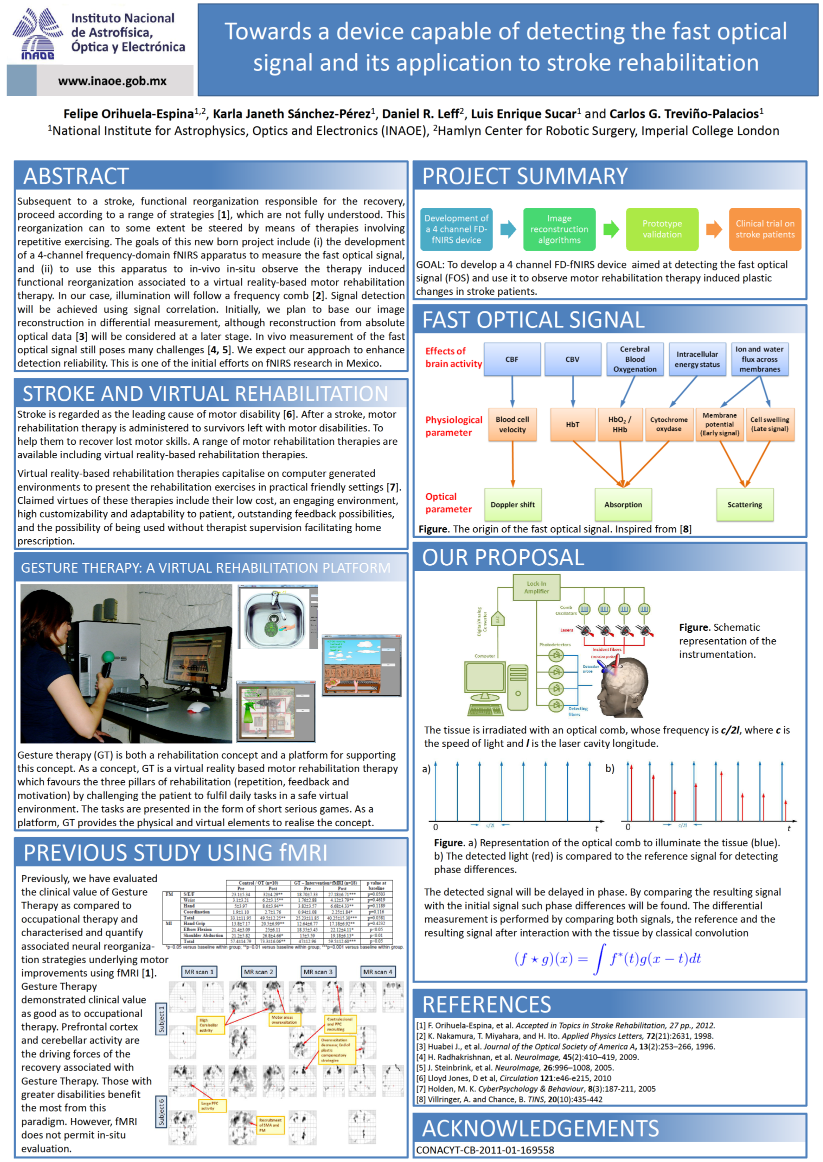
Tabla 3.3 Taxonomía de criterios para el diseño de juegos de rehabilitación.

Open challenges

- Transfer of knowledge
  - It is critical to investigate indispensable elements that make a serious game an effective tool for rehabilitation, with special emphasis on transfer of knowledge from the virtual to the real world and identifying game elements that increase adherence to the games and by extension to the therapy.
  - This may further reduce the excessive reliance on premature clinical trials

Open challenges

- Functional reorganization of the brain
  - Employing neuroimaging techniques other than fMRI, such as fNIRS, will permit us to interrogate the brain with higher ecological validity



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Towards a device capable of detecting the fast optical signal and its application to stroke rehabilitation

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ABSTRACT

Subsequent to a stroke, functional reorganization responsible for the recovery, proceed according to a range of strategies [1], which are not fully understood. This reorganization can to some extent be steered by means of therapies involving repetitive exercising. The goals of this new born project include (i) the development of a 4-channel frequency-domain fNIRS apparatus to measure the fast optical signal, and (ii) to use this apparatus to in-vivo in-situ observe the therapy induced functional reorganization associated to a virtual reality-based motor rehabilitation therapy. In our case, illumination will follow a frequency comb [2]. Signal detection will be achieved using signal correlation. Initially, we plan to base our image reconstruction in differential measurement, although reconstruction from absolute optical data [3] will be considered at a later stage. In vivo measurement of the fast optical signal still poses many challenges [4, 5]. We expect our approach to enhance detection reliability. This is one of the initial efforts on fNIRS research in Mexico.

STROKE AND VIRTUAL REHABILITATION

Stroke is regarded as the leading cause of motor disability [6]. After a stroke, motor rehabilitation therapy is administered to survivors left with motor disabilities. To help them to recover lost motor skills. A range of motor rehabilitation therapies are available including virtual reality-based rehabilitation therapies.

Virtual reality-based rehabilitation therapies capitalise on computer generated environments to present the rehabilitation exercises in practical friendly settings [7]. Claimed virtues of these therapies include their low cost, an engaging environment, high customizability and adaptability to patient, outstanding feedback possibilities, and the possibility of being used without therapist supervision facilitating home prescription.

GESTURE THERAPY: A VIRTUAL REHABILITATION PLATFORM

Gesture therapy (GT) is both a rehabilitation concept and a platform for supporting this concept. As a concept, GT is a virtual reality based motor rehabilitation therapy which favours the three pillars of rehabilitation (repetition, feedback and motivation) by challenging the patient to fulfil daily tasks in a safe virtual environment. The tasks are presented in the form of short serious games. As a platform, GT provides the physical and virtual elements to realise the concept.

PREVIOUS STUDY USING fMRI

Previously, we have evaluated the clinical value of Gesture Therapy as compared to occupational therapy and characterised and quantify associated neural reorganization strategies underlying motor improvements using fMRI [1]. Gesture Therapy demonstrated clinical value as good as to occupational therapy. Prefrontal cortex and cerebellar activity are the driving forces of the recovery associated with Gesture Therapy. Those with greater disabilities benefit the most from this paradigm. However, fMRI does not permit in-situ evaluation.

		Control / OT (n=10) Pre	Control / OT (n=10) Post	GT – Intervention+fMRI (n=18) Pre	GT – Intervention+fMRI (n=18) Post	p value at baseline
FM	S/E/F	23.1±5.34	32±4.29**	18.70±7.33	27.18±6.71***	p=0.0503
	Wrist	3.1±3.21	6.2±3.15**	1.76±2.88	4.12±3.79**	p=0.4619
	Hand	5±3.97	8.6±3.94**	3.82±3.57	6.68±4.33**	p=0.1189
	Coordination	1.9±1.10	2.7±1.76	0.94±1.08	2.25±1.84*	p=0.116
	Total	33.1±11.95	49.5±12.25**	25.23±11.85	40.25±15.30***	p=0.0581
MI	Hand Grip	13.8±7.17	20.5±6.99**	12.64±6.77	17.18±6.92**	p=0.4232
	Elbow Flexion	21.4±3.09	25±6.11	18.35±5.45	22.12±4.11*	p<0.05
	Shoulder Abduction	21.2±5.82	26.8±4.66*	15±5.59	19.18±6.13*	p<0.01
	Total	57.4±14.79	73.3±16.06**	47±12.96	59.5±12.60***	p<0.05

*p<0.05 versus baseline within group; **p<0.01 versus baseline within group; ***p<0.001 versus baseline within group.

MR scan 1 / MR scan 2 / MR scan 3 / MR scan 4; Subject 1; Subject 6; High Cerebellar activity; Motor areas overexcitation; Contralesional and PPC recruiting; Overexcitation decrease; End of plastic compensatory strategies; Large PFC activity; Recruitment of SMA and PM

PROJECT SUMMARY

Development of a 4 channel FD-fNIRS device → Image reconstruction algorithms → Prototype validation → Clinical trial on stroke patients

GOAL: To develop a 4 channel FD-fNIRS device aimed at detecting the fast optical signal (FOS) and use it to observe motor rehabilitation therapy induced plastic changes in stroke patients.

FAST OPTICAL SIGNAL

Effects of brain activity: CBF; CBV; Cerebral Blood Oxygenation; Intracellular energy status; Ion and water flux across membranes

Physiological parameter: Blood cell velocity; HbT; HbO_2 / HHb; Cytochrome oxydase; Membrane potential (Early signal); Cell swelling (Late signal)

Optical parameter: Doppler shift; Absorption; Scattering

Figure. The origin of the fast optical signal. Inspired from [8]

OUR PROPOSAL

Lock-In Amplifier; Digital/Analog Converter; DAC; Comb Oscillators; Lasers; Photodetectors; Computer; Incident fibers; Emission probe; Detection probe; Detecting fibers

Figure. Schematic representation of the instrumentation.

The tissue is irradiated with an optical comb, whose frequency is ***c/2l***, where ***c*** is the speed of light and ***l*** is the laser cavity longitude.

Figure. a) Representation of the optical comb to illuminate the tissue (blue). b) The detected light (red) is compared to the reference signal for detecting phase differences.

The detected signal will be delayed in phase. By comparing the resulting signal with the initial signal such phase differences will be found. The differential measurement is performed by comparing both signals, the reference and the resulting signal after interaction with the tissue by classical convolution

$$(f \star g)(x) = \int f^*(t)g(x-t)dt$$

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Open challenges

- Current limitations in how the brain recovers and relearns limit the impact of therapies
  - Virtual Rehabilitation (VR) a (yet) potentially groundbreaking tool

- Virtual Rehabilitation remains mainly oriented as a compensatory and/or sustitutory therapy
  - …and even as these our knowledge about how it modulates cortical activity remains very limited.

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THANKS, QUESTIONS?

BACK UP SLIDES