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Multimodal systems for training in Virtual Environments

Emanuele Ruffaldi

9th July 2015

ECP Milan

Overview

- Training objectives in sport via VR/AR
- Training basics
- Feedback types
- Feedback design
- SKILLS rowing system
- Case studies from the SKILLS rowing
- Conclusions

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Training objectives in sport via VR/AR

- Objectives
  - Performance Assessment
  - Train athlete on related task
  - Train athlete on simulated task
- Issues
  - Motion/Force ranges of real task
  - Transfer from AR/VR to real task

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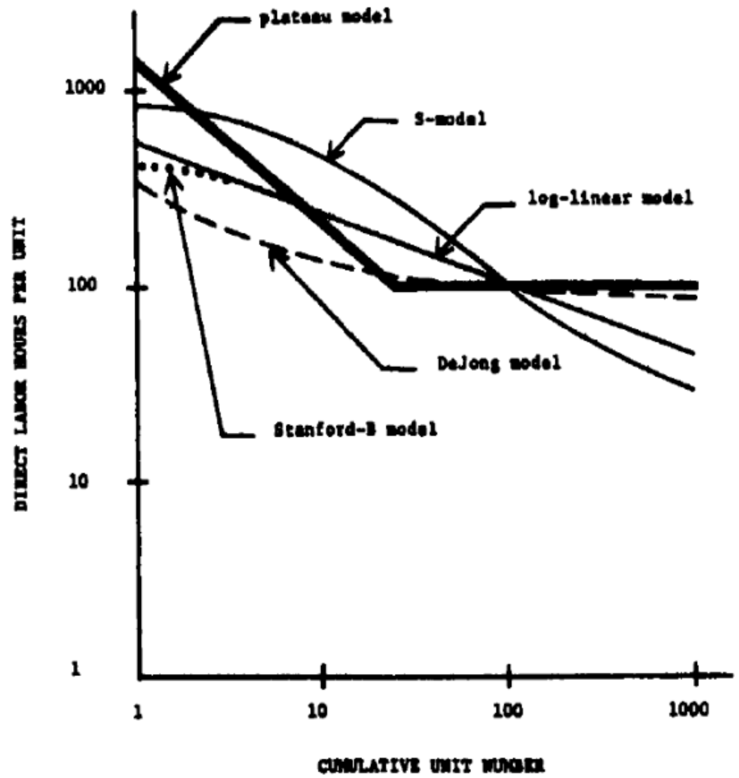
Training Basics

- Process to make one or more humans, namely the trainees, acquire or improve skills
- Training involves **learning**
- Learning curves
- Power law of practice



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Training Basics

- Knowledge of **results** and knowledge of **performance**
- **Role of instructions**: uniformity of instructions is fundamental to assess training effectiveness
- **Information processing and cognitive load**: training always requires a trade-off between the amount of information that may contribute to learning and the cognitive load that they cause

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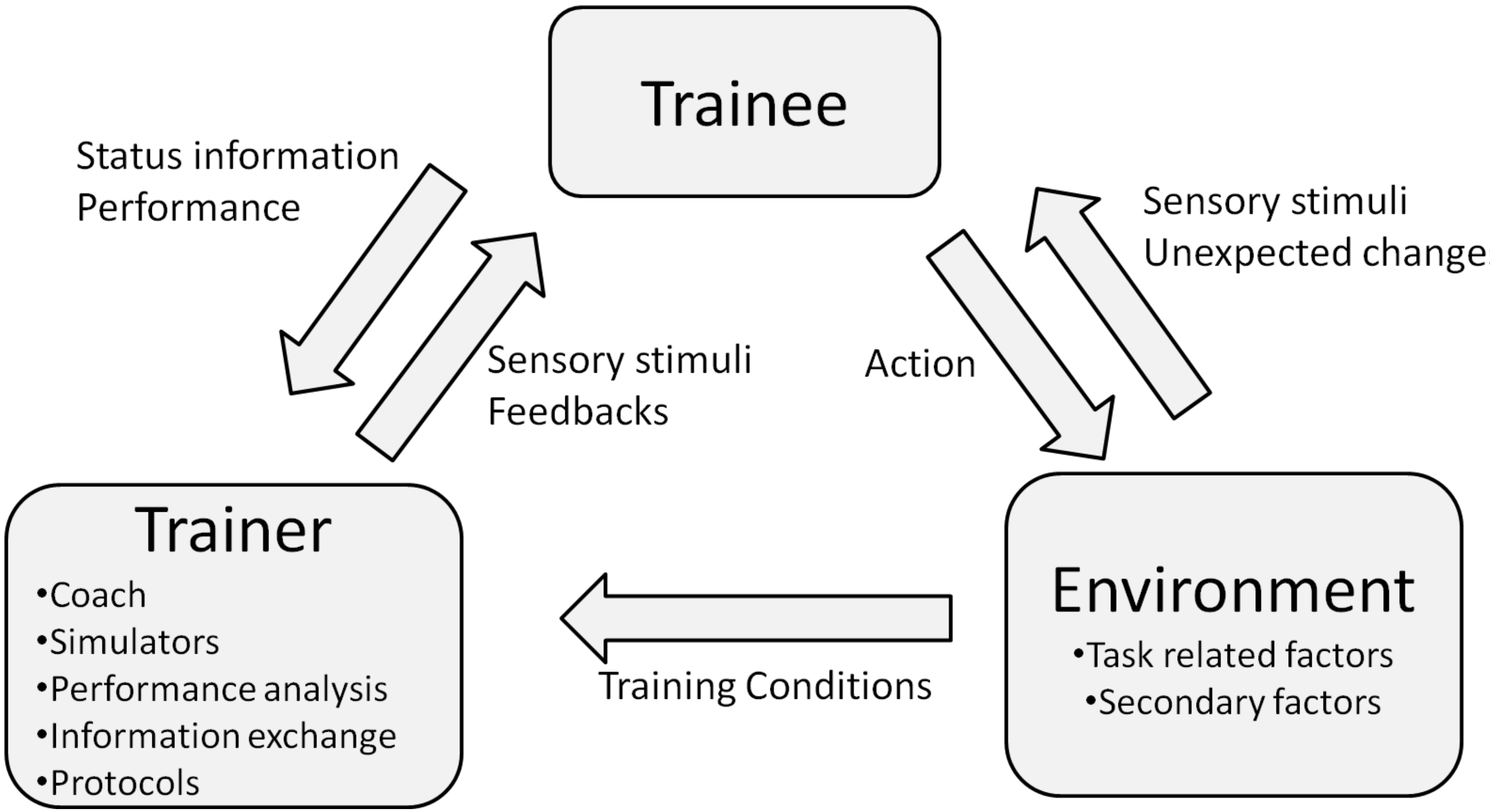
The training loop



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Fidelity of a Training system for VR(AR

- **Fidelity** is related to the features of the real task that are simulated in the training system. It is determine by both **what** and **how** those features are simulated
- It is better not to simulate that to simulate in a way that is detrimental for the training goal
- It is irrelevant to simulate features irrelevant for training
- Realism does not means fidelity

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Feedback, stimuli and information exchange

- **Feedback** is an information about the performance or the result of the performance with respect to the goal of the task that is returned to the trainee
- **Stimuli** are actions of the system on the user that are not necessarily intended to be feedback
- The flow of information between the training system and the trainee is called **information exchange**

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Feedback, stimuli and information exchange

- Examples of feedback:
  - Score of an exam
  - Beep after a mistake
  - Screen getting red as the character life is going to end in a computer game
  - Verbal report by a coach
  - Elapsed time over a run

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Feedback, stimuli and information exchange

- Examples of stimuli
  - Gun shot to start a race
  - Semaphore
  - Opponent in a VE

The design of a VE for multimodal training requires a clear separation between Stimuli and Feedback allowing the researcher to control Feedback in the experimental/training situation

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Affordances

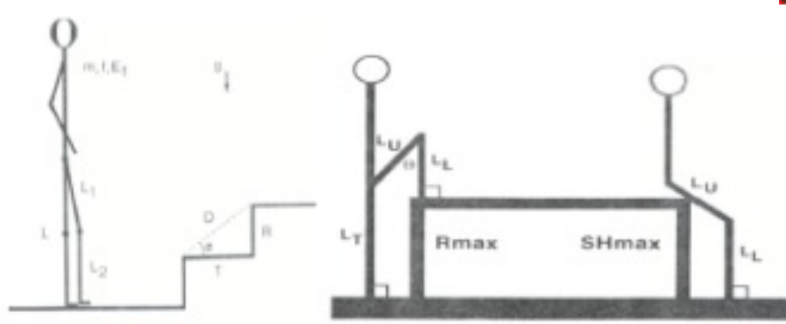
- Definition of affordances from Gibson:

all "action possibilities" latent in the environment, objectively measurable and independent of the individual's ability to recognize them, but always in relation to agents and therefore dependent on their capabilities

- In other words:

how inherent "values" and "meanings" of things in the environment can be directly perceived, and how this information can be linked to the action possibilities offered to the organism by the environment

- Therefore:
  - Affordances are opportunities for action
  - Affordances constrain what behaviors are possible in a given situation, what behaviors are easy or hard, efficient or inefficient, and so on



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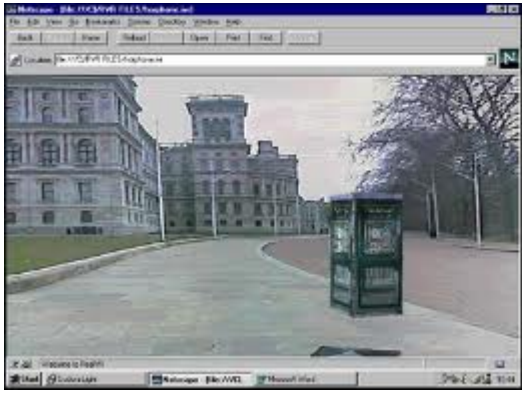
Affordances in VE



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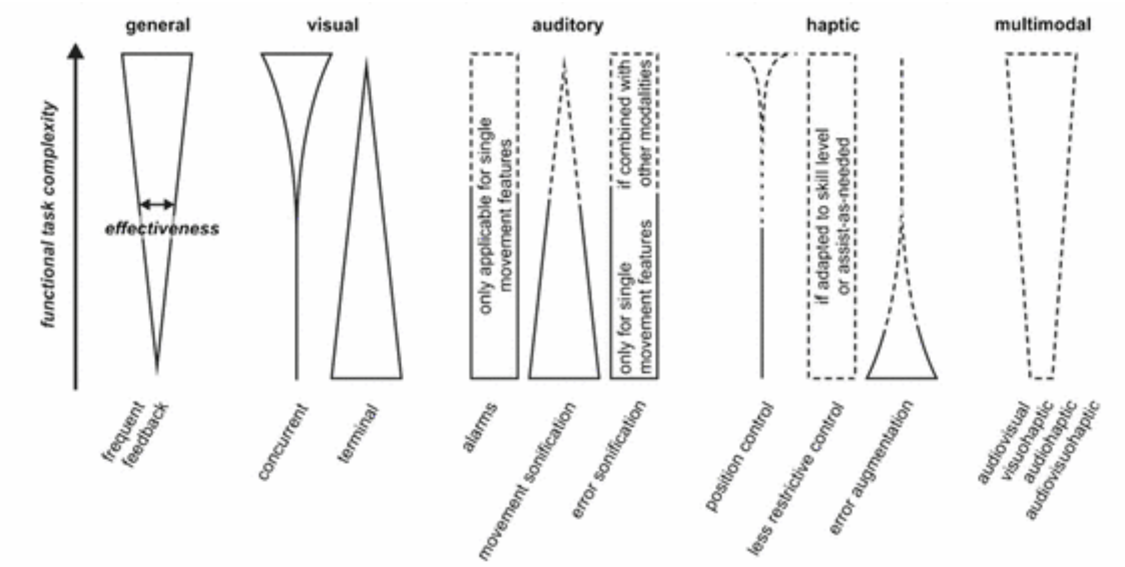
Categories of Feedback

- Proposed categorizations
  - Schmidt (experimental psychology):
    - Inherent (e.g. Ball does not go into the basket)
    - Augmented: augments inherent feedback
  - Reiner: review of existing works



  - Ruffaldi (feedback for VE based training systems): feedback can be identified by three categories: **meaning, medium and format**

Ruffaldi E., Filippeschi A., Avizzano C.A., Bardy B., Gopher D. & Bergamasco M. (2011) “Feedback, affordances, and accelerators for training sports in virtual environments“ doi:10.1162/pres_a_00034 Presence: Teleoperators and Virtual Environments 20(1) issn:1054-7460 33–46

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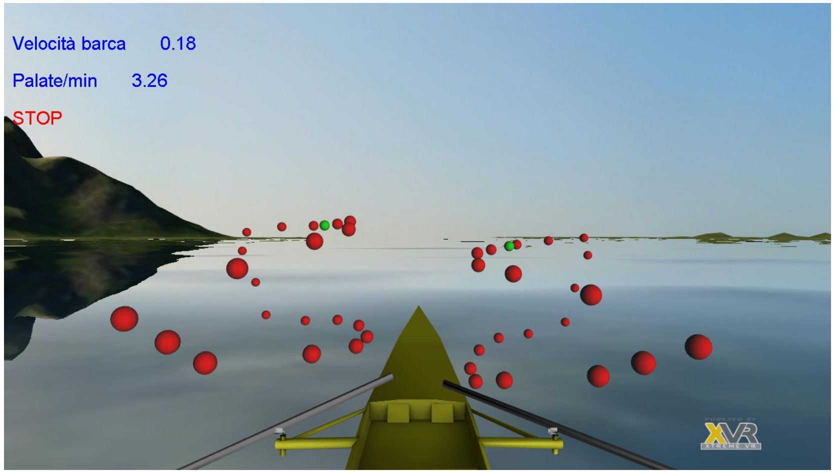
Categories of Feedback

- Meaning:
  - **Informative**: Informative feedback gives the user information about given parameters for providing the user KP or in some cases KR
  - **Guidance**: provides directions to the user about the next action to be performed, or constraint for its motion



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Categories of Feedback

- Medium:
  - **Modality**: The perceptual channel used to deliver feedback.
  - **Mediator**: The entity that mediates the information. distinguish between direct feedback, for example, on-screen or audio messages, compared to more complex behaviors that are presented in the virtual environment. Basic informative feedback coming from the trainer can be delivered on-screen, while other feedback can be embodied in VE entities, for example, feedback coming from virtual humans.

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Categories of Feedback

- Format:
  - **Dynamics**. Feedback provided statically or dynamically. Dynamic representations are often used with concurrent feedback, whereas static representations are more suitable for focusing on specific aspects or for providing the user with a summary or synthetic information about the performance.
  - **Concurrency**. Feedback provided in sync with the action or out of sync with the action.
  - **Frequency**. The frequency of the feedback provided during training. For simple tasks reduced frequenc of the feedback proved to be more effective for retention of skills.
  - **Continuity**. The continuous or discrete nature of the dependent variable.
  - **Adaptation**. Feedback provided (in-)dependently of the trainee's level of expertise, fatigue, etc. Adaptation proved to be effective to reduce the dependence of the trainee on feedback (Guidance Hypothesis)

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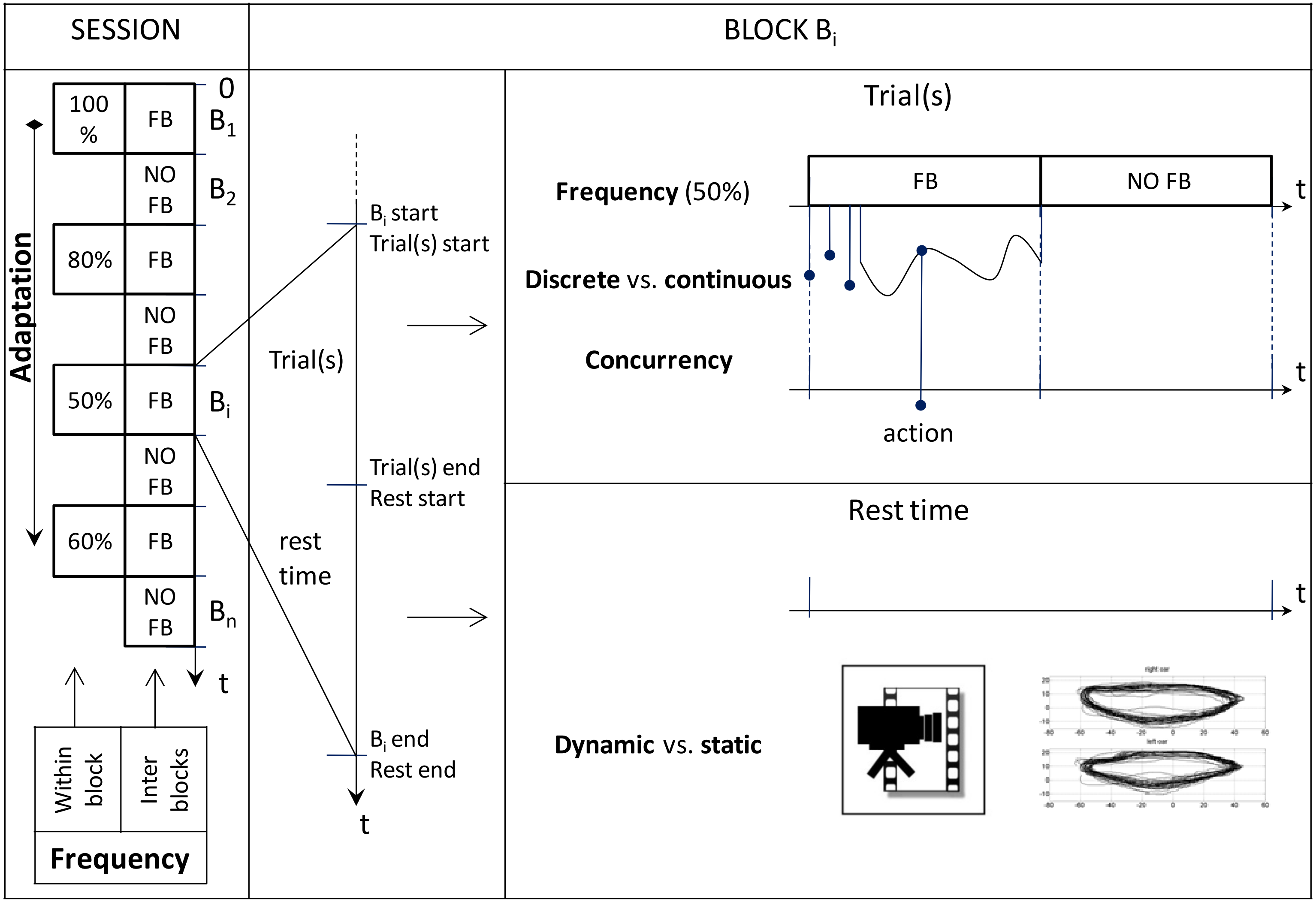
Categories of Feedback



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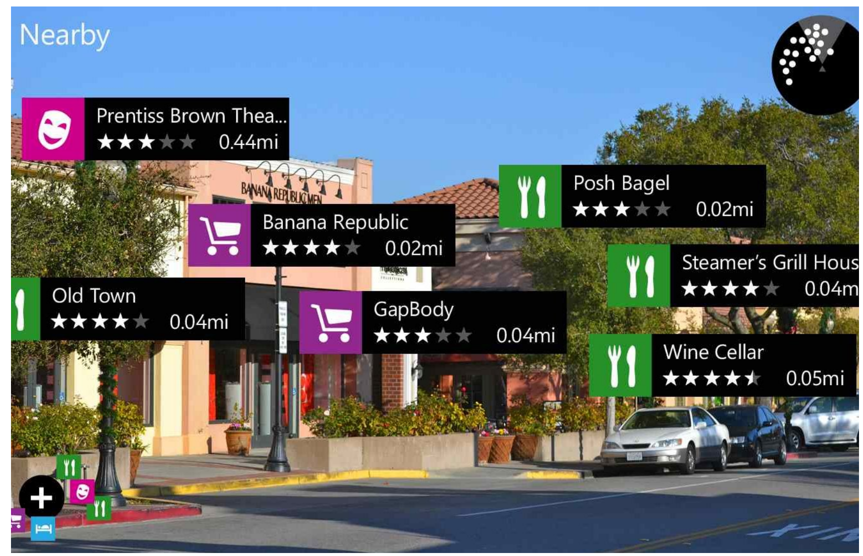
Visual Feedback

- **Symbolic** and superimposed to the environment



- Require processing to be related to the task, cognitive load decreases with training

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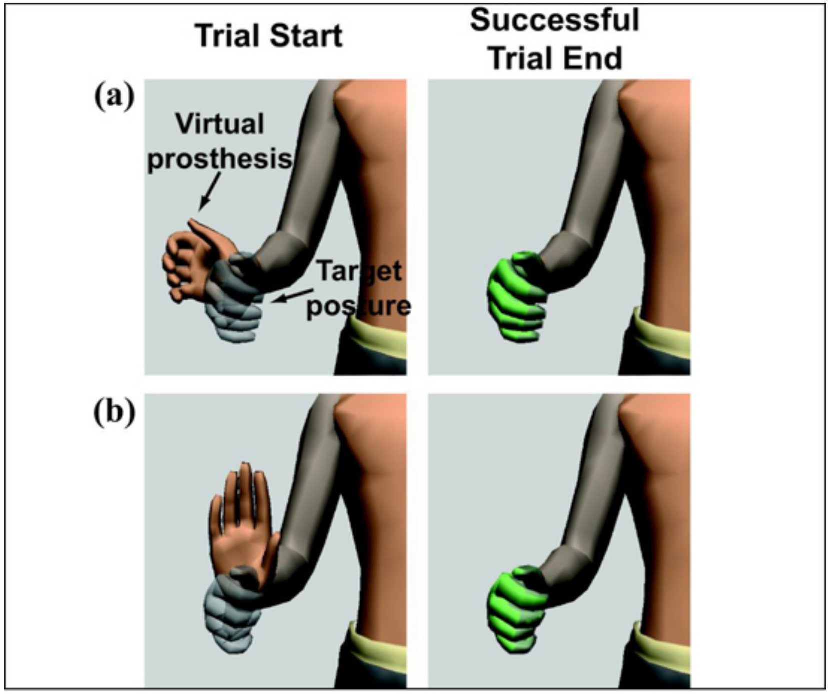
Visual Feedback

- Embedded in the VE



- Intuitive, allows to convey information in a natural manner.
- Raises issues of coherence with the environment

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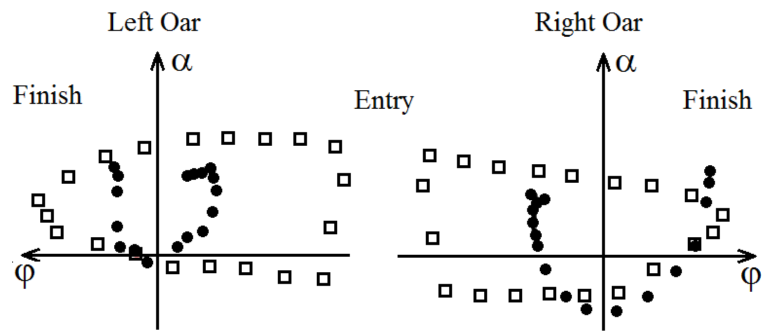
Visual Feedback

- Delayed visual feedback and summary



- Mental practice
- Self judgement of errors: development of metacognition

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Visual Feedback Issues

- Visual feedback requires several processing phases that mostly occur purposely
- Visual feedback attracts trainee's attention
- Visual feedback causes a considerable cognitive load

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Auditory Cues and Feedback

- Why auditory cues
  - Recognize temporal pattern and changes
  - Recognize frequency of the signal
  - Rapid auditory detection
  - Complement visual cues
- Objectives
  - To deliver KP and KR
  - To deliver information about the task
  - To deliver stimuli
  - To augment presence
  - To deliver feelings and moods

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Auditory Cues and Feedback

- Auditory cues for the realism:
  - Noises
  - Sounds
  - **Binaural recording** for stereo auditory rendering
    - Head transfer function
- Auditory stimuli and feedback
  - Warnings, triggers, pacers
  - **Sonification**: transformation of data relations into perceived relations in an acoustic signal for the purposes of facilitating communication or interpretation

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Auditory Cues and Feedback

- Auditory feedback processing highly depends on how intuitive is the cue
- Coordination tasks benefit from auditory cues
- Auditory feedback can be processed with a reduced cognitive load

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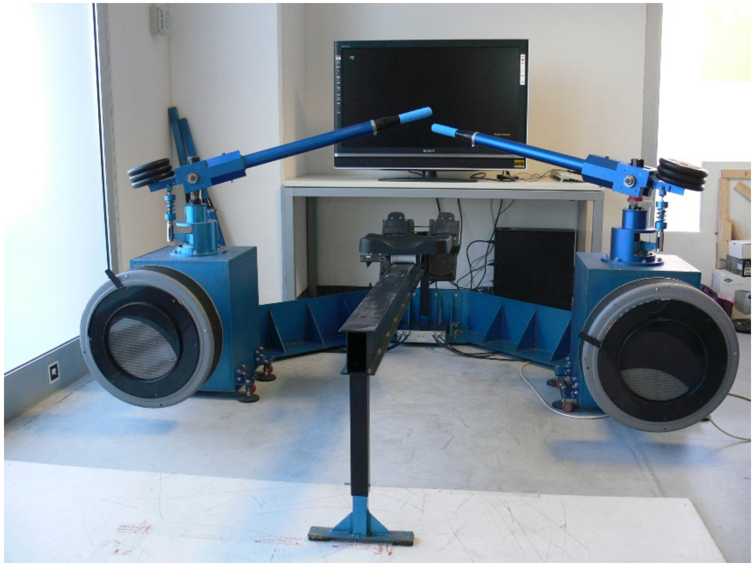
Haptic Cues and Feedback

- Haptic interfaces for kinesthetic cues



- Replicates physical constraints of the virtual environment in the real world

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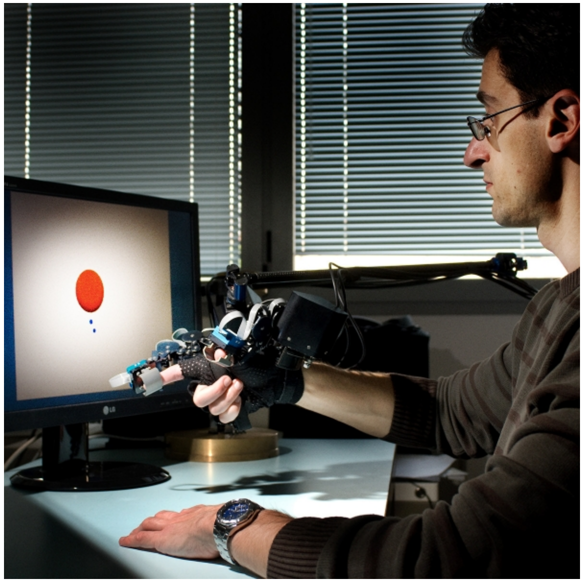
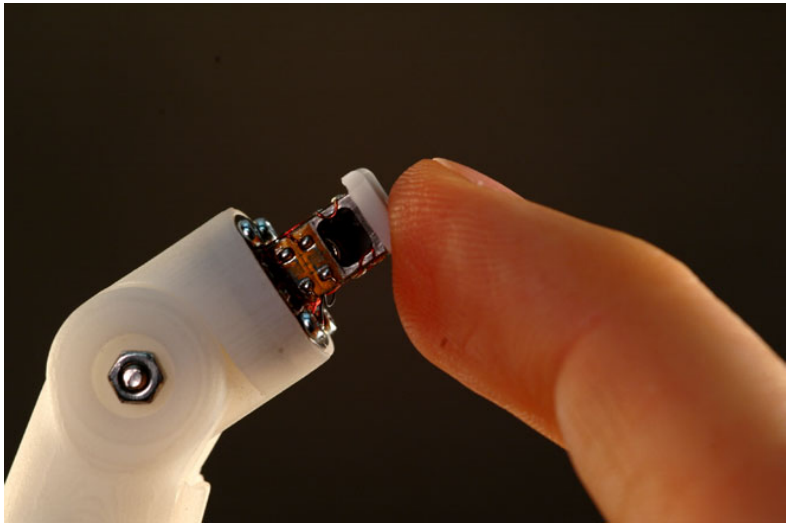
Haptic Cues and Feedback

- Haptic interfaces for tactile cues





- Replicates physical constraints of the virtual environment in the real world

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Haptic Cues and Feedback

- Haptic feedback is easily processed
- Produce fast learning
- Possible negative effects on retention and transfer of skills as prone to make the user dependent on it
- Issue of kinematic mapping of the haptic interface in the VE

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Vibrotactile Feedback

- Vibrotactile feedback
  - Fully wearable
  - Provided by arrays of motors mounted on human limbs where feedback has to be delivered
  - Used as an alternative to haptic modality

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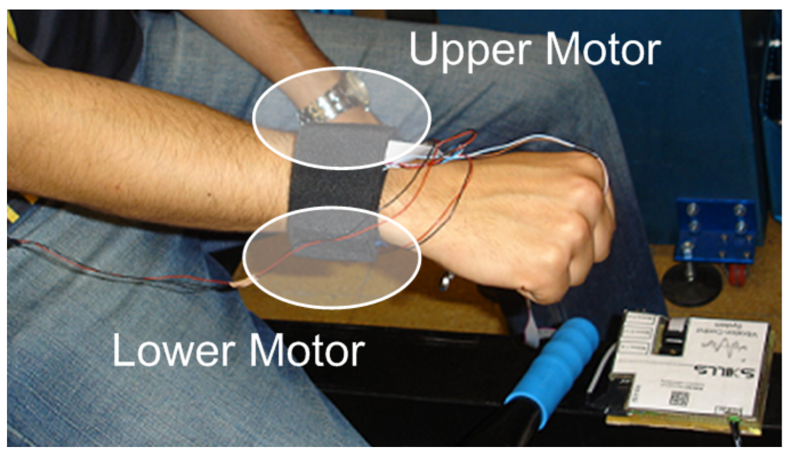
Vibrotactile Feedback

- Vibrotactile feedback for knowledge of results



Ruffaldi E., Filippeschi A., Frisoli A., Sandoval O., Avizzano C.A. & Bergamasco M. (2009) "Vibrotactile perception assessment for a rowing training system" doi:10.1109/WHC.2009.4810849 World Haptics Conference IEEE 350-355

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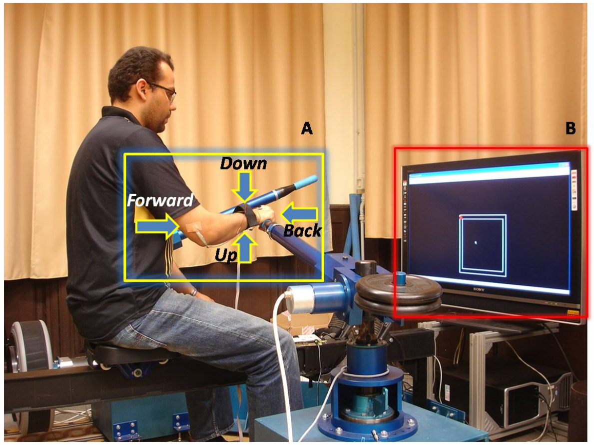
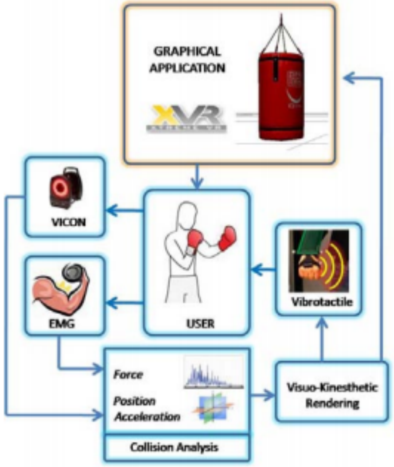
Vibrotactile Feedback

- Vibrotactile for force rendering
  - As a guidance



  - Force feedback



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Vibrotactile Feedback

- Processing difficulty depends on the level of interpretation of the stimulus
- Perception of vibrotactile stimuli is exponential: **not suitable** to be used on a scale, better as discrete feedback
- If used as a guidance may cause either **high or low cognitive load** depending on the difficulty of the trainee to process the signal

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Multimodality

The combination of several modalities for the information exchange

- **Pro**:

  exploiting multiple channels to convey information to the trainee, synergies of information channels allow to provide the trainee with much more information and to make it easier to be processed and exploited

- **Con**:

  risk to saturate the cognitive load of the trainee causing confusion, inability to process information, uncertainty on what information is currently guiding the trainee performace

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Multimodality

- Visual + Auditory feedback and cues
  - Visual is dominant
  - Auditory is complementary
  - Combination provides benefits both in learning and retention

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Multimodality

- Visual + haptic feedback and cues
  - Visual is dominant
  - Coherence is a key issues as kinematic has to be mapped
  - Combination of the two modalities led to controversial results, benefits of the combination of these feedbacks is still debated
  - Guidance hypothesis still hold when visual feedback is on

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Multimodality

- Visual + vibrotactile feedback and cues
  - Visual is dominant
  - The combination of the two provides benefits for learning but retention and transfer effects are still debated
  - Works from Brezael seem to demonstrate benefits also for retention

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Multimodality

- Effects of multimodal feedback:
  - Improvement in learning when consistent
  - Retention is also improved when avoiding dependence of the user on the interface
  - Trainees rely more on multimodality as the task complexity increases

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Role of latency

- It applies to concurrent feedback
- Different perception thresholds of delay for different perceptual channels
- Trainees rely more **on the feedback having the lower latency**
- Detrimental for coordination tasks

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Information exchange for training: enaction

- Enaction: "Cognition" is to be defined as the process whereby a living organism, interacting with its environment, "brings forth" or *enacts* the "world" in which it lives
- Enactive knowledge comes by doing, introducing an interdependence between the environment and the trainee
- Multimodal interfaces are particularly suited to ease this acquisition of knowledge as they enhance the communication possibilities between the trainee and the environment.

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ROWING CASE STUDY

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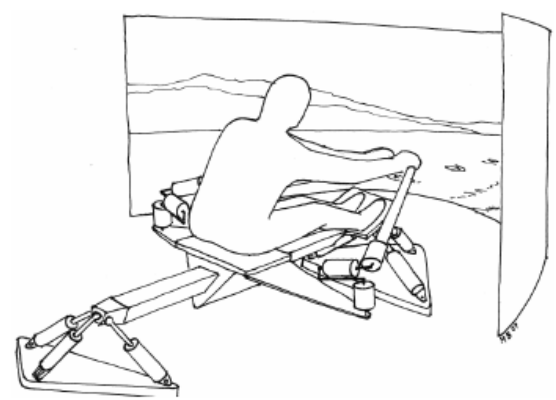
Rowing Training Challenge

Design and development of a multi-modal Rowing demonstrator with the main purpose of skills transfer for training **intermediate-experts** rowers

Out-door

In-door



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Research Objectives

- **Basic Challenges in VE training**
  - Use of multimodal feedback for complex motor task
  - Use of Virtual Humans for training
- **Design and Validate a Rowing training system**
  - Methodology for Design and Evaluation
  - Architectural
  - Support data management
- **Training of Specific Rowing Aspects**
  - Technique
  - Energy Management
  - Coordination
- **Model the Rowing Skill**
  - Real-Time Scoring
  - Integrated with Training

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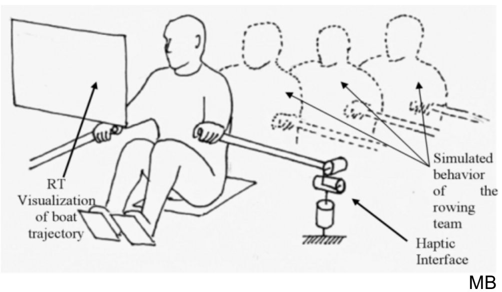
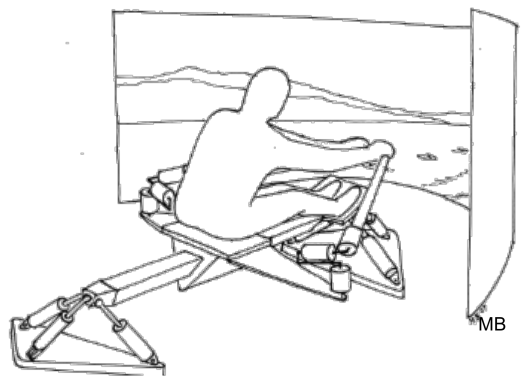
SPRINT

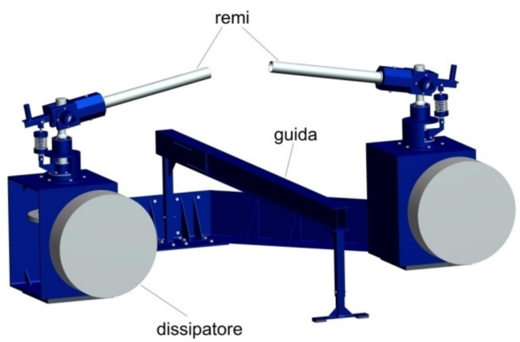
Skills Professional Rowing IN-door Trainer





Conceptual Idea

Immersive Configuration



Platform Design

Training Configuration

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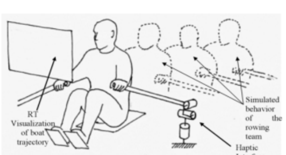
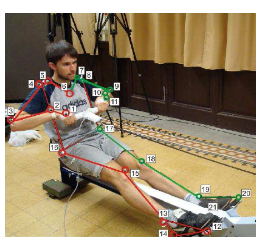
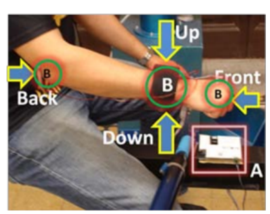
Phases of the Work

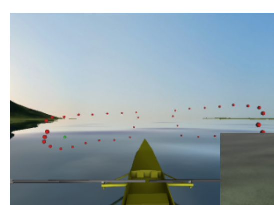
Task Analysis | Design | Platform | Experiment | Prototype | Evaluation

2007 | 2008 | 2009 | 2010 | 2011









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Methodology

GOALS
- Three Scenarios have been identified:
- **Technique**
- **Energy management**
- **Team Rowing**

PLATFORMS
- Three platforms designed
- SPRINT
- Light Weight Rowing
- Boat

CAPTURING
- Performed on platforms for supporting training and modeling

ANALYSIS
- Modeling of the Rowing Skill
- Segmentation
- Biomechanics
- Energy
- Coordination
- Audio

ACCELERATORS
- Specialized Training Feedback
- Augmented Visual
- Virtual Human
- Vibrotactile

TRAINING PROTOCOLS
- Energy
- Team
- Techopt timing
- Techopt path
- Techopt Transfer

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Platforms

SPRINT

LWR

Boat

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Design Requirements

- **Objectives**
  - Focus on Training, not Simulation
  - Training based Design Decisions
  - *Provide feedback on postures and movements*
  - *Provide feedback on specific sub-goals*
- **Kinematics**
  - same movement of outdoor rowing
- **Dynamics**
  - water **resistance** and **entrance**
- **Training Features**
  - Scull or Sweep with same Device

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Design Method

- **Design Information**
  - From Manuals
  - From Coaches
  - From Expert Captured data
- **Validations and Refinements**
  - Experts (Questionnaire)
  - Training with Novices
  - Training with Intermediate

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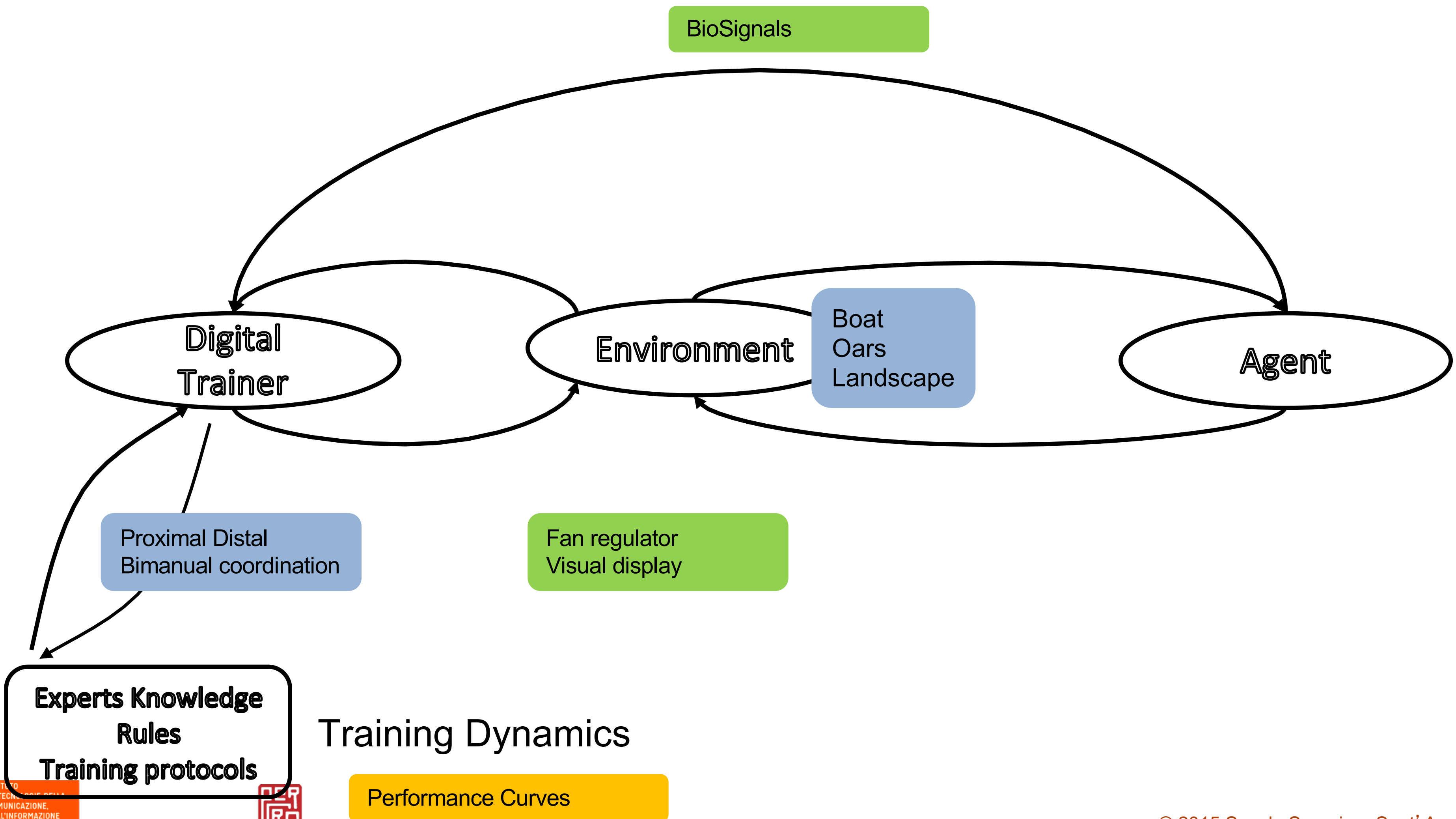
Information Processing Model



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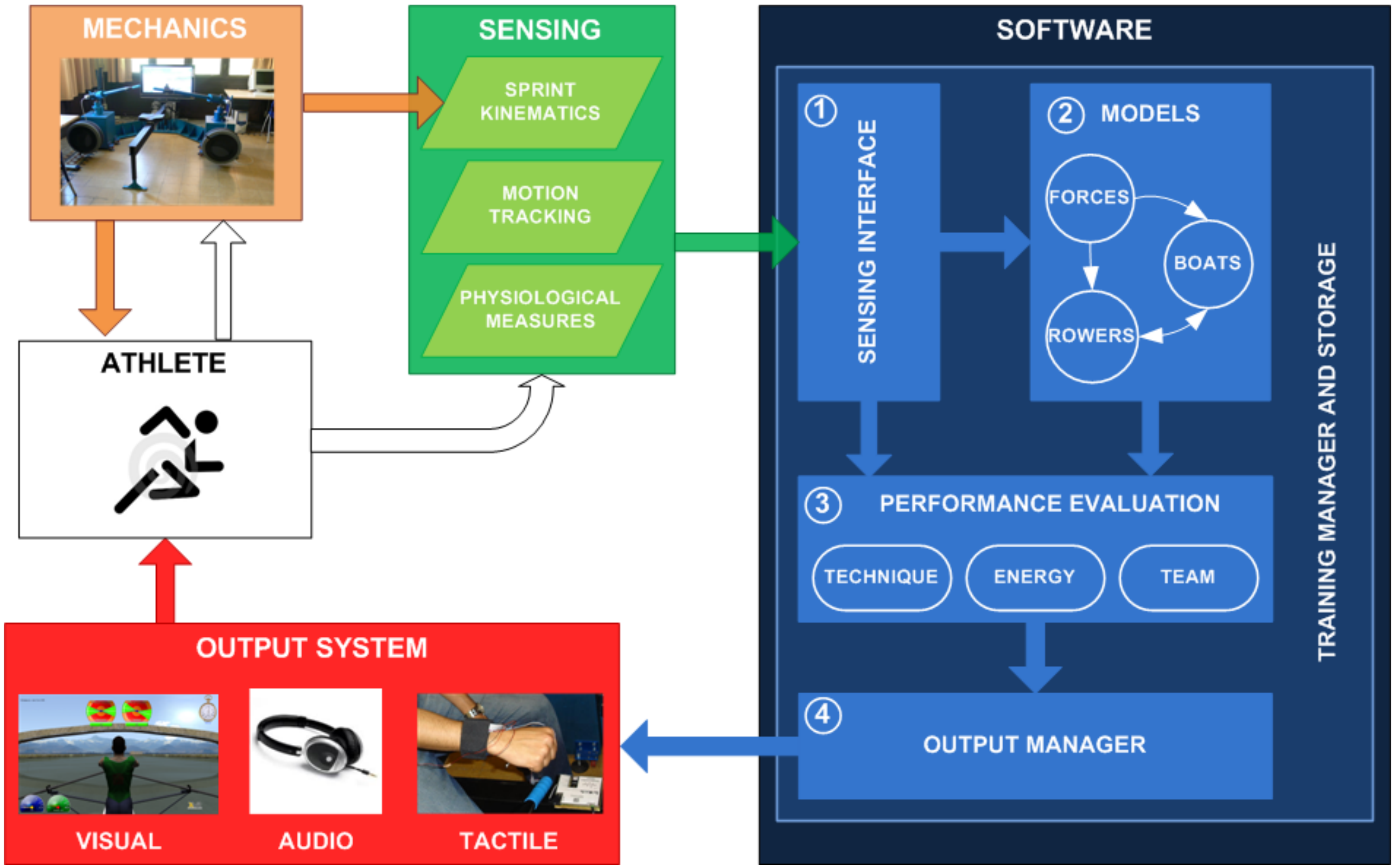
Interaction Principle



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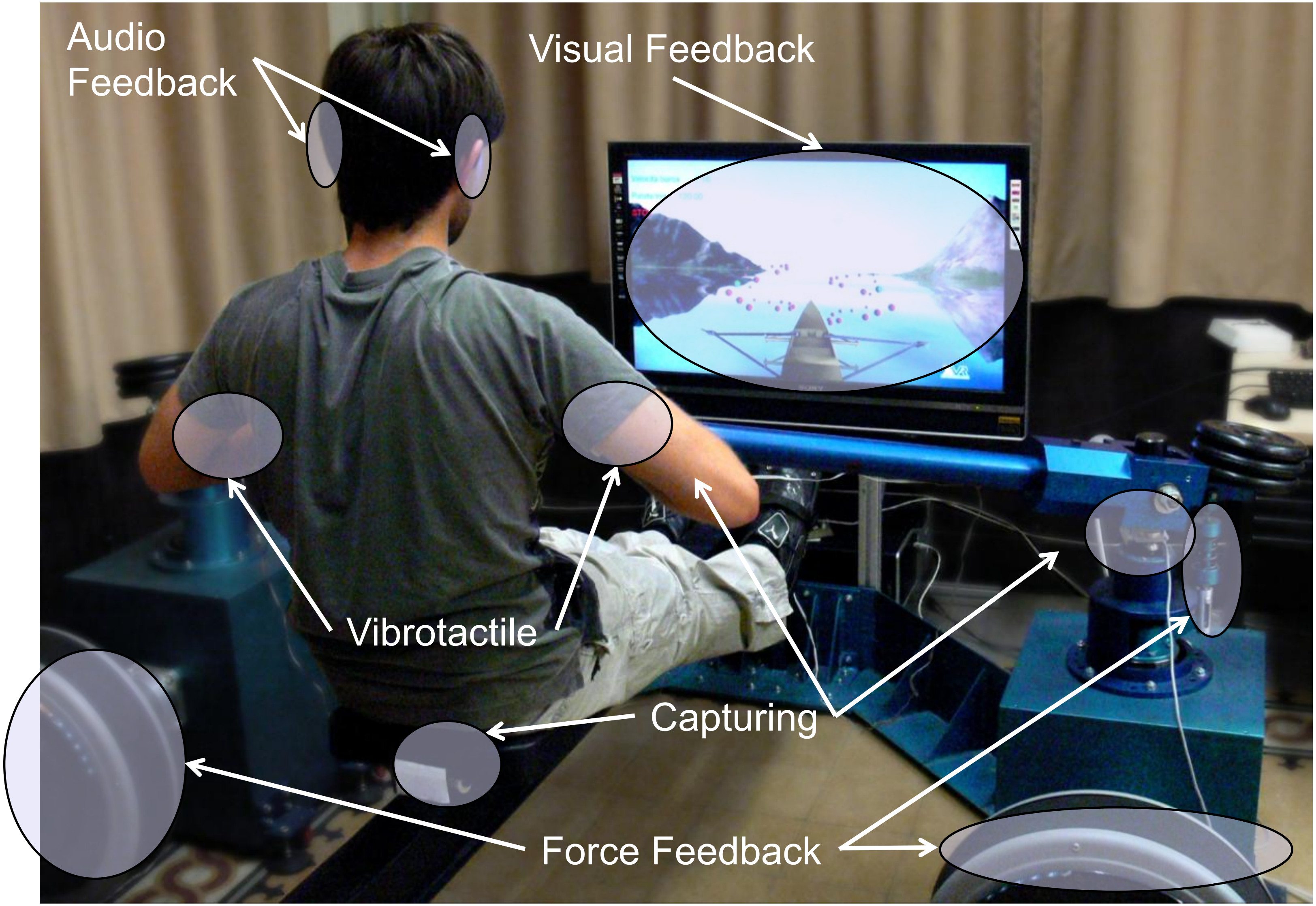
SPRINT Experience



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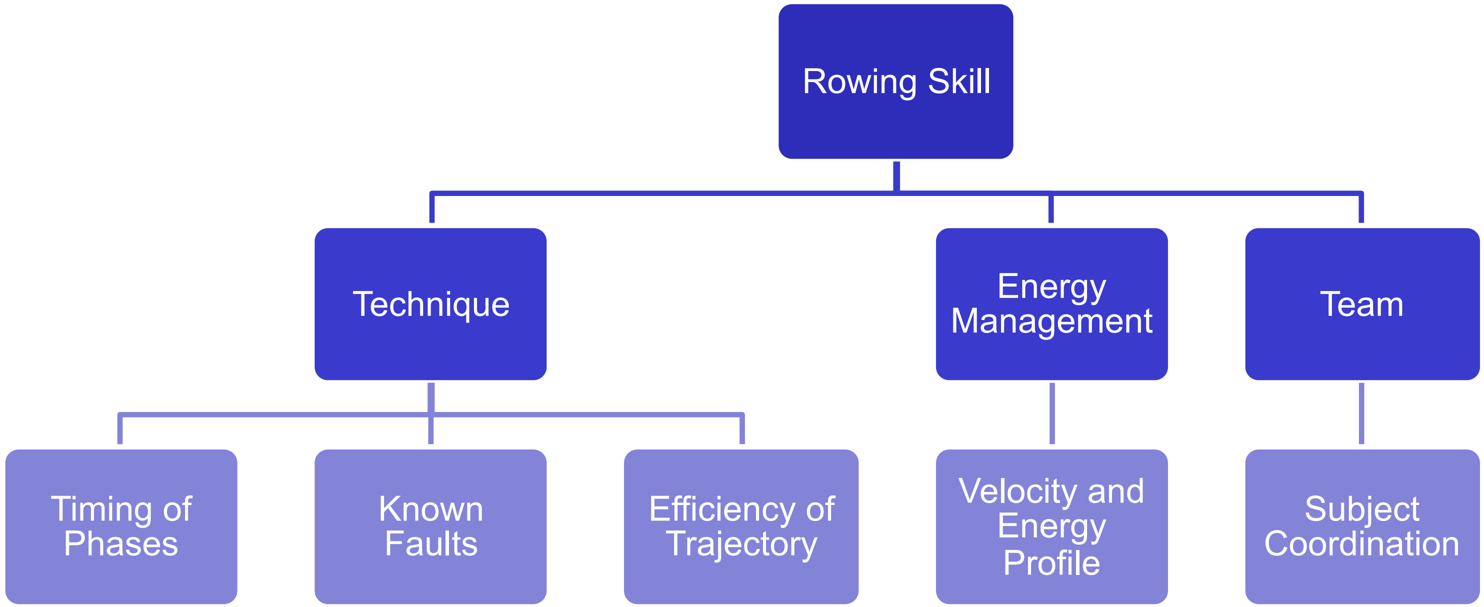
Rowing Skill



Technique

- **Control flexibility and attention management**
- **Procedural skills**
- **Coping strategies**
- **Bi-manual coordination**
- **Balance and posture control**
- **Perception-by-touch**

Energy

- **Control flexibility and attention management**
- **Coping strategies**
- **Perception-by-touch**

Team

- **Control flexibility and attention management**
- **Procedural skills**
- **Coping strategies**
- **Balance and posture control**
- **Perception-by-touch**

These aspects have been modeled and integrated in real-time capture and analysis in Simulink

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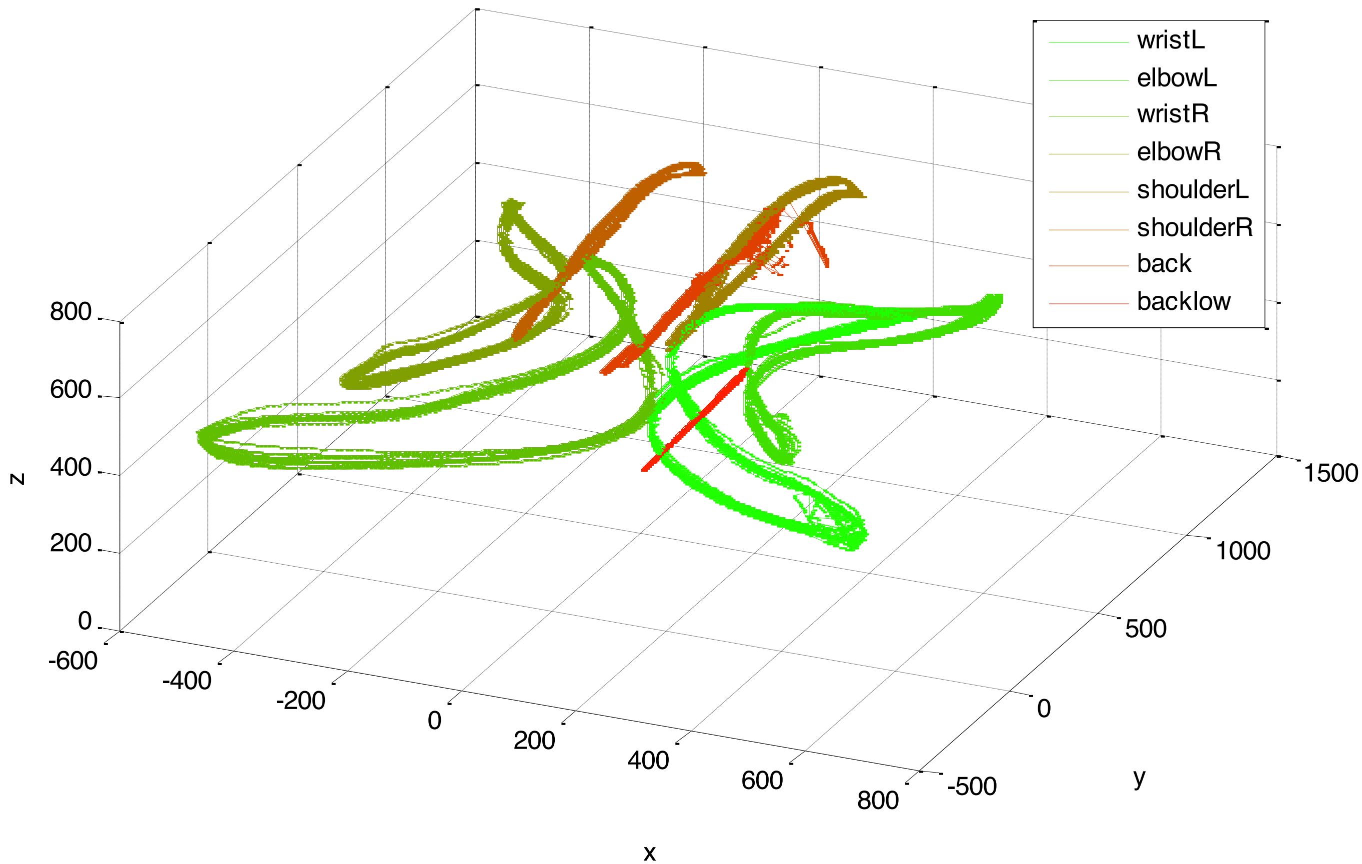
Biomechanical Modeling



Filippeschi A. & Ruffaldi E. (2013) "Boat Dynamics and Force Rendering Models for the SPRINT System" doi:10.1109/TSMC.2013.2284495 Human-Machine Systems, IEEE Transactions on 43(6) issn:2168-2291 631–642

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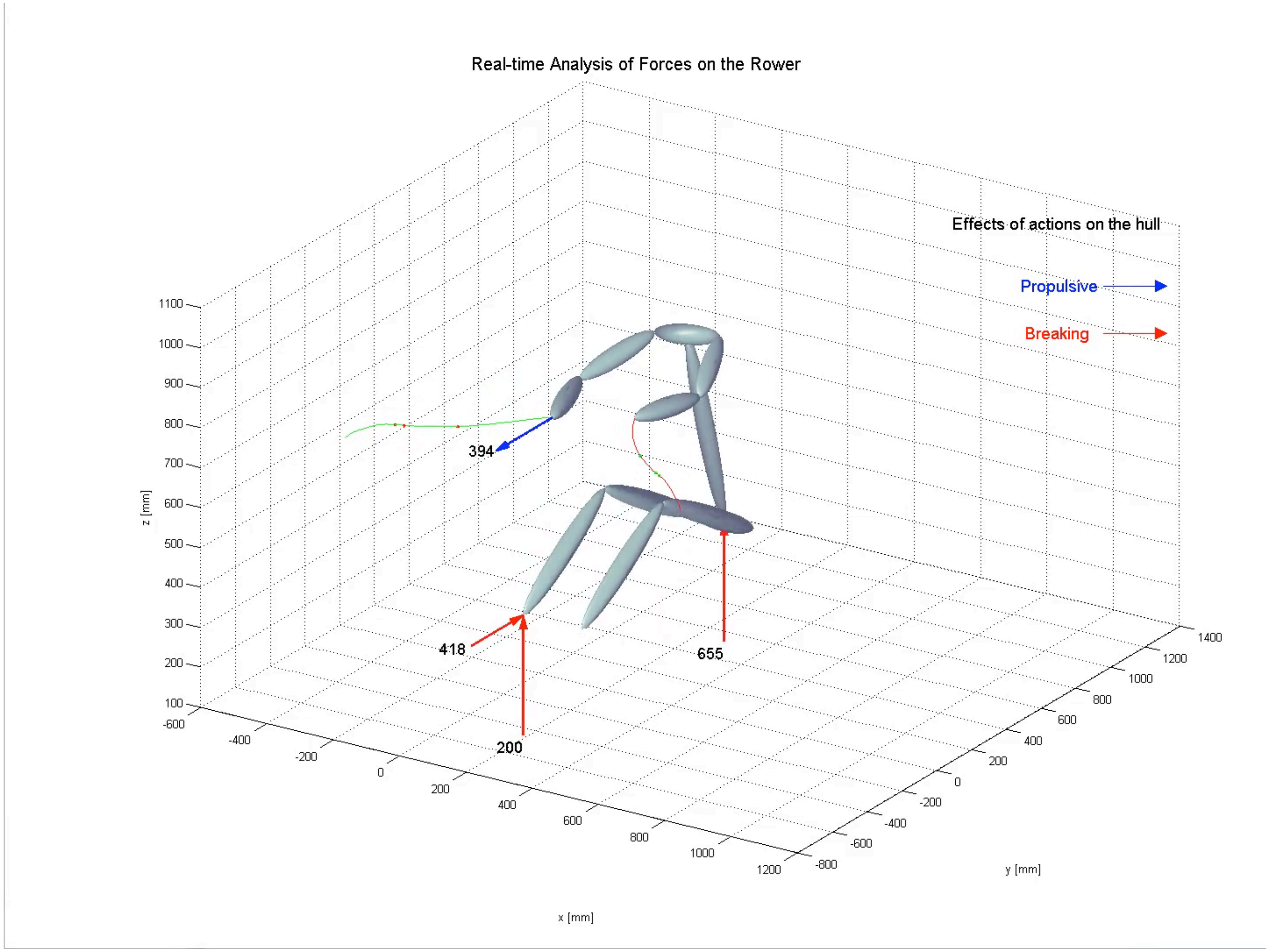
Biomechanical Modeling



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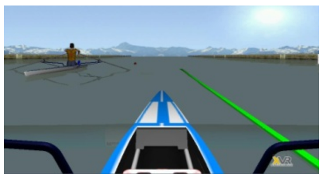
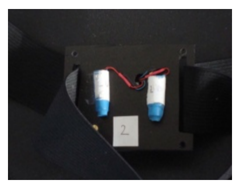
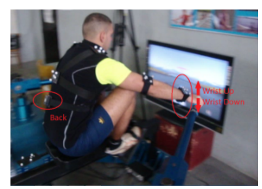
Training Accelerators

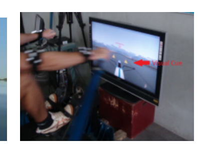
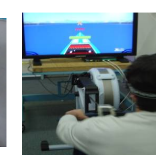
Virtual Human




Localized Vibrotactile

Augmented Visual

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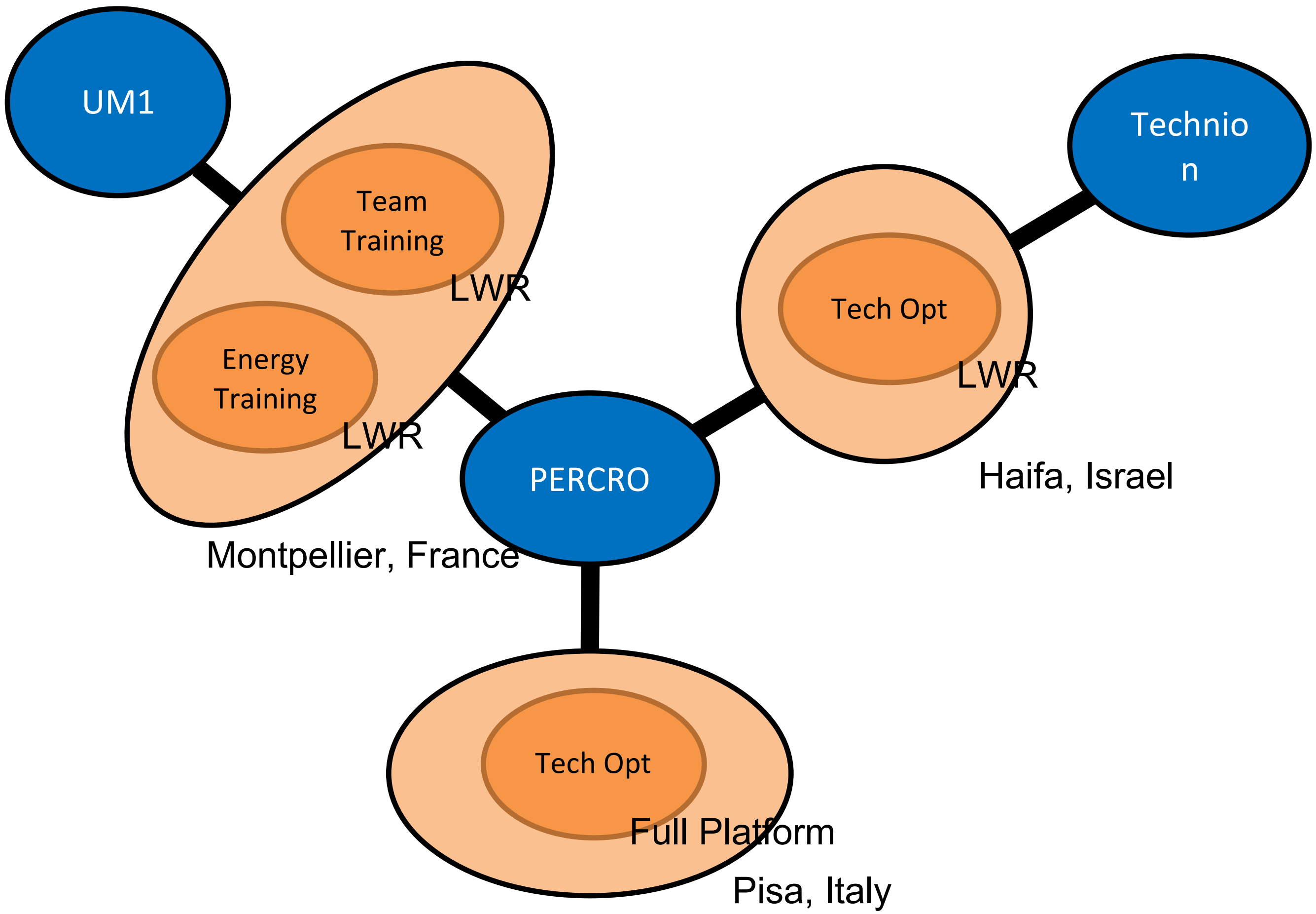
Evaluations



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Transfer

- **Research Question**: how it is possible to correct specific subject errors in intermediate rowers in a short timeframe?
- **Proposed Approach**: leveage previous results on multimodal technique training. Extend them with real-time error recognition

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Methodology

The approach pursued is based on a combination of Expert Data acquisition and Knowledge from Coach and Manuals

1) Manuals provide well known errors
2) Ask experts to perform correct behavior and known errors
3) Process everything using Machine Learning

For the purpose of

- Obtaining a way to identify error
- Score Athletes for training

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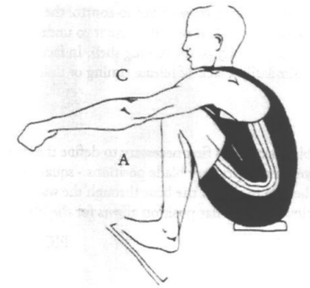
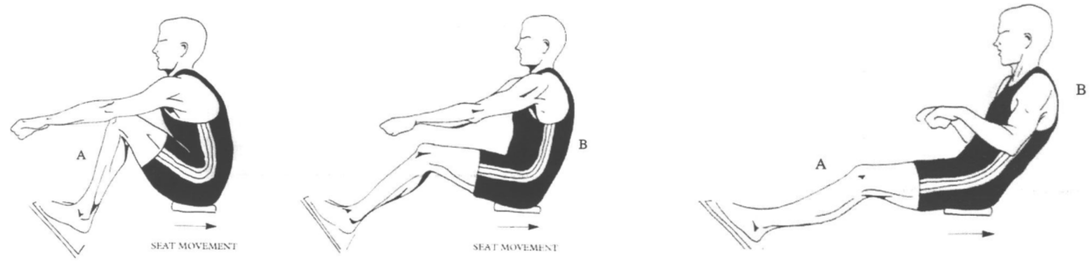
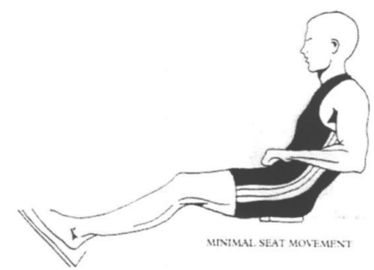
Sculling Phases



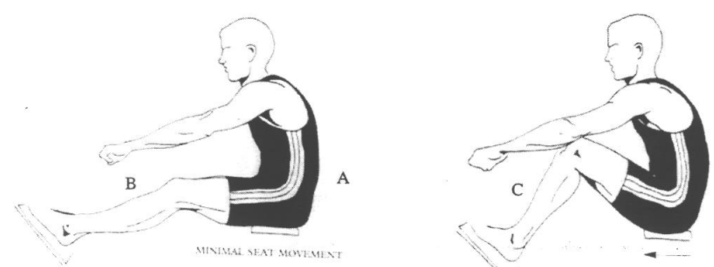
Catch (Blades enter into the water)



Drive (Leg Drive, Back Swing Arm Draw)



Release (No Propulsion, Blades out of Water)



Recovery

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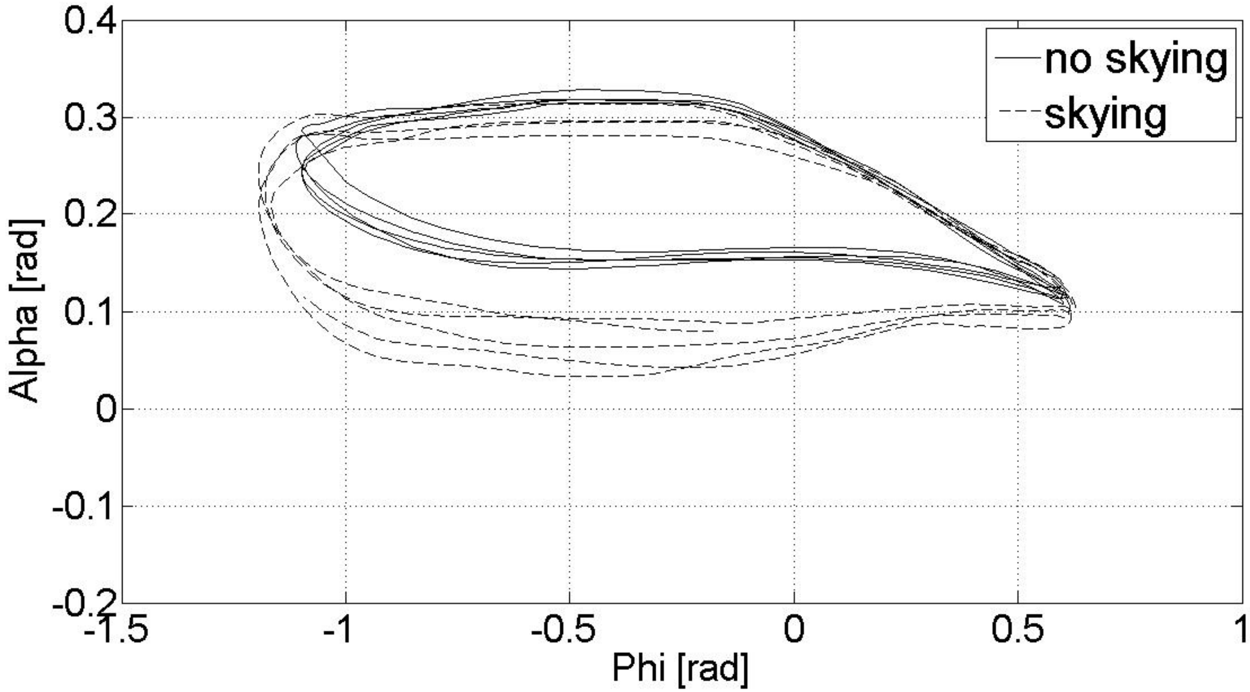
Skying Error



Blades Skying	Blades too high off the water at catch.	1. Handles are lowered before being raised. 2. Outside shoulder too low.	1. Row with oars on top of water.

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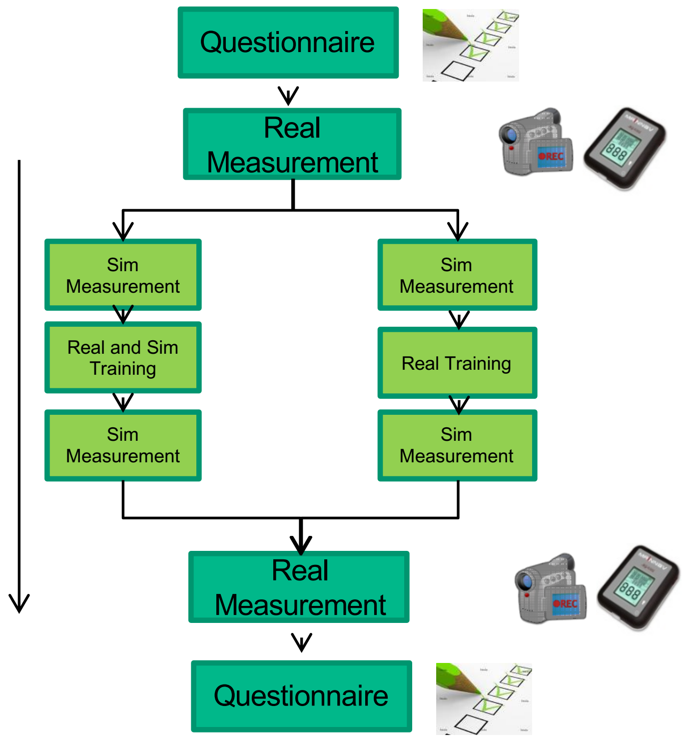
Transfer Design



- Record subject on the real boat
- Integrate VE training in real training

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Performance and Feedback

- **Performance:** score based on the real-time recognition of errors
- **Feedack:**
  - Visual feedback in the environment

- **Protocol:** 40 days, twice per week
- **Population**: rowers with 5-8 years

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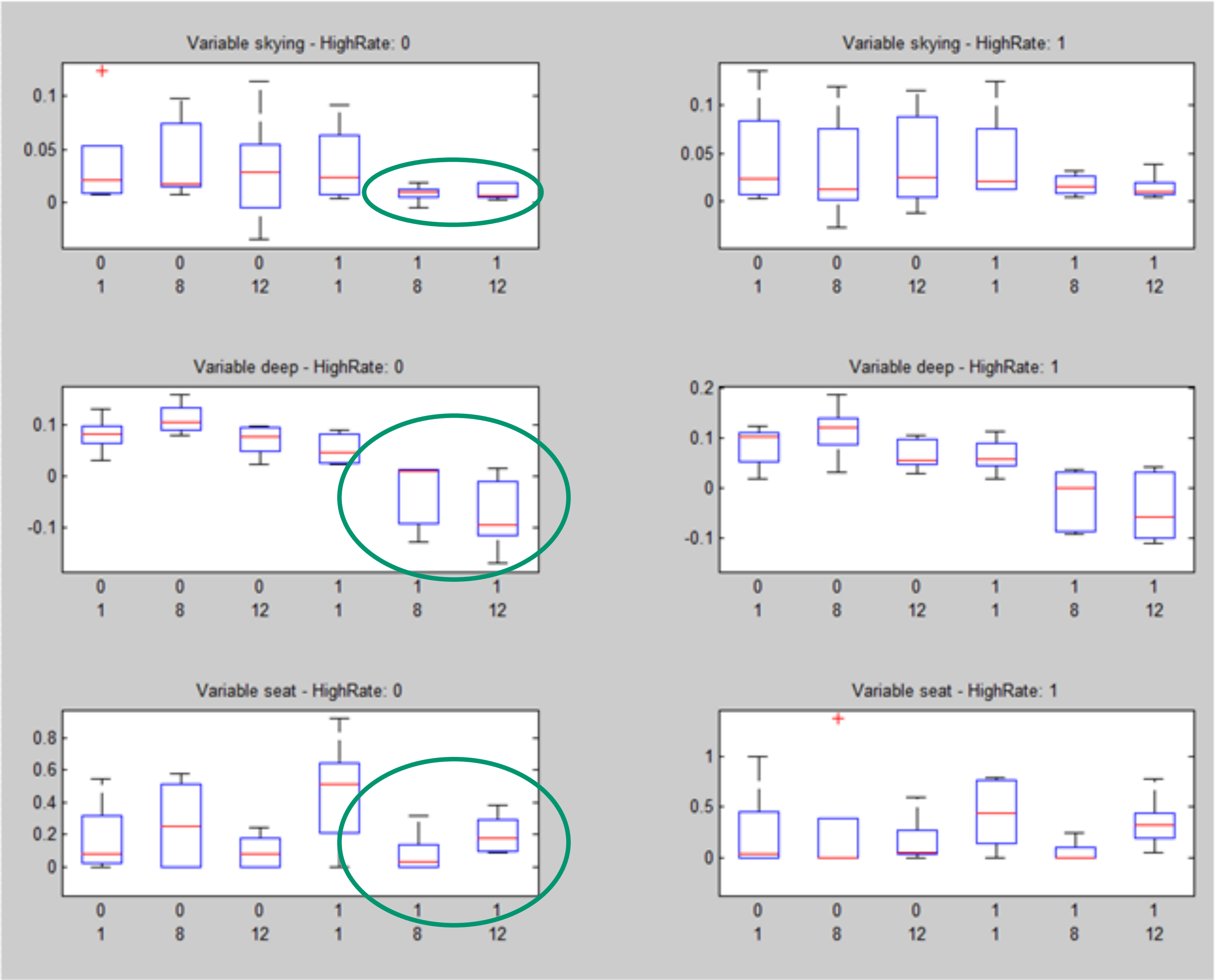
Results on SPRINT



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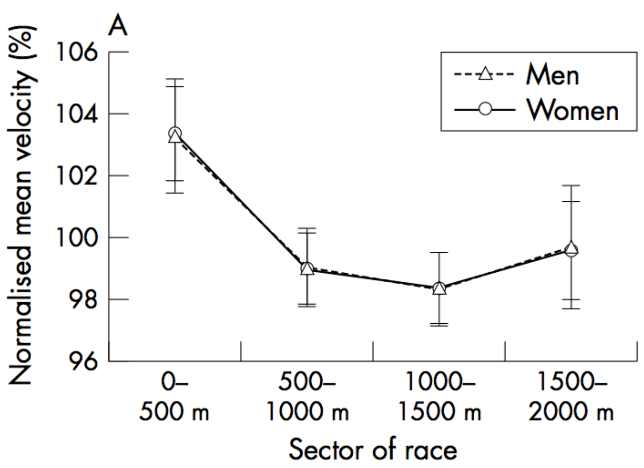
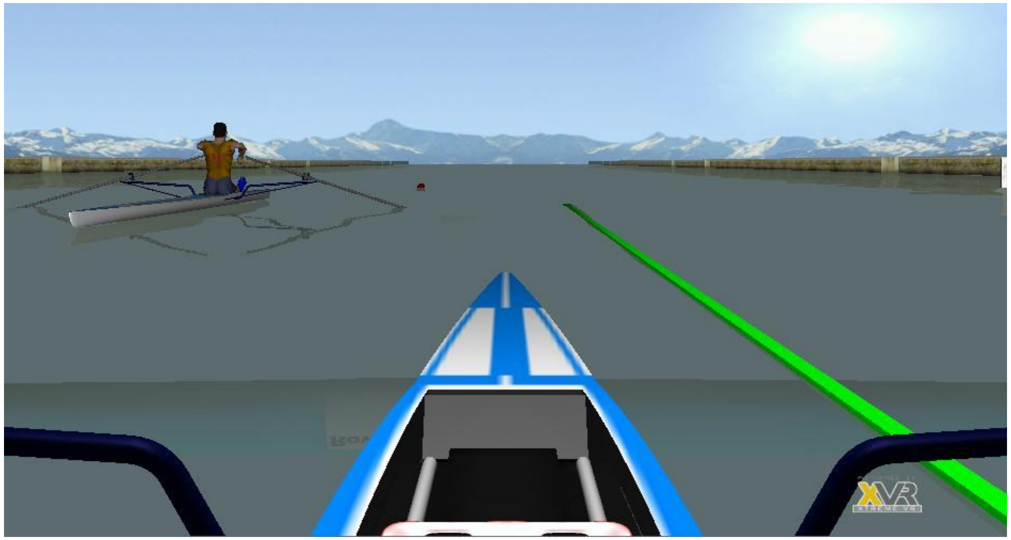
Energy Management Training

- **Problem**
  - Train profile of 2000m based on expert profile
- **Feedback**
  - Use Virtual Human showing (guidance) correct behavior as a reference to be kept at given distance
    - Guidance is Progressively (not Adaptively) reduced during the protocol
- **Subjects**
  - 15 males novice rowers whose ages ranged between 21 and 29 years completed the protoco
- **Protocol**
  - VO2 maximum test of subject
  - PRE assessment test
  - Training (1 month duration)
  - POST assessment
  - RETention after 30 days
  - TRAnsfer to 2500m after 30 days





Hoffmann C.P., Filippeschi A., Ruffaldi E. & Bardy B.G. (2014) *Energy management using virtual realit improves 2000-m rowing performance*“doi:10.1080/02640414.2013.835435 Journal of Sports Sciences issn:1546-4261 1-9

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Energy Management Feedback

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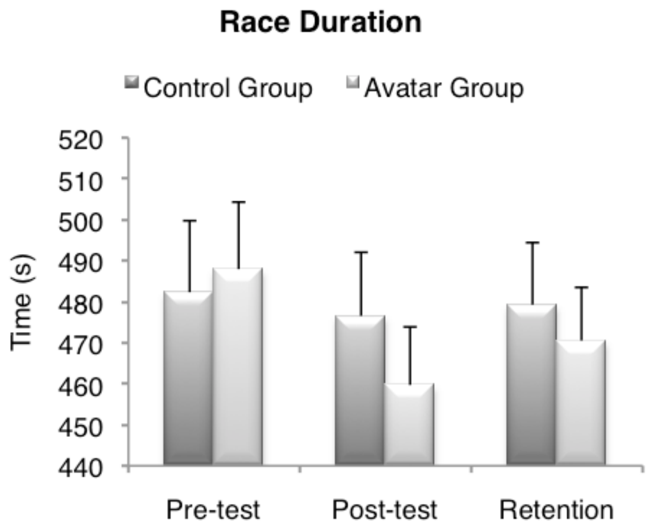
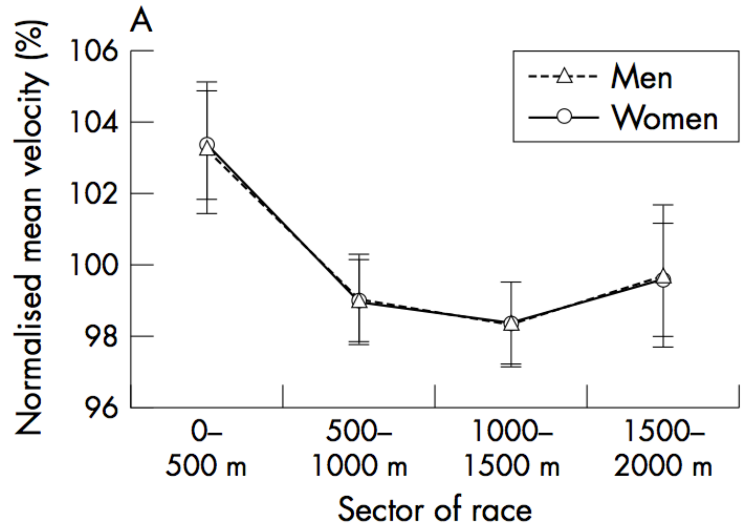
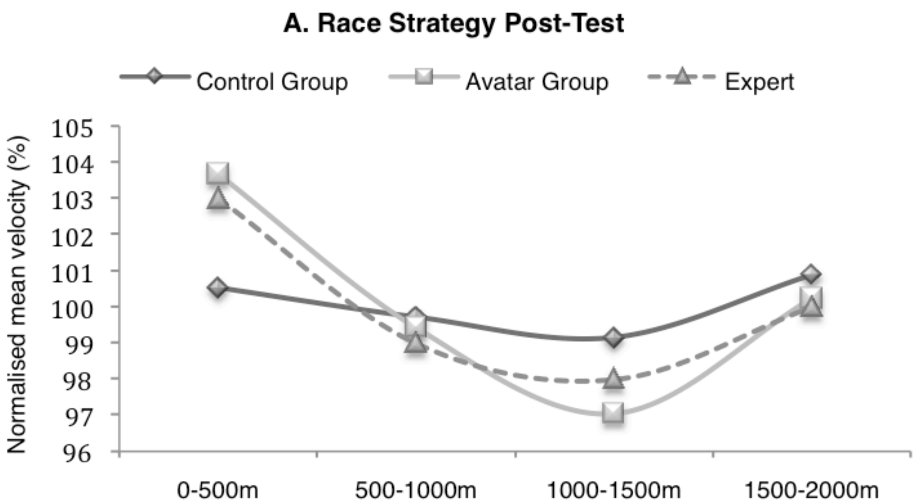
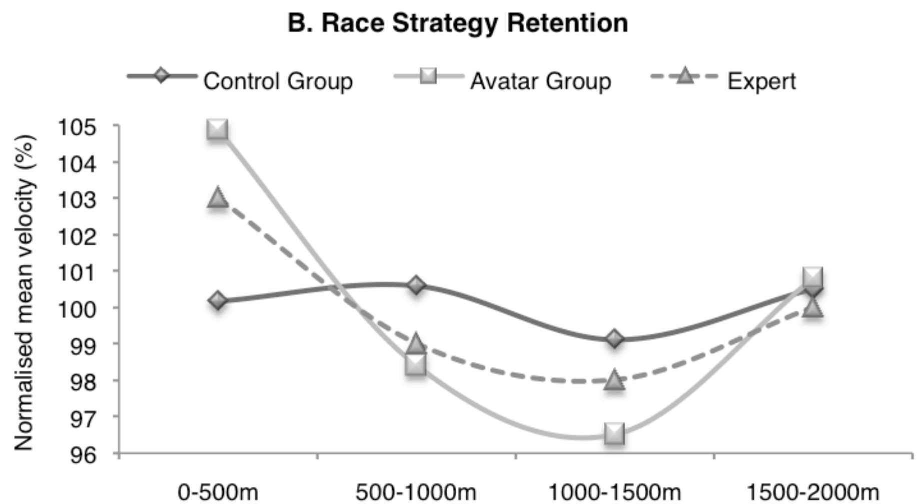
Energy Management Training









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Team Coordination Feedback

Varlet M., Filippeschi et al.. (2013) “Virtual Reality as a Tool to Learn Interpersonal Coordination: Example of Team Rowing“ doi:10.1162/PRES_a_00151 Presence: Teleoperators and Virtual Environments 22(3) issn:1054-7460 202-2015

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Future Directions for SPRINT

- SPRINT
  - Moving toward active Force feedback
  - Integrate Boat performance in training
  - Generative models of Virtual Rower (DMP like)
  - Moving toward Team boat simulation
  - Better usability for Rowing Clubs
- Sports in VE
  - Role of Robotics
  - Embedded Sensing

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Tele-presence for Improving Task

Virtual Reality can be used for learning a task in an ergonomic way in simulation, or in Tele-presence by the help of a remote expert.

Huang, W., Alem, L., & Tecchia, F. (2013). HandsIn3D: supporting remote guidance with immersive virtual environments. In Human-Computer Interaction–INTERACT 2013 (pp. 70-77). Springer Berlin Heidelberg.

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Conclusions

- New sensing and AR display allow for “ecological” training
- Physiological measures allow for more personalised and real-time feedback
- Machine Learning allow for analysis of skills and performance in new ways

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THANKS!

Emanuele Ruffaldi
www.eruffaldi.com

Project Website

www.percro.org/sprint/

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