Visual Biofeedback for Upper Limb Compensatory Movements: A Preliminary Study Next to Rehabilitation Professionals

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Abstract

In this preliminary study, we propose visual biofeedback techniques for representing compensatory movements that are commonly found in upper limb rehabilitation exercises. Here, visual biofeedback is represented by stick figures adorned with different graphical elements to highlight abnormal motor patterns. We explore 4 visual biofeedback techniques for analysing movements designed for neuromotor rehabilitation of the upper limb. Co-design sessions were conducted next to 5 rehabilitation professionals. The resulting visual designs were then evaluated by 3 other physiotherapists, each evaluated the visual biofeedback of two types of compensatory movements: arm elevation-flexion and cephalic tilt. Results indicate that although there is a preferred technique, participants suggested to design a novel representation that should incorporate features from different sources, thus designing a hybrid visual biofeedback technique.

CCS Concepts

• ***Human-centered computing*** → ***Empirical studies in HCI;*** • ***Applied computing*** → ***Life and medical sciences;***

1. Introduction

Critical to any movement disorder evaluation or treatment is the visual assessment of compensatory movements performed by patients. Such movements occur whenever patients manifest alternative muscle activation patterns when trying to compensate for motor function deficits, which in turn, leads to exercises that do not follow the right motor patterns to achieve the desired postures. Compensatory movements ultimately result in pain and inhibition of motor recovery [BH16]. Unfortunately, common clinical practice encourages subjective interpretations as compensatory movements are evaluated in plain sight (i.e., by visual inspection). Therefore, therapists lack the required objective information about their patients' adherence to rehabilitation exercises [BH16].

Towards a more objective interpretation of a patient's motion, interactive rehabilitation systems with corrective visual biofeedback appear as plausible candidates to improve compensatory movement evaluation. In this preliminary study, we are interested in how different visual biofeedback techniques can leverage motion analysis by representing upper limb compensatory movements in real-time. Each visual technique resulted from co-design sessions with rehabilitation professionals that were assessed by third-party physiotherapists to determine which designs can be used as effective depictions in rehabilitation practices.

2. Related Work

Amidst the visual biofeedback techniques used in physiotherapy, the most commonly displayed representation of motion consists of stick figures adorned with graphical elements that highlight biomechanical features [KVDG*]. Such simplified abstractions provide adequate visual biofeedback regarding motion performance [KVDG*, CGE*14], while contributing to the visualization of correct relationships between multiple connected joints, to explore and analyze data sets from biomechanical and neuromuscular simulations [KERC09,PST11]. Despite its clinical relevance, such biomechanical representation usually does not contemplate compensatory movements. In fact, little attention has been given to compensatory movement visualization [RSP*09]. Even so, the existing studies have focused on specific motion impairments, proposing specialized designs to evaluate and analyse compensatory movements, namely correct pelvis and trunk movements for total hip replacement patients [HBFS12], postural control [CGE*14], dynamic stability while walking [HHS15] or dynamic balance control in chronic stroke survivors [WHS16]. Regarding the upper limb, very few studies have reported the importance of visual biofeedback of compensatory movements [LMC*12, PFK*16]. Even less have yet validated their interfaces next to physiotherapists, lacking interface designs that feature user-centered visual biofeedback to aid compensatory movements detection [RSP*09].

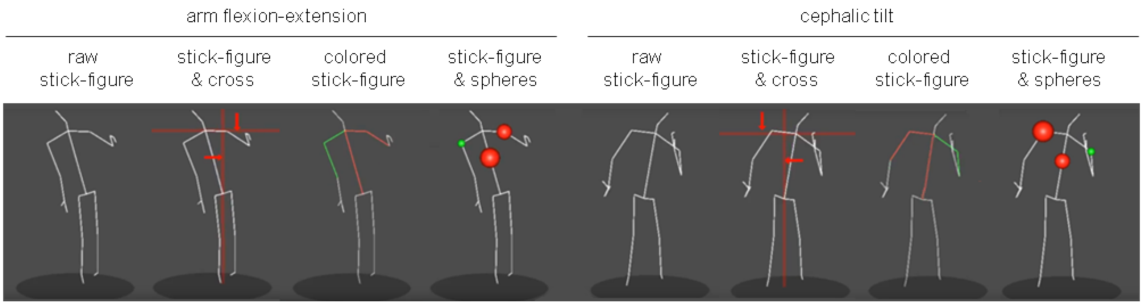

Figure 1: *Visual biofeedback techniques for representing compensatory movements during arm flexion-extension and cephalic tilt.*

3. Co-design Sessions

In collaboration with 1 physical physician, 2 rehabilitation physicians, and 2 physiotherapists from the Hospital Prof. Dr. Fernando Fonseca (E.P.E.), we designed visual biofeedback techniques for two types of compensatory movements that occur during upper limb rehabilitation: arm elevation-flexion and cephalic tilt. The design of the visual biofeedback techniques was iteratively developed based on an assortment of feedback collected from discussion sessions with domain experts. Each co-design session consisted of a presentation of design concepts, for instance, visual references showing motion capture data acquired from a Kinect™ sensor that they could critique, along with careful observation and interviews to collect their needs and to instill future directions of the designs. This process resulted in the following set of requirements: (i) any graphical representation should focus on essential kinematic and compensatory information; (ii) each visual biofeedback technique should manifest a perceptible simplicity; (iii) the joints of interest are shoulder joints, elbow joints; and (iv) inspired on a posture correction mirror, the domain experts strongly suggested using vertical and horizontal lines superposed to the stick figure.

3.1. Visual Biofeedback Techniques

Based on the co-design sessions, 4 visual biofeedback techniques were designed and implemented: *raw stick-figure*, *stick-figure & cross*, *colored stick-figure*, and *stick-figure & spheres*. The visualization displays joints and body extremities as points and body segments as line segments that add up to a stick figure representation of the whole body (Figure 1). Whenever the upper limb or trunk are incorrectly positioned, each visual biofeedback technique would included one of the following graphical elements to the stick figure (Figure 1): (a) color coded vertical and horizontal lines plus corrective arrows, (b) color coded stick-figure parts, and (c) radius varying spheres attached to notable joints. Compensatory movements were detected by measuring the slope of the line segment that connects both shoulders to calculate the unevenness of the shoulder girdle, and relative inclination of the trunk with respect to the vertical line. As for the color code it goes from green (correct movement) to yellow (tolerable movement) ending in red (incorrect movement). We have developed a graphical interface in Unity™ and Kinect™ SDK to visually represent the data acquired from a single depth-sensor camera (i.e., a stick-figure with 25 notable points), along with the graphical elements to portray important kinematic data and compensatory movements in real-time. To evaluate the visual biofeedback techniques, we asked a physiotherapist (24 years of experience) from a different clinical institute, the University Health Center Egas Moniz, to mimic the movements of a patient with unpaired upper limb, namely arm flexion-extension and cephalic tilt (e.g., hand to the mouth movement), while acquiring the kinematic data with a Kinect™ camera.

4. Evaluation

In order to evaluate the the potential clinical usefulness of the visualization techniques and to receive feedback on whether the design requirements were fulfilled or not, we conducted a user study using a think-aloud protocol and semi-structured interviews next to 3 physiotherapists from another institute, the Egas Moniz Health School. Participants had between 24 to 36 years of experience. All of them were potential users of the visualization techniques in their current work and were familiar with visual biofeedback as a concept. However, none had seen such visualization techniques prior to the study. Each physiotherapist visualized 8 short animations (2 movements $\times$ 4 visual designs) in a randomized order.

The major conclusions of this preliminary study are that *raw stick-figure* and *colored stick-figure* were considered to be not very useful as they provide a greater cognitive load on how to identify compensatory movements, whereas *stick-figure & cross* and *stick-figure & spheres* were considered much more useful as they enhanced the visualization of compensatory movements and promoted an easy reading of the different angles between segments. All participants highlighted how helpful the cross lines were to indicate the degree of shoulder and trunk unevenness, and also that the color code made sense. In addition, two participants revealed that the radius varying spheres may be a very interesting visual technique for their patients as it emphasizes the corrective information in a ludic manner (due to their balloon-like appearance). Finally, each participant suggested that a hybrid visual that combines *stick-figure & cross* and *stick-figure & spheres* should be more adequate as it provides a more complete set of information.

5. Acknowledgments

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