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

\begin{itemize}
  \item Human-centered computing \rightarrow Empirical studies in HCI;
  \item Applied computing \rightarrow Life and medical sciences;
\end{itemize}

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], 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 [RSP09]. 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 [HBF12], postural control [CGE09], 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,PFK]. Even less have yet validated their interfaces next to physiotherapists, lacking interface designs that feature user-centered visual biofeedback to aid compensatory movements detection [RSP09].

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from a single depth-sensor camera (i.e., a stick-figure with 25 no-

to the vertical line. As for the color code it goes from green

relevant kinematic and compensatory movements in real-time. To

evaluate the visual biofeedback techniques, we asked a physiother-
apist (24 years of experience) from a different clinical institute, the

3. Co-design Sessions

In collaboration with 1 physical physician, 2 rehabilitation physi-
cians, 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

arm flexion-extension: arm elevation-flexion and cephalic tilt. The de-
sign of the visual biofeedback techniques was iteratively developed

based on an assortment of feedback collected from discussion ses-
sions 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

you 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 cor-

rection 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 visual-

alization displays joints and body extremities as points and body

segments as line segments that add up to a stick figure representa-
tion of the whole body (Figure 1). Whenever the upper limb

or trunk are incorrectly positioned, each visual biofeedback tech-
nique 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 seg-

ment that connects both shoulders to calculate the unevenness of

the shoulder girdle, and relative inclination of the trunk with re-

spect 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 no-
table points), along with the graphical elements to portray impor-

tant kinematic data and compensatory movements in real-time. To

evaluate the visual biofeedback techniques, we asked a physiother-
apist (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 acquir-
ing the kinematic data with a Kinect™ camera.

4. Evaluation

In order to evaluate the the potential clinical usefulness of the visu-
alization techniques and to receive feedback on whether the design

requirements were fulfilled or not, we conducted a user study us-
ing 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 con-

cept. However, none had seen such visualization techniques prior

to the study. Each physiotherapist visualized 8 short animations (2

movements × 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 iden-
tify compensatory movements, whereas stick-figure & cross and

stick-figure & spheres were considered much more useful as they

enhanced the visualization of compensatory movements and pro-
noted an easy reading of the different angles between segments.

All participants highlighted how helpful the cross lines were to in-
dicate 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 informa-

tion in a ludic manner (due to their balloon-like appearance). Fi-
nally, each participant suggested that a hybrid visual that combines

stick-figure & cross and stick-figure & spheres should be more ad-

equate as it provides a more complete set of information.

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References


