Study of stressful gestural interactions: an approach for assessing their negative physical impacts

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ABSTRACT

Despite the advantages of gestural interactions, they involve several drawbacks. One major drawback is their negative physical impacts. To reduce them, it is important to go through a process of assessing risk factors to determine the interactions' level of acceptability and comfort so as to make them more ergonomic and less tiring. We propose a method for assessing the risk factors of gestures based on the methods of posture assessment in the workplace and the instructions given by various standards. The goal is to improve interaction in virtual environments and make it less stressful and more effortless.

1. INTRODUCTION

Gestural interactions allow users to manipulate a digital system using gestures, which can be compared to vocabulary for gestural interactions. Saffer (2008) defines a gesture as "any physical movement that a digital system can sense and respond to without the aid of a traditional pointing device such as a mouse or stylus. A wave, a head nod, a touch, a toe tap, and even a raised eyebrow can be a gesture." They differ from 'traditional' interactions (mouse or keyboard interactions, for instance) insofar as the latter do not consider the way in which the user performs the action. For example, the way in which the user presses a keyboard button does not matter: the only important thing is the fact that the button has been pressed, not the way of pressing it (Kurtenbach et al. 1990). In addition, more 'traditional' interactions provide a limited set of interactions depending on the structure of the input device (the number of buttons on a mouse, for instance) (Baudel, 1993; Isenberg and Hancock, 2012). Gestural interactions, on the other hand, allow users to take advantage of their whole body to interact with systems, therefore providing new interaction modalities and expanding the interaction vocabulary, resulting in a more flexible interface.

One of the purposes of gestural interactions is to facilitate interaction with virtual environments. They aim at being intuitive, easy to use and learn, since lots of them are based on the emulation of natural gestures (Rauterberg, 1999). Some can even fulfill specific needs, such as those of physically disabled people (Jégo et al, 2013). These interactions are supposed to entail less cognitive and physical effort than 'traditional' interactions: for example, the use of a mouse, which demands a physical effort because of its distance from the user, calls for the user's arm to be outstretched while requiring a very accurate gesture when pointing (Lalumière and Collinge, 1999). A well-thought gestural interaction could indeed solve those problems.

However, gestural interactions using movements requiring substantial physical effort can be associated with musculoskeletal disorders. What is more, the extended and/or frequent use of such systems can result in an overuse of the muscles in charge of performing expected gestures (Sparks et al, 2011).

There exist stressful, tiring, illogical gestures and some might be impossible to perform for certain people. For instance, interaction with some gestured-controlled TV sets is considered stressful (Freeman and Weissman, 1995) because of the high position of the hand during use. Interaction with touchscreens also affects user comfort negatively because of the need to keep one's arm outstretched (Lalumière and Collinge, 1999). The use of big screens is sometimes considered stressful to the neck because of frequent movements of the head and eyes (Bowman et al, 2006).

Few studies have been conducted on how to reduce the physical impact of gestural interactions on the human body and, as a result, non-ergonomic, stressful gestures that are difficult to use are often created, for want of guidelines (Aimaiti and Yan 2011). Interaction using such gestures can lead to various musculoskeletal injuries.

©2016 ICDVRAT; ISBN 978-0-7049-1547-3

To the goal of analyzing and assessing the health risks associated with gestures, we have studied task assessment methods in the workplace. Just like gestural interactions, those tasks consist of movements repeated frequently. In such assessment methods, physical impact of gestures is affected, for example, by the angle of the joint used in the gesture, the gesture's duration, its repetition, etc. The evaluation of those factors allows the assessment of gesture quality and consequently of their physical impact which, in turn, allows the design and implementation of ergonomic gestures that will cause neither pain nor stress, and which will be easier to use. We aim to implement a gesture assessment method based on certain criteria and factors stated in current studies.

In a first part, we present the medical problems related to gestures used in videogames and the workplace. The second part studies the existing assessment methods of physical movements. In the remaining parts, we propose a synthesis and an analysis of said methods as well as our own approach to assessing gestural interactions.

2. POTENTIAL NEGATIVE IMPACTS OF GESTURES

As mentioned previously (cf. Introduction), gestural interfaces are used more and more frequently in numerous domains. The use of such interfaces implies the performance of certain types of movements, sometimes repeatedly and/or for a long time, necessitating some effort. The overuse of the muscles in charge of these gestures can cause musculoskeletal disorders (MSDs). "The term MSD groups some fifteen diseases acknowledged as work-related pathologies. These pathologies represent more than 70% of known work-related pathologies" (Aptel et al, 2011). MSDs affect the muscles, tendons and nerves of upper and lower limbs, at the level of wrists, shoulders, elbows or knees.

A lot of MSDs have resulted from the frequent use of gestural interactions, such as those included with the Wii® gaming console (Jones and Hammig, 2009).

2.1 Painful gestures

Painful gestures are often caused by being subjected to an external or internal force and by exceeding the standard angle range at which joints are normally used. Those out-of-range angle values can be occasioned by numerous movements such as extension, flexion, abduction, adduction, pronation, etc. The movement range determines whether the joint is overly used and if the gestures resulting from the movement are potentially painful. Besides, static and dynamic constraints on some parts of the human body impact movement range and interdependence. (Nielsen et al, 2003; Eaton, 1997), for example adduction (moving a body part towards the median axis of the body), abduction (moving a body part outwards from the median axis), as well as pronation and supination, which designate limb rotations.

2.2 Injuries related to videogames based on gestural interactions

The repeated use of videogames can cause musculoskeletal injuries: for example, the use of the Wii® gaming console has occasioned sore muscles and knee, shoulder and heel injuries (DOMS: Delayed Onset Muscle Soreness) (Sparks et al, 2011).

Videogame-related injuries can be classified in four categories:

1. Tendinopathy: tendon injuries.
2. Bursite: swelling and irritation of one or several bursa.
3. Enthesitis: inflammation of the sites where tendons and ligaments are inserted into the bone.
4. Epicondylitis (tennis elbow): painful inflammation of the tendon on the outside of the elbow.

The main cause for such injuries and inflammations is the repeated stress undergone by involved muscles. According to the National Electronic Injury Surveillance System (NEISS), a high percentage of MSDs (67%) involve the use of Wii® in playing virtual sports (Jones and Hammig, 2009).

2.3 Work-related injuries

The movements used during gesture interactions are extremely similar to those performed in the completion of some work-related tasks at the level of repetitions, extended time span, involved muscles, postures and the force exerted (Sparks et al, 2011; Muse and Peres, 2011). These movements could occasion injuries called "Repetitive Strain Injuries" (RSIs). Several diseases have been associated with RSIs such as tendinitis, bursite, tenosynovitis, carpal tunnel syndrome, etc. (Simoneau et al, 1996). Symptoms such as pain, discomfort, and a sensation of localized fatigue in an overused joint can all point to RSIs.

The risk factors associated with the onset of RSIs and their level of severity depend on time span, frequency and intensity, and have been classified in six categories: awkward postures, force, effort and musculoskeletal load, static muscular work, exposure to certain physical stressors, repetition and the unvarying nature of the work, as well as organizational factors.

Effort depends on the joints involved, movement direction, posture and individual characteristics (Aptel et al, 2011).

In gestural interactions, most gestures are deemed natural (natural user interface) (Rauterberg, 1999), and require certain spatial movements, which in turn demand some effort as well as an internal or external force which can over-exert muscles and tendons affected by these activities (Sparks et al, 2011). Moreover, these movements are repetitive, and occur over a long time span (Aimaiti and Yan 2011). It is therefore possible to speculate that videogame- and work-related injuries are similar to those resulting from gestural interactions. It is rather clear that movements with extended arms, device vibrations and activities involving one's arm are very similar.

According to Nielsen (Nielsen et al, 2003) the basic principles of gesture ergonomics are: avoiding external positions, avoiding repetition, muscle rest, favoring neutral, relaxed positions, avoiding static positions as well as avoiding internal and external forces on joints and the interruption of the natural flow of bodily fluids.

3. GESTURE ASSESSMENT METHODS

It is crucial to find gesture assessment methods to devise gestures which do not lead to fatigue and health hazards.

3.1 Gesture assessment

The reduction of the negative physical impact of gestures requires an assessment procedure. This procedure would allow determining the level of comfort and the stress they cause by measuring risk factors related to said movements. Assessment methods are classified in two categories:

3.1.1 Subjective methods. Most studies on the assessment of the negative impact of gestures and physical movements in general resort to subjective methods (Nielsen et al, 2003; Muse and Peres, 2011). Amongst those, one can find:

- The Body Discomfort Diagram method (BDD), which assesses the level of discomfort in different parts of the body using a diagram of the body and an assessment scale. The diagram allows identifying and assessing the places and sources of discomfort by marking the affected areas (Cameron, 1996).
- Scoring methods, where a number of points is assigned to each single movement and criterion, resulting in a final score which determines the gesture's level of comfort. Each single score is decided either by the users (Nielsen et al, 2003) or by experts (ergonomists, etc.) (McAtamney and Corlett, 1993).
- Other methods are used, such as questionnaires (Ha et al, 2006), interviews, open-ended questions (Muse and Peres, 2011).

3.1.2 Objective methods and angle measurements. There exist methods and standards which allow the assessment of physical movements in a more objective way:

- *Electromyogram.* The electromyogram is a tool which measures muscle activity through the detection and recording of electric signals sent by muscle motor cells used during activity. The electric signal is amplified and processed to determine the level of muscle force exerted. (Long et al, 1970; Freivalds, 2004). This technique is used by Muse and Peres (2011) to measure muscle activity pertaining to the gestures and effort when interacting with touch-enabled devices.
- *RULA (Rapid Upper Limb Assessment).* RULA is a risk-factor assessment technique for upper limbs, geared towards individuals subjected to postures, forces and muscle loads potentially leading to MSDs (McAtamney and Corlett, 1993). The assessed factors are: number of movements, static work, force, work posture and working time.

  RULA allows the attribution of a final assessment score for each posture ranging from 1 to 7. This score indicates the level of discomfort for the posture: the higher the score, the higher the risk. It follows diagrams specifying the ranges of joint angles for various body parts. In these diagrams, a score is given to each movement depending on its angle (the farther the angle from a neutral position, the higher the score). This numbering system is also used to specify the level of force exerted as well as static and repetitive muscular activity. To calculate the scores, three score charts —defined by ergonomists— are used (McAtamney and Corlett, 1993).

The use of RULA is manual and the assessment is only possible for one side of the body at once (left or right).

- *The ISO 11226 standard.* The ISO 11226 standard (ISO, 2000) aims at assessing health hazards for workers involved in manual labor. The assessment process involves specifying and classifying posture conditions for each body part as acceptable or not. These conditions comprise joint angle, time-related aspects and movement repetition. The classification is based on experimental studies as well as the current knowledge in ergonomics.

  The assessment procedure is a one- or two-step process. The first step measures joint angles. If said angles do not exceed a given limit, the posture is deemed 'acceptable'. If not, the second step focuses on the time span for which the posture is sustained. Extreme angles are never recommended. There exist several methods to recognize postures, such as observation, video, etc. Other factors are considered while assessing static postures, such as support (or its absence), sitting or standing position, etc.

- *The AFNOR NF EN 1005-4 standard (Safety of machinery – Human physical performance).* NF EN 1005-4 is an AFNOR standard (CEN, 1998) aiming to improve machine design in order to decrease health risks by avoiding postures and stressful movements leading to MSDs. This is done through the specification of various recommendations as well as a posture- and movement-related risks assessment method.

  It defines a posture and movement assessment procedure related to working with machinery. The assessment can either be 'acceptable', 'acceptable under conditions' or 'unacceptable'. The assessed risk factors are: movement angle, gesture time, frequency, etc. In situations determined as 'acceptable under conditions', other risk factors must be considered, such as duration, repetition, period of recovery, the presence of a support to the body, etc.

In addition, some assessment methods for physical movements and some specifications for acceptability status for joint angles ranges were presented by 'Institut National de Recherche et de Sécurité' (INRS, National research and safety institute) (Aptel et al, 2000). Their objective was to better diagnose the work conditions in order to prevent musculoskeletal disorders.

3.2 Creating non-stressful gestures

Gesture creation by the user results in gestural interfaces taking user preferences and needs into account. Approaches to creating gestural interfaces are based on the concept of interface adaptability (Bobillier-Chaumon et al, 2005). One way is to use predefined (standard) gestures, where standard gestures are conceived from natural human gestures. A set of gesture vocabulary is derived by observing, collecting and assessing natural gestures performed by operators during scenarios (Nielsen et al, 2003; Ruiz et al, 2011; Wobbrock et al, 2009). The assessment is used to select the final gestures that will be used. Only few studies take physical factors into account during gesture assessment. Another way is to let the user define the gestures he wants to use in a preliminary step before starting to use the system (Jégo et al, 2013). However, the physical impact of the resulting gestures is not assessed.

4. DESIGNING AN ASSESSMENT METHOD FOR GESTURAL INTERACTIONS

We aim to design an assessment method for gestures used during interaction that would minimize their negative physical impacts. A complete gesture consists of a set of single gestures whose assessment results in an overall assessment of the gesture. The assessment of these gestures is done through the assessment of certain conditions and variables of the postures and physical movements effected. These conditions are: joint angles, posture duration, frequency, muscle load and external force.

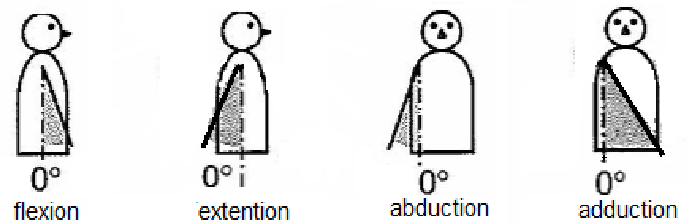

Figure 1. *Shoulder movements [Aptel et al, 2000], modified.*

Variables will be assessed based on specifications for acceptable and unacceptable movements in various studies and standards (CEN, 1998; ISO, 2000; Aptel et al, 2000; McAtamney and Corlett, 1993). These specifications assess movement variables, thereby evaluating the quality of the gesture.

The data related to each joint is organized in tables specifying all possible movement types for said joint and giving acceptable or unacceptable values for the various criteria and variables of movement. The angle of movement is a key factor in the assessment process, since it indicates the level of joint stress and, consequently, the potential discomfort to which that stress could lead.

The various levels of acceptability and comfort for shoulder movements (Figure 1) are shown in Table 1. In this table, the acceptability of postures and gestures is mainly determined with joint angles. What is more, gesture duration, movement frequency and other factors potentially affecting the level of comfort are assessed, such as supports for the body, an even distribution of weight on legs and feet, etc. Joint ranges are classified in 'acceptable', 'acceptable under conditions' or 'unacceptable' categories. The acceptability of movements is always connected to tasks with enough variation at the mental and physical levels (ISO, 2000). Similar tables for each joint have been compiled and are not printed here for want of space.

Table 1. *Recommendations for shoulder joint angles (CEN, 1998; ISO, 2000; Aptel et al, 2000; McAtamney and Corlett, 1993).*

Movement	Source	Acceptable limit (1)	Acceptable under conditions – Not recommended (2)	Unacceptable limit (3)
Antepulsion (Flexion- front)	AFNOR 1005-4	0° -20°	- 20° - 60° if static: (supported arm) or (short duration + recovery time) . - 20° - 60° if frequent. - 20° - 60° if: - frequency <10 per min - short duration - > 60° if short duration and not frequent	- > 60° if static - > 60° if frequent
	INRS	0° -20°	20°-60°	> 60°
	Tab Reg G			> 60°
	RULA	20° (1 pt)	20° - 45° (2 pts) 45°-90° (3pts)	> 90° (4 pts)
Retropulsion (Extension- back)	AFNOR 1005-4	0°	> 0° if : - not frequent - short duration	> 0° if static > 0° if frequent
	ISO 11226	0°		> 0°
	INRS	0°		> 0°
	RULA	0°-20°(1 pt)	> 20° (2 pts)	
Adduction	AFNOR 1005-4	0°	> 0° if : - not frequent - short duration	> 0° if static > 0° if frequent
	INRS	0°		> 0°
Abduction	AFNOR 1005-4	0° - 20°	- 20°-60° if static: (supported arm) or (short duration + recovery time) - 20° - 60° if not frequent. - 20° - 60° if: - frequency <10 par min - short duration - > 60° if short duration and not frequent	- > 60° if static - > 60° if frequent
	ISO 11226	20°	20°-60° (with support or check max time)	> 60°
	INRS	20°	60°	> 60°
	RULA	stressful (1 pt)		
Elevated shoulder	AFNOR 1005-4		stressful : if not frequent	stressful if frequent
	ISO 11226			stressful
	RULA	stressful (1 pt)		
Hyperadduction of the arm (with shoulder antepulsion)	ISO 11226			stressful
Extreme external rotation				
Arm support	RULA	- 1 pt		
Trunk leaning forward				

The measurement of time is crucial in the assessment of the acceptability of work postures: the longer the gesture and the higher number of repetitions, the more stressful the movement is. The different approaches use various strategies to measure time. Some measure movement frequency (repetition) (CEN, 1998; McAtamney and Corlett, 1993), others measure gesture duration (ISO, 2000), etc. Table 2 below shows ways of assessing time according to various approaches. In ISO 11226, the assessment of gesture duration is necessary when one gets a result that is 'acceptable under conditions'. In that case, time is of the essence in the assessment process. The standard comprises graphs which plot the relationship between joint angle range and the maximum acceptable gesture duration. According to these curves, the movement is deemed acceptable if it does not exceed the maximum time (y) depending on the joint angle (x). The equations in Table 2 are calculated from these graphs (ISO, 2000; ISO, 2006). Some approaches use a scoring system based on an accumulation of points (McAtamney and Corlett, 1993; Nielsen et al, 2003). Besides, other approaches depend on joint angle testing followed by gesture duration to determine its acceptability (ISO, 2000). The information about the levels of acceptability of joint ranges, duration and other risk factors (such as repetition, force, muscle load, etc.) defined in various approaches are collected and organized so as to be used in the assessment process which aims to determine the level of acceptability of the gesture.

5. SOFTWARE STRUCTURE

5.1 Approach

Our goal was to develop a computer application that would allow detecting the conditions and variables of users' freeform empty-handed gestures, assess them, and determine their level of acceptability automatically according to various pre-existing methods and standards. The variables are mainly joint angles, duration, frequency, supports for the body, movement and posture style (weight distribution on both feet, rotation, etc.) This application could be used in the design phase of gestural interactions to decide which gestures are best. What is more, it could be used to assess pre-existing gestural interfaces and find out whether they are stressful.

Table 2. *Recommendations for the duration and frequency of movements. The application's inputs are: The physical movements detected by a Kinect device (which will probably be replaced by a more accurate device in the future).*

Inputs	Method
ISO11226 (ISO, 2000)	Trunk: for a leaning movement ranging between 20°- 60°, time acceptability is calculated with this equation: $y = -\frac{3}{40}x + \frac{11}{2}$
	Head: For a supported bowing movement ranging between 25°-85°, time acceptability y is: $y = -\frac{7}{60}x + \frac{131}{12}$
	Shoulder: For a supported abduction (elevation) ranging between 20°-60°, time acceptability y is: $y = -\frac{1}{20}x + 4$
RULA (McAtamney and Corlett, 1993)	Time is incorporated in the static load (calculate load versus time separately). Scores A or B is increased by 1 point if the posture is static Scores A or B is increased by 1 point if repeated (more than 4 times per minute).
AFNOR (CEN, 1998)	Movement repetition (if frequency >= twice per minute) Duration (according to ISO 11226).

5.2 Input

The application's inputs are:

- The physical movements detected by Kinect (which will probably be replaced by a more accurate device in the future). From the capture, we deduce:
  - angles
  - duration
  - repetition
- The presence of supports for the body and the possible presence of a rotation are manually entered for the time being.
- The tables of acceptable values for the following methods:
  - RULA

– ISO 11226
– AFNOR 1005-4
– INRS

5.3 Outputs

The application outputs results in a dialog box which includes:

- A binary assessment (acceptable or not) of the evaluated body posture, depending on the analysis through each approach we have implemented (RULA, INRS, ISO, AFNOR). Said assessment will only return 'acceptable' if the collected data is deemed 'acceptable' to each of the aforementioned standards and methods. We have adopted such an approach to ensure a maximum level of safety.
- In the case of a non-acceptable evaluation of the gesture, acceptability results broken down by body part will also be displayed, so as to easily locate the stressful areas which invalidated the assessed gesture.
- On the application interface, stressed joints will be colored in red in real time as shown in Figure .

5.4 Architecture

The application's design emphasizes clarity, modularity and revisability. It was indeed essential, when envisioning a basis which could be adapted to various uses and custom applications, that designers of gestural interactions could modify the software as they see fit without causing the whole program architecture to fall apart. It also makes potential evolution of test methods possible, following progress in the field or, in the case of a custom application, specific constraints or in-house assessment methods. It is thus very easy to modify or add tests to the aforementioned standards and objective methods included in the application. Furthermore, in the perspective of maximum safety, the software was designed to detect the maximum angles reached in the course of a gestural interaction, and it computes its assessments from these maximums, according to the standards and methods stated above.

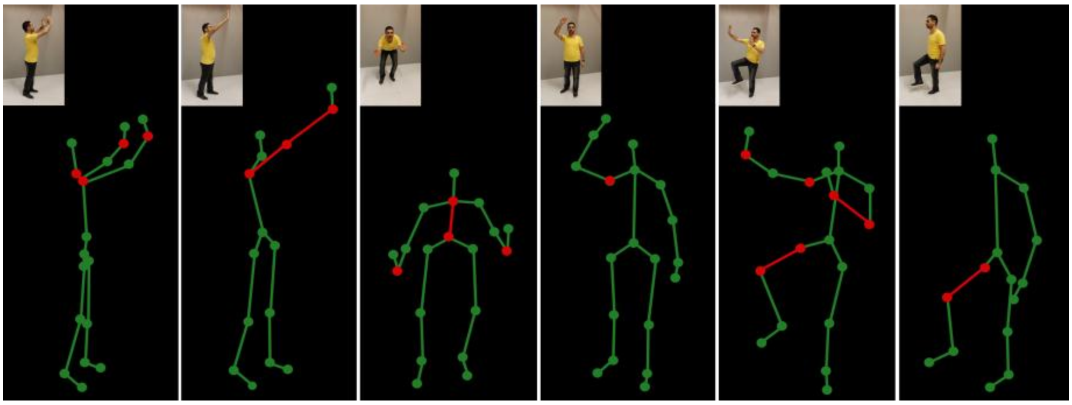

Figure 2. *Stressed joints, colored red in the application real-time output (simulated).*

6. PERSPECTIVES

6.1 Assessment

The goal of the assessment is to define less stressful standard gestural interactions. We will test a gestural interaction using certain joints (for instance shoulder, elbow, wrist, etc.) to decide on whether it is stressful. If it is, we will be able to point to the problematic joint(s) and the reasons for the stress (extreme angle, repetition, etc.) A subject will perform gestural interactions and the software will assess those gestures and display the assessment result (acceptable / unacceptable). It will also be possible to test several gestures and compare them to find the least stressful. We also collect additional subjective data from users to incorporate them into the assessment process for a better appreciation of user stress.

6.2 Validation of the application (Method)

We are aiming at validating our method through performing an experiment where subjects manipulate a gestural interface through performing certain tasks in different conditions. The application then evaluates the physical stress and gives results about the level of fatigue for each gesture and each joint. Furthermore, subjective results are collected from the subjects through a questionnaire about the level of the fatigue they felt in each condition and each joint. The results given by the subjects and those given by the application will be analyzed and compared to find whether they are correlated and by consequence whether the method is valid or not.

- Subjects. 26 potential users of virtual reality systems (students, museum visitors, videogame players, etc.).
- Tasks. We are currently developing several elementary and composite tasks to test our approach. For example, the tasks of selecting and moving an object, exploring a scene, etc. The first one is to arrange items, that is to select an object among several in the stock box, move and drop it in the corresponding box. Each task can be performed in different conditions (box height, number of times, time required, accuracy, etc.) Each subject is asked to arrange objects in various boxes using gestural interaction.
- Physical devices: Microsoft Kinect for Xbox® motion sensor and a computer screen showing the movements and assessment results.

6.3 Improving detection accuracy

We are for the moment using the Microsoft Kinect for Xbox® motion sensor to detect the movements. We plan to use more accurate movement detection techniques, such as a multi-Kinect system and / or an ART-Tracking movement detection system. We preferred using the Kinect device for his portability and usage facility (Zerpa et al 2015) .We are also thinking of using an EMG to detect the level of physical effort exerted, thereby making the method even more objective.

7. CONCLUSION & FUTURE WORK

In spite of the undeniable advantages of gestural interactions, the latter still exhibit several weaknesses, amongst which their negative physical impact on the subject performing them. In order to reduce that impact, it is important to implement a risk-factor assessment procedure to determine the levels of acceptability and comfort of the suggested gestures. This will ensure that the interactions created are more ergonomic and less stressful.

We propose a semi-objective assessment method of the gestures' risk factors based on the assessment of work-related tasks and the specifications found in certain standards.

Our objective is to try to improve interaction in virtual environments and make them easier and less detrimental to subjects. Moreover, our method may be used to assess physical movements in other fields, such as work posture, ergonomics or even physical therapy: the modular nature of our software makes it easily amendable —and, with some little work on the coding side, configurable— by the end-user. It is therefore feasible for a physical therapist in a context of rehabilitation, to change the default joint angle values (as well as other risk factors) provided in the software, taking some trauma into account, and then assess patient movement in real-time while avoiding unnecessary stress on traumatized joints.

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