Reducing Gestural Interaction Physical Stress in Virtual Environments: an Experiment

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ABSTRACT
Despite the advantages of gestural interactions, they involve several drawbacks. One major drawback is their negative physical impact. 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. We present our experiment which aims at validating our approach of evaluating gestural interactions.

Author Keywords
Gestural interaction; gesture assessment; musculoskeletal disorders; gestural stress.

ACM Classification Keywords
H.1.2 [Models and Principles]: User/Machine Systems - Human factors; H.5.2 [Information interfaces and presentation]: User Interfaces - Evaluation/methodology; Ergonomics; Interaction styles (e.g., commands, menus, forms, direct manipulation).

INTRODUCTION
One of the purposes of gestural interactions is to facilitate interaction with virtual environments. They aim at being intuitive, easier to use and learn, since lots of them are based on the emulation of natural gestures [22]. Some can fulfill specific needs (such as those of physically disabled people [15], etc.). 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 [16].

However, musculoskeletal disorders associated with gestural interactions can be caused by movements requiring substantial physical effort. What is more, the extended and/or frequent use of such systems can result in an overuse of the muscles in charge of performing those gestures [25].

There exists stressful, tiring, illogical gestures and some might be impossible to perform for certain people (physically disabled people, for instance, but not only): the interaction with some gestured-controlled TV sets is considered stressful [10] 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 [16]; the use of big screens is sometimes considered stressful to the neck because of frequent movements of the head and eyes [5].

Few studies have been conducted on how to reduce the physical impact of gestural interactions on the human body, and this sometimes resulted in the creation of non-ergonomic, stressful gestures that are difficult to use [3]. Interaction with such systems can lead to various musculoskeletal injuries.

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 work tasks consist of movements repeated frequently.

The 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 such factors allows the assessment of gesture quality and consequently of their physical impact. This allows the design and implementation of ergonomic gestures that will cause neither pain nor stress, and that 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 and the existing assessment methods of physical movements. The second part presents a synthesis and an analysis of these methods as well as our own approach. In a last part, we detail our experiment as well discuss the results we have obtained.

PRIOR WORK
As mentioned before (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." [1]

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 [14].

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 could be painful. Besides, static and dynamic constraints on some parts of the human body impact movement range and interdependence. [8, 25].

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 involves repeated physical movements that occasion sore muscles and knee, shoulder and heel injuries (DOMS: Delayed Onset Muscle Soreness) [25].

Videogame-related injuries can be classified in four categories: Tendinopathy, which means tendon injuries; Bursite, which means swelling and irritation of one or several bursa; Enthesitis, which refers to inflammation of the sites where tendons and ligaments are inserted into the bone and Epicondylitis (tennis elbow), which is a 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 [14].

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 [20, 25]. 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. [26]. Symptoms such as pain, discomfort and a sensation of localized fatigue of an overused joint can all point to RSIs.

According to [26], 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, efforts and musculoskeletal load, static muscular work, exposure to certain physical stressors, repetition and the unvarying nature of the work and organizational factors.

Effort depends on the joints involved, movement direction, posture, type of grip and individual characteristics [1].

Risk factors can be decreased by adapting workstations and improving several elements: physical environment, task characteristics, technical aspects, individual, etc.

In gestural interactions, most gestures are deemed natural (natural user interface) [22], 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 [25]. What is more, these movements are repetitive, and occur over a long time span [3]. 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 [21] the basic principles of gesture ergonomics are: avoiding external positions, avoiding repetition, muscle rest, favoring neutral, relaxed positions, avoiding static positions, avoiding internal and external forces on joints and the interruption of the natural flow of bodily fluids.

GESTURE ASSESSMENT

Assessment methods

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 these movements. Assessment methods are classified in two categories:

Subjective methods:

Most studies on the assessment of the negative impact of gestures and physical movements generally resort to subjective methods [20, 21]. Amongst those can be found:

a. 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 of discomfort by marking the affected areas [6].

b. 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 [21] or by experts (ergonomists, etc.) [19].

c. Other methods are used, such as questionnaires [11], interviews, open-ended questions [20].

Other methods and angle measurements:

There exist methods and standards which allow assessing physical movements in a more objective way:

a. Electromyogram

The electromyogram can measure 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. Electric activities vary according to the number of muscle motor units involved, which vary according to force. [18, 9]. This technique is used by [20] to measure muscle activity pertaining to the gestures and effort when interacting with touch-enabled devices.

b. RULA (Rapid Upper Limb Assessment)

RULA is a fast risk-factor assessment technique for upper limbs, geared towards individuals subjected to postures, forces and muscle loads potentially leading to MSDs [19]. The assessed factors for the selected tasks are: number of movements, static work, force, work posture, working time. RULA allows the observation of work posture, the identification of muscular stress and 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.

c. The ISO 11226 standard

The ISO 11226 standard [12] aims at assessing health hazards for workers involved in manual labor. This standard defines comfortable and uncomfortable work-related postures and allows their assessment. The assessment process involves specifying and classifying posture conditions as acceptable or not. These conditions comprise joint angle, time-related aspects and movement repetition. Each body part and joint is assessed separately. The assessment procedure is a one- or two-step process. The first step measures joint angles. If the angle doesn't exceed a given limit, the posture is deemed 'acceptable'. If not, the second step focuses on the time span of the movement.

d. The AFNOR NF EN 1005-4 standard (Safety of machinery – Human physical performance).

NF EN 1005-4 is an AFNOR standard [7] that defines a posture and movement assessment procedure related to working with machinery. The goal of this assessment is to ensure machinery design matches the recommendations aiming at avoiding postures and stressful movements leading to MSDs. The assessment can either be 'acceptable', 'acceptable under conditions' or 'unacceptable'. In situations determined as 'acceptable under conditions', other risk factors must be considered and additional measurements are needed. Factors which can be assessed are: duration, repetition, period of recovery, the presence of a support to the body, etc. The risk factors considered in this standard are: movement angle, gesture time, frequency, etc. This standard refers to other standards, amongst which ISO 11226, presented above.

Creating non-stressful gestures

There exist several approaches to creating gestural interfaces that take user preferences and needs into account. Sometimes, predefined gestures are created, in which case the gesture vocabulary is derived by observing, collecting and assessing gestures done by some test subjects. Generally the assessment is done only by those subjects [21, 23, 27, 28]. On the other hand, in some methods, users are requested to create their own user-defined gestures. In this approach, the user defines the gestures they want to use in a preliminary step, before they start using the system [15]. Both approaches only take subjective assessment into account to define the gesture set. Our goal is to develop an automated, more objective method which could replace the latter subjective methods at the initial gesture definition step.

ANALYSIS AND COMPARISON OF APPROACHES, PROPOSITION

We aim to design an assessment method for gestures used during interaction that would minimize their negative physical impacts. This method is supposed to be more objective and allow automatic assessment of gestures, which can help designers to choose non-stressful gestures without the need to refer to subjective assessment every time. A complete gesture consists of a set of single gestures whose assessments result in an overall assessment of the gesture. Assessments of these gestures are 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. Variables will be assessed based on specifications for acceptable and unacceptable movements in various studies and standards [2, 7, 12, 19]. 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 that 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 by 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 both 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 [12]. Similar tables for each joint have been compiled and are not printed here because of space constraints. To understand the data shown in the table, we refer to the different evaluation strategies used by the aforementioned approaches:

- In RULA, acceptability is determined using a posture scoring system which works by adding points. Only the final score can rate the gesture on an acceptability scale.

- In the AFNOR 1005-4 standard, each movement close to the limits of mobility is unacceptable if frequent (that is, if repeated as little as twice per minute). The assessment of gesture duration depends on ISO 11226 specifications.
- A static posture is a posture maintained for more than 4 seconds according to [12], more than a minute according to [19].

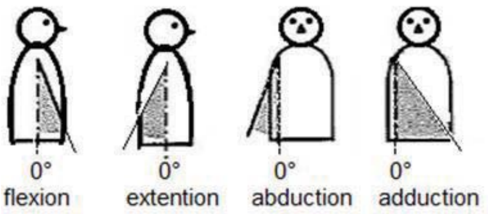

Figure 1. Shoulder movements [2], modified.

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) [7, 19], others measure gesture duration [12], etc. In ISO 11226, the assessment of gesture duration is necessary when one gets a result that is 'acceptable under conditions' (owing to the movement's exceeding joint angle limits). 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 maximal time according to the joint angle [12, 13].

Some approaches use a scoring system based on an accumulation of points [19, 21]. In this case, the gestures' final score is determined by adding the scores of the single movements which the gesture consists of: the more stressful the gesture, the higher the score. Besides, other approaches depend on joint angle testing followed by gesture duration to determine its acceptability [12]. The information about the levels of acceptability of joint ranges, duration and other risk factors (such as repetition, force, muscle load, etc.) are collected and organized so as to be used in the assessment process. This process aims to determine the level of acceptability of the gesture according to the information collected.

Our approach uses Microsoft Kinect SDK to detect joint positions [24]. From these data, the system deduces joint angles. Duration and repetition of the movement are also calculated. Other variables, such as the presence of body supports, which can't be detected by Kinect, are entered manually by the evaluator. The application's output is a binary assessment (acceptable or not) of a body posture. The result obtained is considered 'acceptable' only if all gesture assessment results according to all standards and methods implemented within the system are 'acceptable'. It will however be deemed 'unacceptable' if any standard or method yields an 'unacceptable' result for the gesture. We have adopted such an approach to ensure a maximum level of safety. In addition, the system finds the average fatigue level of each joint according to each method. This can be used to compare joint fatigue levels over different tasks, as is done in our data analysis (see Results and discussion).

In the perspective of maximum safety, the software was designed to detect the maximum angles reached in the course of a gestural interaction, and to compute its assessments from these maximums, according to the standards and methods stated above. The measurements of time and frequency, used for the assessment of gestures following the AFNOR 1005-4 standard are only triggered when the threshold value (which requires time span to be taken into account) is exceeded (an angle of 20° for arm abduction, for example [7]).

METHOD AND EXPERIMENT

Our experiment aimed at validating our approach by evaluating the system's results. Such an evaluation was performed through a comparison between the system's evaluations and subjects' evaluations of their fatigue levels after performing some tasks using gestural interactions.

Participants

Twenty-six participants (aged 29 ± 10 years old), 17 males and 9 females, who all had beginner level with gestural interactions, were tested (we were aiming to test a gestural interface destined to the general public).

Tasks and Procedure

Participants were asked to perform —in a random order— two tasks in a virtual environment. One task was deemed "difficult" when the other was deemed "easy". The task was about arranging objects: the subject would pick an object from a stock box, and then move and drop it into the appropriate box. Subjects completed the task in three steps, using gestural interaction:

1. picking the object from the stock box (at a height of 90 cm), by pointing at it with their right hand and then closing it.
2. moving the object by moving their right hand towards the appropriate, illuminated box.
3. dropping the object in the appropriate box by opening their hand.

There were a total of six boxes; only three were visible in each task. In each task, a light indicated to subjects where to put their object. In each condition, the task was repeated 30 times in order to move 30 objects from the stock box to the other boxes. The number of times was chosen after pretests. Subjects were asked to return to a resting position between each task. The order in which tasks were performed was random. During the interaction, our system detected joint positions and angles, as well as evaluated them.

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) ou (short duration + recovery time). - 20° - 60° if frequent. - 20° - 60° if: - frequency <10 per min - short duration - > 60° if: - short duration. - 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. - 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)		
Hyper adduction of the arm	ISO 11226			stressful
Extreme external rotation				
Arm support	RULA	- 1 pt		
Trunk leaning forward				

Table 1. Recommendations for shoulder joint angles [2, 7, 12, 19].

The task was performed in two conditions, cf. Figure 2.

- Condition 1, "difficult": the task was supposed to be tiring; the levels of destination boxes were above shoulder level. Boxes' heights were respectively 160, 180, and 170 cm.

  In this case, subjects had to raise their hand in order to move the object and drop it into the appropriate box. In addition, this condition requested more precision than the other.

- Condition 2, "easy": the task was supposed to be easier; the level of boxes was around body center level. Their heights were respectively 85, 80, and 90 cm.

  We began by introducing our work and the experiment steps orally. The subject started their first task in first condition, then filled a questionnaire about the fatigue level felt during a 10-minute break between the two conditions. Next, the subject performed the task in the second condition, which was followed by a second questionnaire about their levels of fatigue. Experiment duration was about 28 minutes, including 8 minutes in average for performing the tasks, and 20 minutes for both breaks.

Apparatus

We used two PCs running Windows 7 combined to two Microsoft Kinect for Xbox® motion sensors.

The first computer was used to run the test application comprising the gestural interface; a video projector was attached to this computer. Unity3D was used to develop our test interface. This computer was connected to the first Kinect which allowed users to manipulate the gestural interface. The Kinect was placed 130 cm to the left of the middle of the active zone (second Kinect). Its height was about 65 cm, its rotation angle was about 30°, cf. Figure 2.

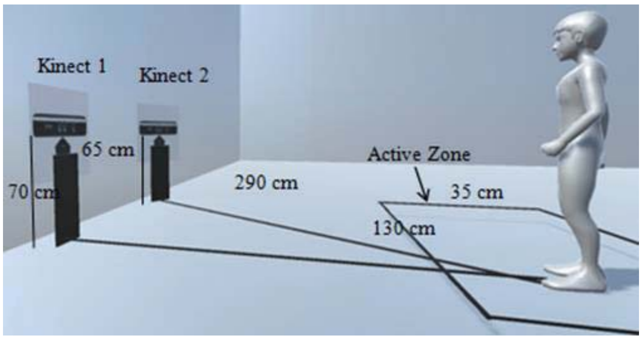

Figure 2. Kinect locations and active zone.

The second computer was used to track user movements, process data, and display results. This computer ran C# code, developed in Microsoft Visual Studio 2013. This second computer was connected to the first Kinect. This Kinect was placed in the middle of the active zone, between the stock box and the first destination box, facing the active zone directly. Its height was about 70 cm.

The active zone was the zone in which the subject was allowed to move to manipulate the gestural interface. Within this area, subjects could be tracked by both Kinects. It was located in front of the second Kinect. Physical markers indicated its limits.

Kinect sensors were used to allow users to interact with the system in conditions as natural as possible. To that effect, we used a Wizard-of-Oz technique [4] to simulate picking and dropping objects. When the subject tried to pick an object (by closing their hand), the experimenter pressed a button, and when they tried to drop it (by opening the hand), the experimenter pressed another button. Subjects were unaware, only knowing that the opening / closing movements were responsible for picking and dropping objects. We used this technique to overcome the limitations of Kinect in detecting accurate movement of the wrist.

Data collection

The validation of our approach was done through analyzing and comparing two categories of measurements.

• Data collected by the system: the system detected positions, angles, duration and repetition for each gesture, and analyzed these data to evaluate the level of tiredness associated to the gestures, determining whether they were acceptable. Evaluation results for each joint were logged every 0.5 second, thus yielding results for ISO and RULA (assessments by the ISO11226 and AFNOR NF EN 1005-4 standards have been merged into a single test and result called ISO. Indeed, AFNOR 1005-4 uses the exact same angle measurements as ISO 11226 and adds to them a frequency factor.) Additional data was also collected by the software, such as information about the subject (name, date of birth, etc.), and information about the task (duration, order, etc.)

• Subjective data: Subjects filled in a questionnaire about their level of tiredness in each joint, the technical and cognitive difficulties they experienced, as well as their physical exercise capabilities. They could also add comments and remarks about the experiment. We used a six-point Likert-type scale for the subjective evaluation (0 for absence of fatigue and 5 the extreme fatigue) [17].

Data processing and statistical analysis

We studied whether means for the detected level of fatigue in each joint were different in the "easy" and "difficult" tasks, and whether the results given by the system were in accordance to those described by subjects. The data outputted by our system consisted of RULA and ISO assessment results. This data was compared to the subjective data for each joint. We calculated the average level of fatigue for every joint in each task, as well as the average subjective fatigue level for all subjects. We used a Wilcoxon test with a *p*-value equal to 0.05, whose null hypothesis was that there was no difference between the fatigue levels in both tasks. A Wilcoxon test was used because results did not follow a normal distribution.

RESULTS AND DISCUSSION

Table 2 shows the average levels of fatigue for the right shoulder, right wrist, and neck in both 'difficult' and 'easy' tasks, according to our various evaluation methods (subjective, RULA and ISO). For the shoulder and neck, the average level of fatigue in the 'difficult' task is higher than that in the 'easy' task. The difference between these two levels in both systems (ISO and RULA) and the subjective data is significant according to the Wilcoxon test. This means that our system's evaluation matches the subjective evaluation for shoulder and neck.

Joint	Method	Mean (SD)		*p*-value
		Difficult Task	Easy Task	
Right Shoulder	Subjective	0.45 (0.24)	0.19 (0.12)	0.00003
	ISO	0.77 (0.12)	0.34 (0.18)	0.00001
	RULA	0.40 (0.08)	0.21 (0.03)	0.00001
Neck	Subjective	0.11 (0.14)	0.04 (0.08)	0.00833
	ISO	0.41 (0.3)	0.20 (0.28)	0.00022
	RULA	0.33 (0.16)	0.26 (0.13)	0.00322
Right Wrist	Subjective	0.15 (0.17)	0.15 (0.17)	0.71270
	ISO	-	-	-
	RULA	0.54 (0.1)	0.51 (0.09)	0.37400

Table 2. Average levels of fatigue for right shoulder, neck and wrist in both "difficult" and "easy" tasks given by subjects, as well as system data (ISO and RULA), p-value yielded by Wilcoxon test when comparing means for both tasks.

As for the wrist, according to RULA results, the average level of fatigue in the 'difficult' task is a little higher than that in the 'easy' task. The difference between them is not statistically significant according to the Wilcoxon test. Subjective results show that levels in both 'difficult' and 'easy' tasks are also almost the same.

Our objective was to verify whether the data produced by our system's evaluation matched subjective assessment in detecting gestural fatigue. We found that the system's and the subjective data for fatigue levels in shoulder and neck were compatible. We think that our system can detect gestural fatigue for both those joints. The higher fatigue level given by the system for the right shoulder in the 'difficult' task is logical, because in this task, the subject raises their hand to a higher level than the shoulder, which is considered stressful according to ergonomic standards and methods. Additionally, for the neck, in the 'difficult' task the gaze level is higher than that in the 'easy' task, so the subject had to raise their head more than what was necessary in the 'easy' task. Time spent performing the 'difficult' task also affected stress levels: the average time for the 'difficult' task was 4.2 minutes versus 3.2 minutes for the 'easy' one.

For the wrist, subjective and system results showed that there was no significant difference between both tasks. The wrist was used almost in the same way in both tasks. We noticed that the fatigue level according to RULA results is much higher than the one yielded by subjective results. We think that this difference is due to various reasons, among which the inability of Kinect to detect the exact wrist position and some of its movements, such as rotation, thus yielding some inaccurate evaluation results. Another reason was the nature itself of wrist movements: such movements are often used in daily life; we therefore posit that subjects underestimated their fatigue. In addition, it was apparent to the experimenters that subjects enjoyed performing such a task of picking and dropping objects using a freehand gesture. We think that our system could do much better if it used a more accurate detection setup, such as a multi-Kinect system and/or ART tracking for example. We are planning to use such a system in our future work. Our system was originally designed using Kinect devices for Kinect's portability and ease of use [29]. It can be implemented easily in workplaces or a laboratory environment without needing a complex and time-consuming setup. There is however a clear substantial tradeoff between the quick and easy setup of a readily usable system and the detection precision expected of its use.

Generally, we think that our system was able to detect fatigue levels in some joints and that these results were in accordance with subjects' evaluations, which means that this system is valid for evaluating these joints. Other joints will be studied later. We think that this method for assessing gestures represents a potentially valuable approach to detecting gestural fatigue. It performs better for some joints than others, depending on the accuracy of movement detection and whether specifications about acceptability levels for these joints are available.

CONCLUSION AND FUTURE WORK

In spite of undeniable advantages to 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 gestural risk factors based on the assessment of work-related tasks and the specifications found in certain standards. We have validated our approach for some joints with a conclusive experiment.

Our objective is to try to improve interaction in virtual, augmented and mixed environments, so as to make it easier and less detrimental to subjects.

As future work, we envision validating our approach for other joints and testing it with more complex tasks. We also plan to integrate other specifications for acceptability. In addition, we are thinking of integrating other factors to the evaluation process, such as accuracy and duration of task as well as psychological influences (pleasure, familiarity, etc.), and study their effects on the evaluation process. Furthermore, we are interested in using a more accurate motion detection system such as ART tracking and integrating additional sensors which could detect some other important variables to the evaluation process such as limb rotations.

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