HIGHLIGHTS

1) The Vink-Hallbeck Model of Comfort Perception is enhanced
2) The concept of Range of Rest Position (RRP) is used
3) A new method to evaluate Posture’s comfort is proposed
4) Subjectivity is minimized in Comfort/Ergonomics evaluations
5) Biomechanics parameters have been used to evaluate the Comfort level

PROPOSAL OF A NEW QUANTITATIVE METHOD FOR POSTURAL COMFORT EVALUATION

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ABSTRACT

In Human-Machine Interface (HMI) design, several parameters have to be correctly evaluated in order to guarantee a good level of safety and well-being of users (humans) and to avoid health problems like muscular-skeletal disease. ISO Standards give us a good reference on Ergonomics and Comfort: ISO 11228 regulation; it deals with qualitative/quantitative parameters for evaluating Postural Ergonomics, using a "Postural Load Index", in push/pull, in manual loads' lifting and carrying and in repetitive actions; those parameters can represent the Ergonomics level of examined posture. While bibliographic references suggest different methods to make ergonomic evaluation like RULA, LUBA and REBA, the state of the art about comfort/discomfort evaluation shows the need of an objective method to evaluate "effect in the internal body" and "perceived effects" in several schemes of comfort perception like Moes', Vink& Hallback's and Naddeo&Cappetti's ones; postural comfort is one of the aspect of comfort/discomfort perception and this paper proposes a new quantitative method for evaluating this aspect of comfort, based on anthropometric parameters and upper limbs posture. The target of this paper is to present and test a "general purpose" method of comfort-measurement that can be applied to different industrial cases: in workspace environments, in automotive passenger compartments, in aeronautic cockpit or in industrial assembly lines.

KEYWORD: ergonomics, industrial design, comfort evaluation, postural analysis

INTRODUCTION AND STATE OF THE ART

In Human-Machine Interface (HMI) design, several parameters have to be correctly evaluated in order to guarantee a good level of safety and well-being of users (humans) and to avoid health problems like muscular-skeletal disease.

ISO 11228 is the only ISO Standard that can give us a good reference on ergonomics and comfort evaluation and its parameters can be synthesized in a "Postural Load Index" that represents the Ergonomics level of examined posture (Annarumma et al., 2008; Naddeo et al., 2010) but does not give us information about the perceived well-being.

Bibliographic references suggest methods like Rapid Upper Limb Assessment (RULA – McAtamney and Corlet, 1993), Rapid Entire Body Assessment (REBA – Hignett and MaAtamney, 2000) and Loading of the Upper Body Assessment (LUBA – Kee and Karwowski, 2001) to perform ergonomic analyses that go by measurement of anthropometric parameters. Postural comfort can be defined as the measure of the "level of well-being" perceived by humans when interacting with a working environment; this level is very hard to detect and measure because it is affected by individual judgments that can be analysed using quantitative/qualitative methods.

Over the past 30 years, we can find a lot of paper dealing with comfort and discomfort; the majority have tried to demonstrate and quantify the relationship between the environmental and physiological factors and the perceived comfort (Galinsky et al., 2000; Hamberg-van Reenen et al., 2008; Naddeo and Memoli, 2009); few papers explaining explicitly the concept of comfort are Helander and Zhang (1997), De Looze et al. (2003), Moes (2005) and Kuijt-Evers et al. (2004), while most of the others worked on the relationship between subjective perception of comfort/discomfort feeling and product/process/interaction/environment/users' factors.

In Vink and Hallbeck (2012) is given an interesting schematization (Fig. 1B) of the mechanism of comfort/discomfort perception that comes from the Moes' (2005) model represented in Fig.1A.

Fig 1: Moes (1A) and Vink&Hallbeck (1B) models of discomfort perception

They start from the following main topics individuated in a wide literature overview, for introducing their model:

1) Sensory input (De Korte et al., 2012; Vink et al., 2012);
2) Activities conducted during the measurement with an influence on comfort (Groenesteijn et al., 2012; Ellegast et al., 2012);
3) Different bodily regions (Franz et al., 2012; Kong et al., 2012);
4) Effect of the product' contour on comfort (Kamp, 2012; Naddeo et al. 2010; Noro et al., 2012);
5) Physical loading (Borg, 1982; Lee et al., 2012, Di Pardo et al. 2008; Zenk et al., 2012).

Moes (2005) deals about a specific case on the topic of "seat-design" and describes that if a person uses a seat with a specific purpose, the interaction (I) arises. For example, this interaction can consist of the pressure distribution of the contact area between the subject and seat. An interaction results in internal body effects (E), such as tissue deformation or the compression of nerves and blood vessels. These effects can be perceived (P) and interpreted, for instance as pain. The next phase is the appreciation (A) of the perception. If these factors are not appreciated, it can lead to feelings of discomfort (D).

Vink and Hallbeck (2012) have modified this model (Fig.1B); in their opinion, the interaction (I) with an environment is caused by the contact (could also be a non-physical contact, like a signal in the study of De Korte et al. [6]) between the human and the product and its usage. This can result in internal human body effects (H), such as tactile sensations, body posture change and muscle activation. The perceived effects (P) are influenced by the human body effects, but also by expectations (E). These are interpreted as comfortable (C), you feel nothing (N), or it can lead to feelings of discomfort (D) [2] and the Discomfort could result in musculoskeletal complaints (M).

This model has been upgraded by Cappetti and Naddeo (2014), as shown in Fig. 2, in order to take into account expectations and perception modification due to testing devices.

Fig 2: Cappetti and Naddeo comfort/discomfort perception model

All presented models take into account the body effects and the perceived effects that are useful to define the Maximum Level of Comfort (MLC) positions in human postures and are needed to make a comfort evaluation based on measurement of the angular Range of Motion (ROM) of each joint Annarumma et al., 2008; Tilley and Dreyfuss, 2001; Cappetti et al., 2011; Apostolico et al. 2013).

Certain medical studies show that each joint has its own natural Rest Posture (RP) (Fagarasanu et al., 2004; Christensen and Nilsson, 1999), wherein the muscles are completely relaxed or at minimum strain level: When this occurs, the geometrical configuration corresponds to the natural position of the resting arms, legs, neck, and so forth. In [Galinsky et alii - 8] it is demonstrated that the rest position minimizes musculoskeletal disease and optimize the comfort perception; in Apostolico et al. (2013), the problem of identifying and using the RP concept in ergonomic/comfort evaluations is addressed; in Christensen and Nilsson (1999) is presented an application in which the “neutral zero position” is defined as a parameter for calibrating mechanical instruments in measuring the neck’s ROM. The RP concept has been used in Apostolico et al. (2013) for experimentally identifying the Range of Rest Posture (RRP).

It was demonstrated that anthropometric parameters can be used to evaluate users’ well-being level (comfort), so, in present work , authors show the procedure used to build curves that represent comfort values along the entire range of postures (joint angle) for each human joint under consideration and proposes a method for postural comfort evaluation for improving the ISO standards’ method.

THEORY

This paper focuses on the numerical and experimental procedure for developing a comfort evaluation method for the upper part of the human body. The authors aim to demonstrate that this approach (based on the spatial configuration of body parts) allows us to define a quantitative method for comfort measurement, which is all-purpose and can be applied to different industrial cases: workplace environments, automotive passenger compartments, aeronautical cockpits, and industrial assembly lines. It can also be used in both the design phases and the optimisation and redesign phases of products and processes in order to improve the postural comfort of users/workers.

In this study, the H-point position was not taken into account because the comfort range of motion (CROM) and RRP can be defined for each human joint independently from H-point behaviour and position. For the evaluation of whole-body comfort, the H-point must obviously be taken into account.

A preliminary bibliographical analysis allows us to define the domain of “comfort function” as the set of angle values that characterises the movements of human joints (ROM). This strongly depends on the subset of values corresponding to a good ergonomic level (not necessarily a comfortable one).

The following joints were taken into account along with their main movements (degree of freedom [DOF]):

- Neck: flexion/extension, lateral flexion, rotation;
- Shoulder: flexion/extension, abduction/adduction;
- Elbow: flexion/extension, pronation/supination;
- Wrist: flexion/extension, radio/ulnar deviation;

In previous studies (Thompson, 2001; Lantz et al., 1999; AMA Guide, 1988; Boone and Azen, 1979; Greene and Wolf, 1989; Luttgens et al., 1997; Koley and Singh, 2008; AAOS-Chicago, 1965; Norkin and Joice White, 2009), several ROMs were defined or suggested for each joint. We prefer to use, as with the CROM, the intersection of all ROMs as suggested in the literature, because non-common values are probably associated with an uncomfortable posture. For example, Table 1 presents the elbow CROM as given in several previous studies, while Table 2 provides our choice for the CROM.

Table 1. The Elbow's Range of Comfort as Given in Previous Studies

Table 2, Elbow CROM (Comfort Range of Motion)

For each human joint, it is possible to define another range, namely the RRP, which is always a sub-range of the CROM and represents a subset of positions in which articular joints can be considered to be "statistically" in rest. This range is obtained from the analysis of humans whose joints are in a natural position with relaxed musculature. Each angular value within the RRP can be considered to be the maximum comfort for the joint angles (Apostolico et al., 2013).

Our comfort evaluation method, like previous methods, defines a mathematical model for evaluating the comfort level (by an index) when measuring joint angles in a given posture. One hypothesis taken into account is that the extremities of the CROMs represent the minimum comfort values (Wang, 2000; Odell, 2007), while the RRP (Apostolico et al., 2013) denotes the range of the maximum comfort values; between these values, the level of comfort is generally unknown. To investigate this, we began with experimental sessions to obtain data on the judgment of several types of postures and then elaborated these data using statistical methods. Finally, the data were synthesised, leading to the definition of the comfort versus posture curve using a neural network.

METHODS

We used the standard Galilean method. Using experimental evidence, we tried to extrapolate a general comfort evaluation law, before testing it in order to achieve a good numerical and experimental level of reliability.

The chosen experimental sample comprises 100 persons with the following characteristics:

- Aged between 20–30 years;
- 50% men and 50% women;
- Not affected by muscular-skeletal diseases.

Subjects were previously informed about the procedure and objectives of the tests.

Table 3: Example of domain division for Elbow's CROM

The CROM for each joint was divided into four sub-ranges, as in the LUBA method (Kee and Karwowski, 2001), by identifying the five main angular values.

We asked subjects to perform several simple actions for each joint in a 6-DOF (A system with only 6 Degree of Freedom – 3 for translation and 3 for rotation) system. The actions were studied and simulated to better uncouple the DOFs from each other; each action took about 10 seconds for the subject to complete. This value was chosen so that the time spent to express a good comfort judgment, can be considered as a parameter that does not affect the same judgment. The “fatigue factor” (also known as muscular-stress or strength factor) was ignored.

Experimental tests provided subjects with the possibility of expressing a comfort rating for each joint and for some chosen postures; the postures were always chosen within CROM bounds, with the evaluation scale ranging from 1 (minimum score) to 10 (maximum score). Authors asked to subjects to make the joints’ movement without moving other body-parts, when possible, in order to better uncouple the joints each other.

Evidently, all acquired data are affected by ungovernable variance due to the subjectivity of participants’ perception and the lack of uniformity in the data. Hence, it is difficult to use mathematical functions (approximation or interpolation) to build a valid model for describing the relation between joint angles and comfort. Therefore, we required a mathematical instrument that was not heavily affected by participants’ subjectivity to allow us to be free from the subjective results of our sample and create a general law for function comfort versus angles. This kind of mathematical model must be developed using data from experimental tests and provide a comfort value for each possible human posture. For the subjectivity-independent experimental work, a neural network (NN) was used (Holzreiter and Köhle, 1993; Jones et al., 2008) to create this variability model. The aim of the NN is to establish the correlation function between angular values and experimental comfort scores. The NN was developed using the following data:

- RRP taken from Apostolico et al. (2013), in which comfort is considered to be the maximum;
- Boundary values of CROM, in which comfort is considered to be the minimum;
- Data from the subjects using the procedures above described.

It is useful to highlight that for some articular joints, such as elbows, the natural rest position (180° in flexion-extension) is very close to the natural ROM bounds, meaning that the maximum comfort value approaches the bound of CROM (see Table 1).

PERFORMED TESTS

Tests were conducted in the VR-Lab at the University of Salerno. The main room was designed to obtain the setup shown in Fig. 3. Angles were measured using photogrammetric analysis. All tests were performed by a standing or seated subject and without applied loads. Each subject has been modelled, in advance, by the DHM (Digital Human Modelling) DELMIA software, by Dassault Systemes, in order to better position him/her while performing the tests.

A paper sheet was placed on the wall to calibrate cameras and correct all photographic errors (fisheye effect, perspective errors, etc.)

Fig.3: VR-Lab set-up: graduated paper sheet and acquisition devices

Each Joint’s CROM has been opportunely divided in sub-ranges (Table.4); we asked to subject to move his/her joints in different position (previously modeled, by DELMIA™, inside each sub-range) and to express a comfort rate between 0 and 10 for each of them.

Table.4: Sub-ranges of Motion for comfort evaluation.

NECK JOINT TEST

To test the neck joints, we prepared a small white board with a written text. Subjects had to read the text at a distance of 80cm, while focusing their eyes on a specific point on the paper (Fig. 4).

Fig.4: Neck Joint Test

By simply moving the text on the dashboard (for example, using a written sheet of paper), it was possible for the subject's neck to move and thus cover the entire neck CROM. At the end of each test, subjects graded their perception of comfort with a score.

SHOULDER JOINT TEST

The shoulder test was performed by preparing a large vertical crossword puzzle with the squares being filled with unordered numbers (written on movable paper sheets). It was previously shown that the paper sheet (on the wall) allowed subjects to move their shoulders into the CROM; the position was identified using the anthropometric measures for each subject and then simulating its movements using DELMIA™ software.

Fig.5: Shoulder Joint Test

In the shoulder test, we asked subjects to execute the following operations (Fig. 5):

1) Stand up in front of the dashboard;
2) Direct their arm to point their index finger towards a number;
3) Completely extend the arm (180° elbow) when pointing to the numbers.

These operations allowed us to test the shoulder in several positions and measure the angles of abduction and adduction. Subjects were asked to score the comfort of each position.

Subsequently, we asked subjects to score the level of comfort when the arm was positioned along the body (shoulder extension equal to 0°) and when the hand reached a handgrip located behind the body with shoulder extension being equal to −45°.

ELBOW JOINT TEST

Two different tests were performed to evaluate the comfort level of the elbow in the CROM because two DOFs were taken into account: flexion/extension and prono-supination.

Fig.6: Elbow Joint - Flexion/Extension Test

Fig.7: Elbow Joint - Prono-Supination Test

The first test used a target that was printed on a virtual sheet (Fig. 6) and moved on the dashboard. Using their index finger, subjects had to follow the target with a blocked wrist and hand, moving only the elbow joint. In this way, the entire angular field of movement of the elbow was tested. The second test used a leverage made by a vertical beam hinged on a cylinder with a bearing (Fig. 7). Subjects had to grasp the beam and rotate it using only the forearm. Comfort associated with an angular position was evaluated by blocking the beam and asking subjects about their perceived comfort.

WRIST JOINT TEST

Two different tests were performed to evaluate the comfort level of the wrist in the CROM because two DOFs were taken into account: flexion/extension and radio-ulnar deviation (Figs. 8 and 9).

Fig.8: Wrist Joint - Flexion/Extension Test

Fig.9: Wrist Joint – Radio-Ulnar Deviation Test

Both tests used the same leverage as in the elbow tests. Subjects had to grasp a beam and rotate it using only the wrist joint. Comfort associated with an angular position was then evaluated by blocking the beam and asking subjects about their perceived comfort.

RESULTS

Experimental data were processed using a NN whose output was the curves representing comfort values with regard to the joint angles for each human joint. The NN was required to produce a high number of points for the ROM domain of each joint. An example of this process, for elbow flexion/extension, is shown in Fig. 10.

Fig.10: Example of Output of NN run: Elbow – Flexion/Extension.

Comfort level curves were determined for each human joint. When a posture is analysed, each joint angle corresponds to a comfort value. All joint values can be evaluated using the curve data and then combined to define an index to represent the global comfort for a determined posture. Each posture can be evaluated exactly as it is defined, that is, as a combination of human joint positions and angles.

The following figures depict all of the comfort curves:

Fig. 11: Neck's Lateral flexion and Rotation Comfort curve

Fig. 12: Shoulder's Flexion/Extension and Abd/Adduction Comfort curves

Fig. 13: Elbow's Flexion/Extension and Prono/Supination Comfort curves

Fig. 14: Wrist's Flexion/Extension and Radio/Ulnar Deviation Comfort curves

A global comfort index can be defined as context-sensitive using different combination rules, the most common being the minimum, maximum, arithmetic/weighted mean, geometric mean, and sum. The minimum rule is applied to evaluate the comfort requirements that must be satisfied; it assigns a minimum score to the posture. The maximum rule is especially applied when at least one of the comfort requirements must be satisfied; it assigns the maximum score to the posture. The arithmetic mean is used when comfort requirements interact with each other; it gives to the posture a score calculated as the weighted/non-weighted mean of several comfort scores. The geometric mean is applied when every value of the evaluated posture deteriorates the final perceived comfort. Finally, the sum can be used when the comfort values for all of the joints equally contribute to the final comfort score.

DASHBOARD/CAR-SEAT TEST CASE

This test was conducted on human postures when seated in a car in the driving position (hands on the steering wheel). Postural parameters (joint angles) were calculated using cameras from different perspectives and software Kinovea© to process the captured images (Naddeo et al., 2013). In the following figures, the reference lines (to take measurements) are underlined in green.

Fig.15; First Driving Posture: car seat far from dashboard

Fig.16; Second Driving Posture: car seat close to dashboard

Fig.17; Third Driving Posture: car seat in correct position

For this specific application, the following parameters are considered to be unimportant because they are very close to the “geometric zero” position:

- Neck: lateral flexion and rotation;
- Shoulder: abduction/adduction;
- Elbow: prono-supination;
- Wrist: flexion/extension.

In the experimental setup, we selected three driving postures. The first (Fig. 15) and second (Fig. 16) are incorrect driving postures, while the third (Fig. 17) is calibrated with respect to ergonomic suggestions given in the literature (Kolich 2003 and Kolich 2008).

Test results are reported in Table 5. As observed, the examined postures result in quite variant comfort values. The use of a sum-like combination rule is due to the influence of all of the joint angles on the overall comfort perception for this specific test (Vergara and Page, 2002).

Table 5. Experimental results when driving a car: acquired angles and correspondent comfort evaluation

The analysis of the first experimental setup (Fig. 15) shows a driver whose body is outstretched on the driving seat, with arms and legs stretched and the hip joints at an obtuse angle. This posture seems to be comfortable in terms of comfort perception, but it implies wide joint angles as each joint is far from a comfortable position. Evidently, the experimental setup is opportunely scaled towards the human percentile.

The analysis of the second experimental setup (Fig. 16) shows a driver whose body is curled up; few would agree that this posture is comfortable, but some people (i.e., those with poor eyesight) assume this posture. It is evident that the elbow flexion/extension value heavily affects overall comfort.

Finally, the analysis of the third experimental setup (Fig. 17) shows the optimal comfort values for the examined postures. The posture assumed by the tester seems to be comfortable and safe while driving (movement analysis is yet to be done). In this case, the comfort score is higher than in the other two.

DISCUSSION

The developed comfort evaluation method can represent a useful support when designing and optimising HMI and work environments.

The most important characteristics of this method are its accuracy and ease of use. It can be applied to several different design contexts and used to support the decision-making steps in industrial projects. The integration of this method into digital human modelling (DHM) software for ergonomic/comfort application may enhance product and process prototyping in a computer-aided design (CAD) and computer-aided engineering environment, thus providing designers with a powerful instrument to preventively evaluate the comfort level of an HMI.

The results of this study only concern the upper limbs, but the research methodology can be applied to the lower limbs and torso. The proposed method can be applied in all cases on which load factors can be neglected (for example, as specified in ISO 11228 normative or in NIOSH method); this limitation represents a challenge for future works.

Future avenues of development should aim to define several parameters and factors that can be applied to comfort results (derived from curves) while taking into account the following:

- Gravitational effect (using the gravity-assisted point from the LUBA method);
- Arm support (e.g., headrest, armrest, or other rest surface);
- Postural equilibrium (weight distribution and operative spatial conditions);
- Handhold type;
- Frequency of repetitive actions;
- Time in the same posture;
- Muscular fatigue due to the applied loads.

Some of these factors have yet to be considered in experimental tests, although they were evaluated empirically; our research group is still working on developing a methodology to objectify these factors.

CONCLUSIONS

An extensive experimental survey on comfort perception was performed to determine the correlation between comfort perception and biomechanics parameters for several well-defined postures.

The use of photographic data acquisition, the RRP concept, and NN allowed us to define and build comfort curves for each DOF of human upper limb joints. The obtained comfort curves are regular and do not show any discontinuity. These curves were then combined to define the new quantitative method for the evaluation of comfort perception based on human posture —the main result of this work— with the results verified in a dashboard and car seat test case. In this test case, the joints' comfort values have been combined with a "sum-like combination rule" after the analysis of the specific test (Vergara and Page, 2002); nevertheless, other combination rules can be investigated, adjusted and correlated to specific case.

Some of the curves are not symmetric because of:

1) The presence of gravity force;
2) The interaction with other human body parts leading to the interference of other joint movements (e.g., the interference of the body with the arms/shoulder adduction/abduction);
3) The natural limits of joint movements (i.e., movement of the elbow).

The proposed method appears to work very well, although it was only tested under the following boundary conditions:

- Subjects were in a standing or seated position (no intermediate positions were tested);
- Arms and legs were free from constraints and footholds;
- All tested positions were evaluated without applied loads.

The results were subsequently used to develop a Comfort Manikin known as CA-MAN©, to be used in a CAD or DHM environment.

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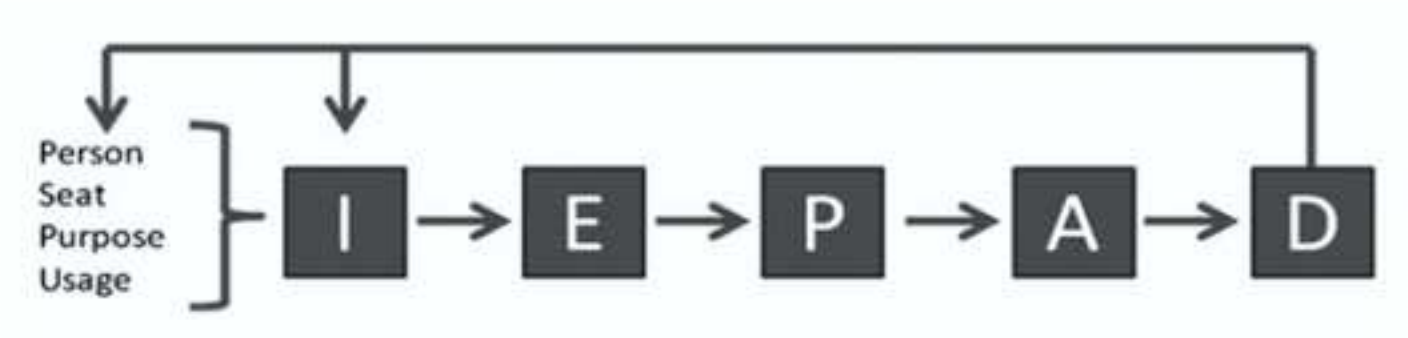
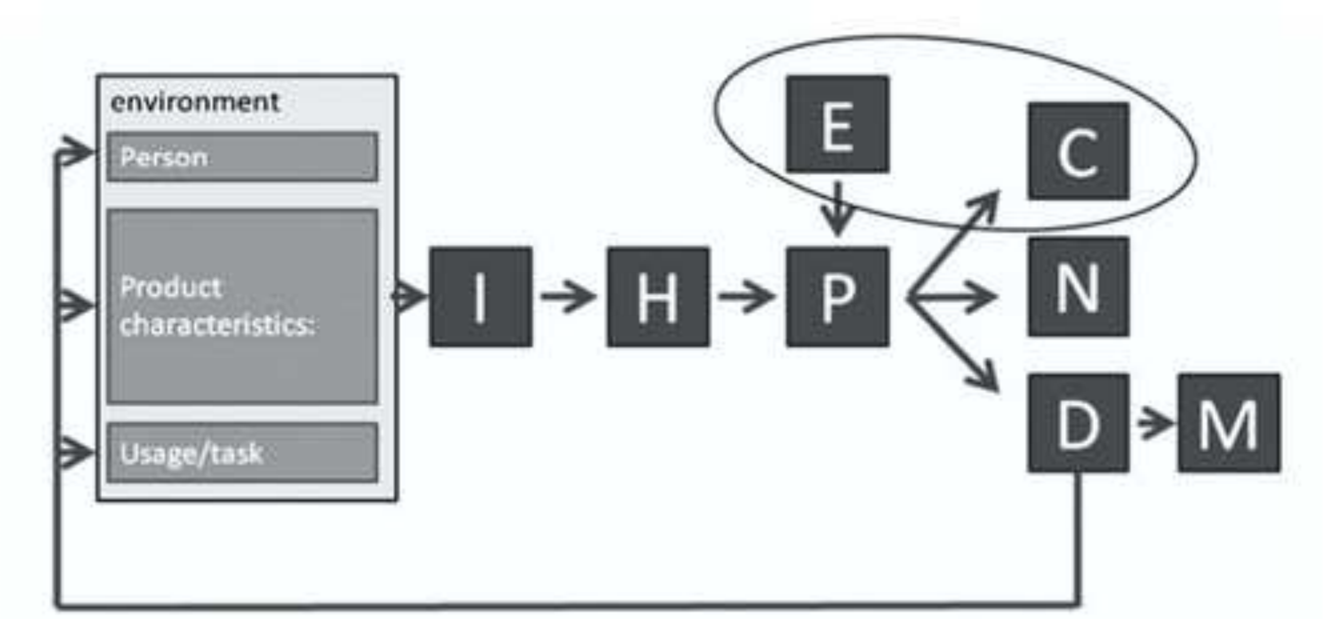


1A: Moes' model of discomfort perception



1B: Vink-Hallbeck model of comfort/discomfort perception

Figure(s)

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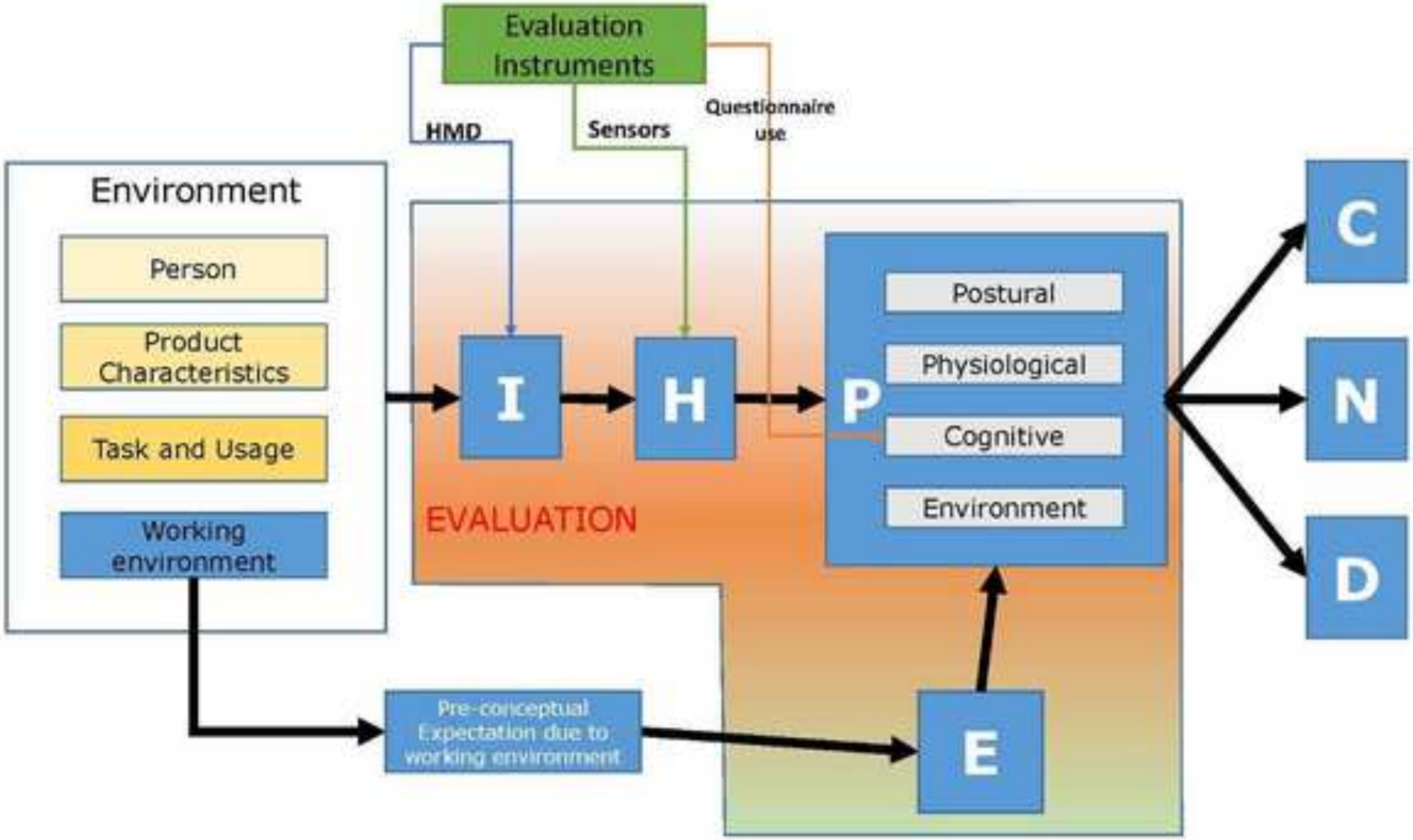
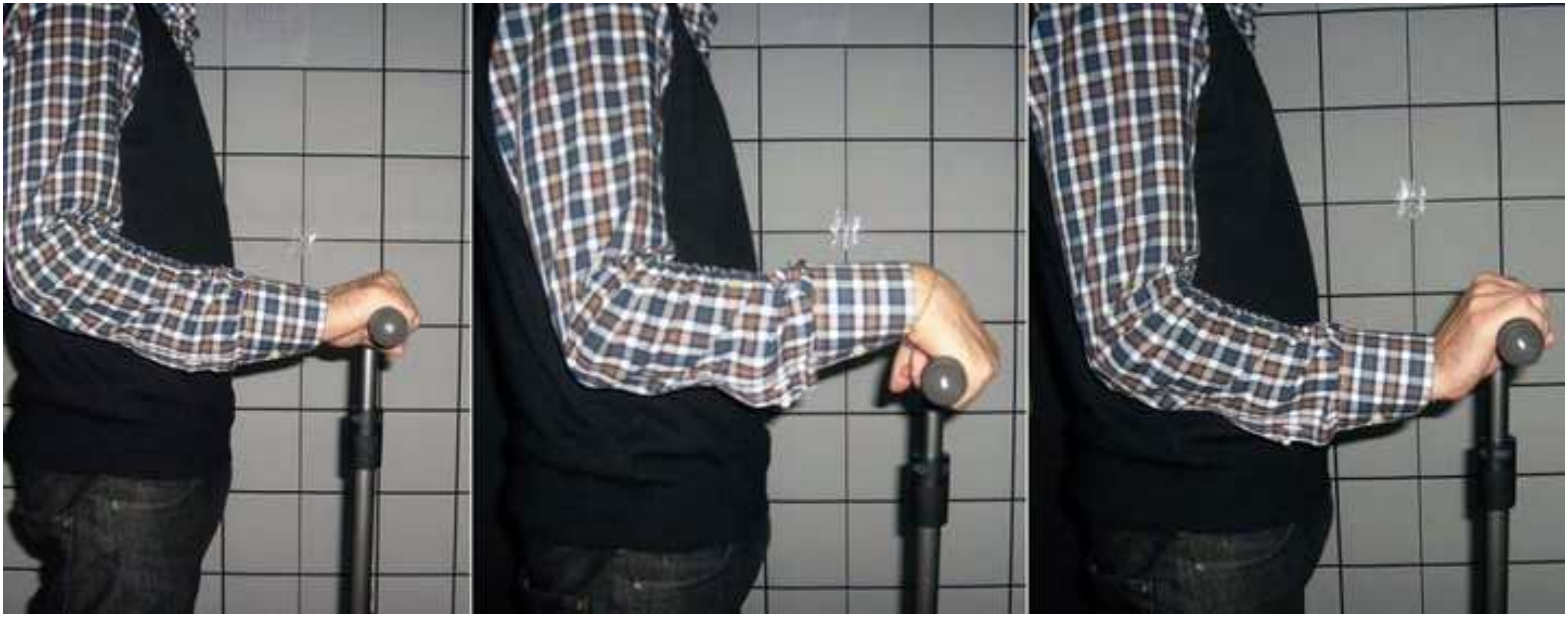


Figure(s)

Figure(s)



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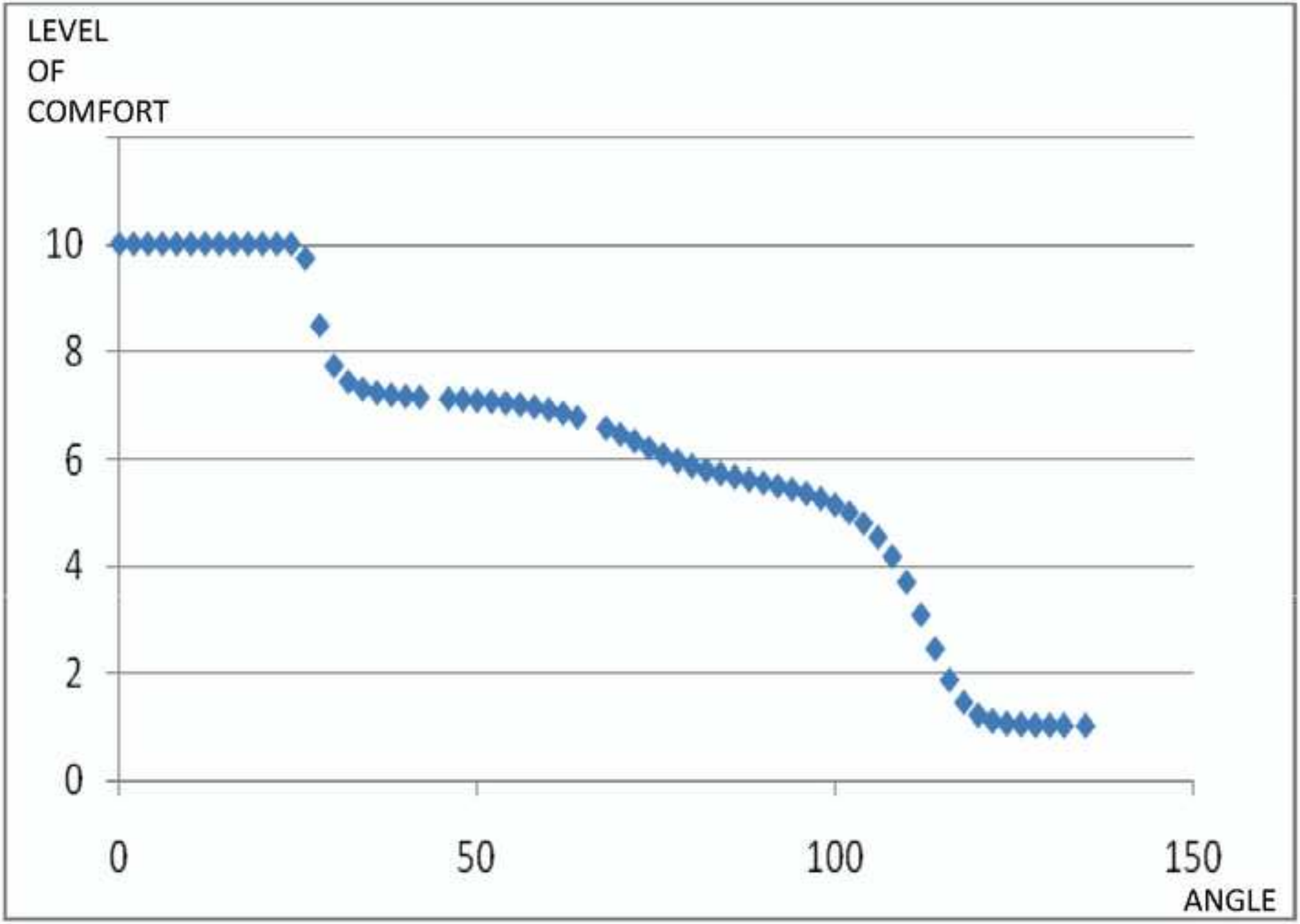
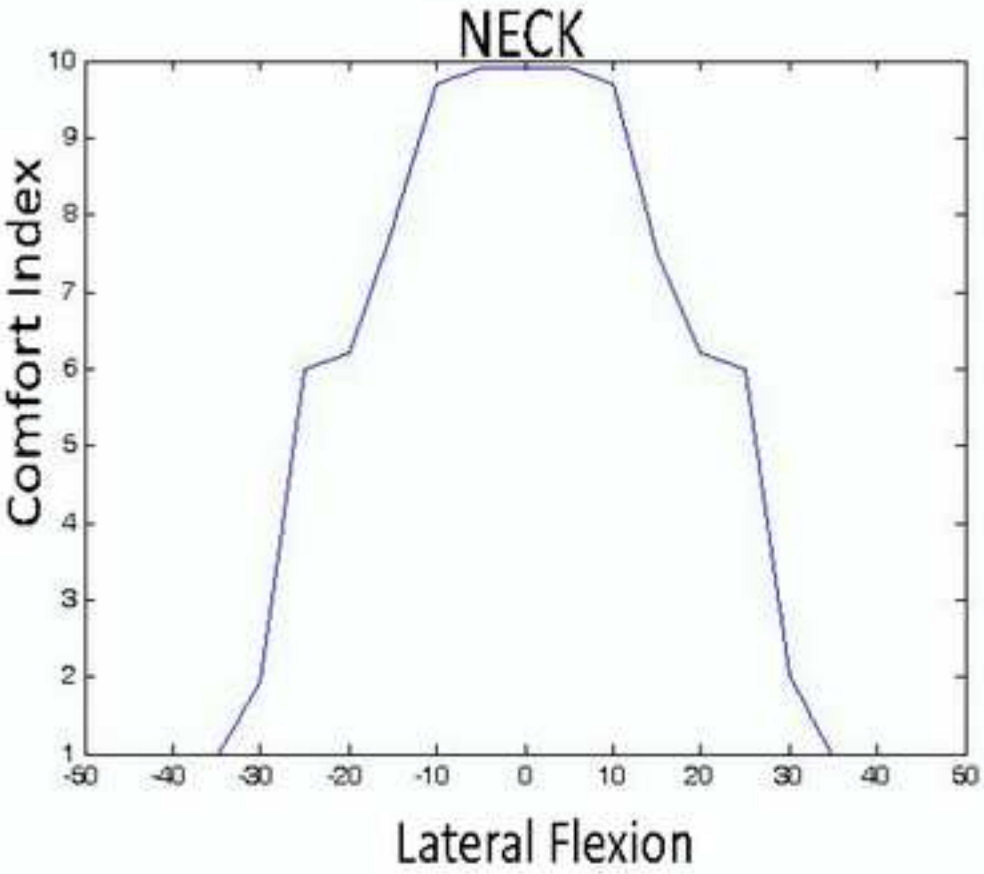
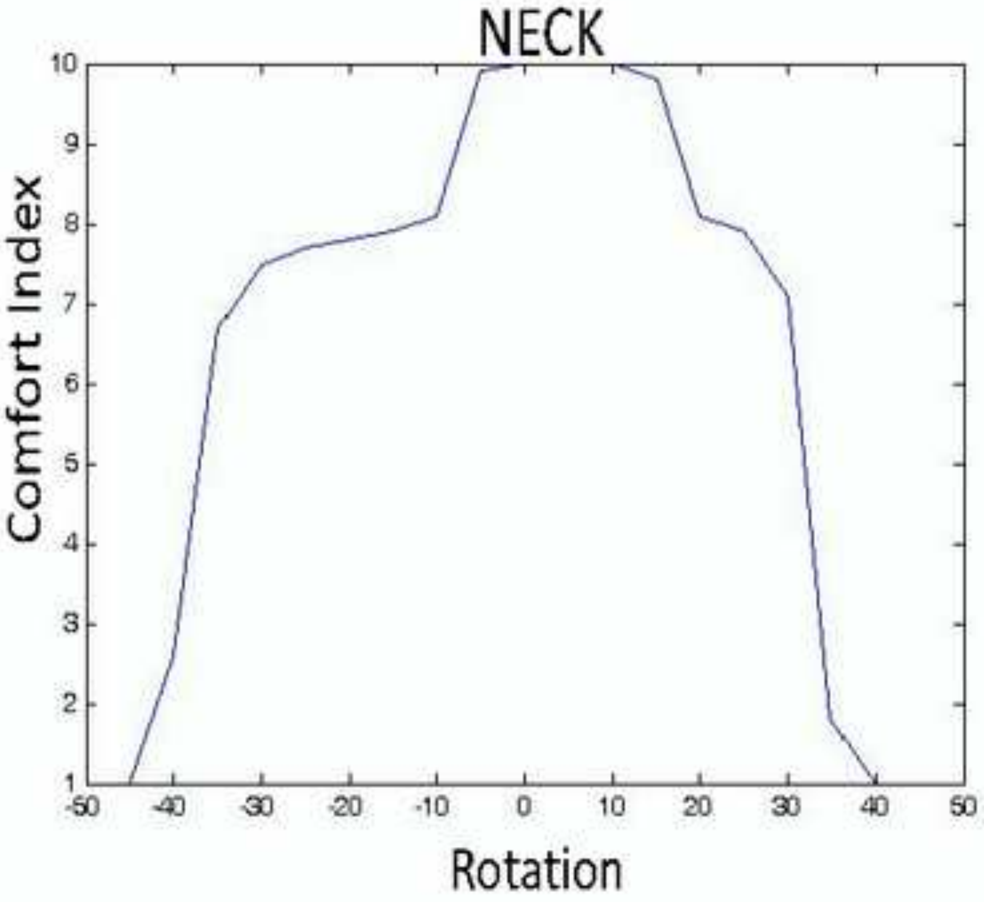
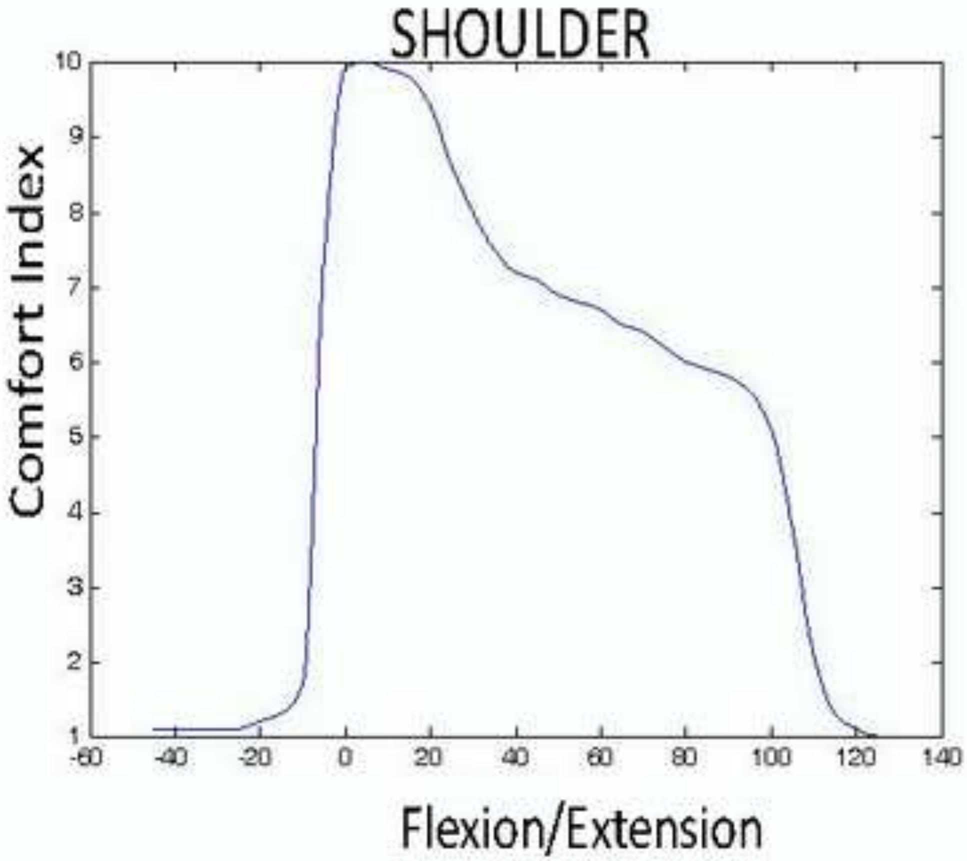
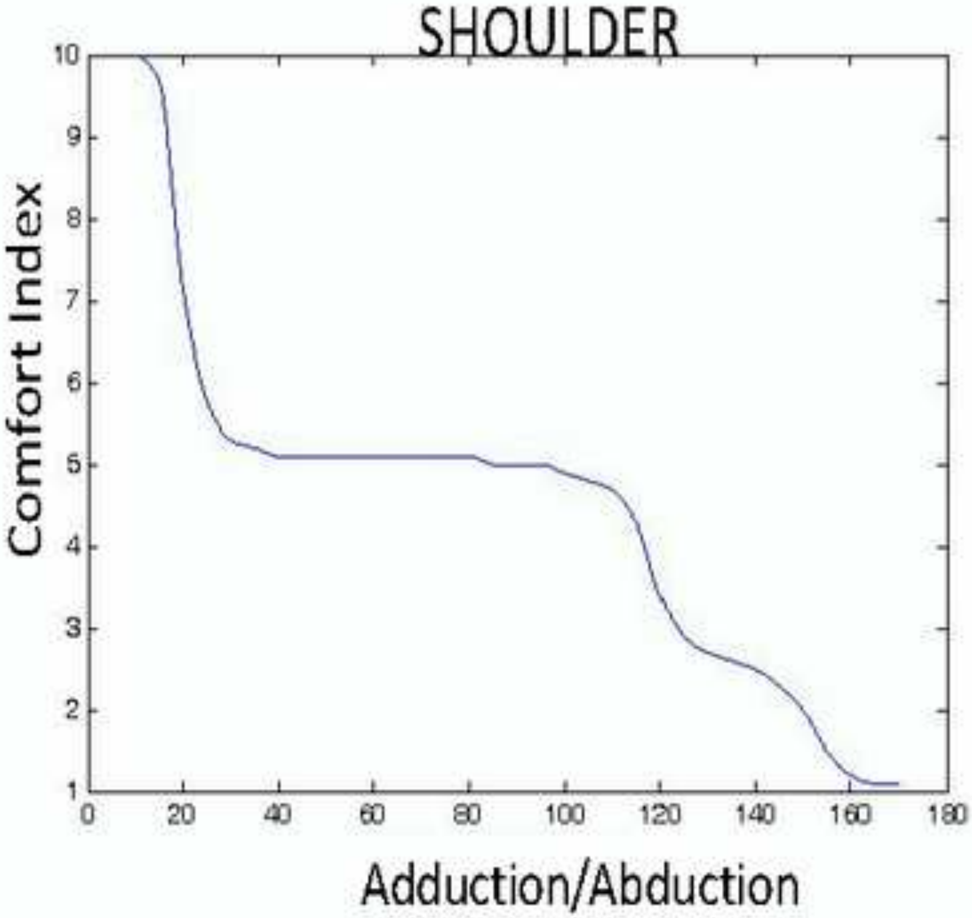
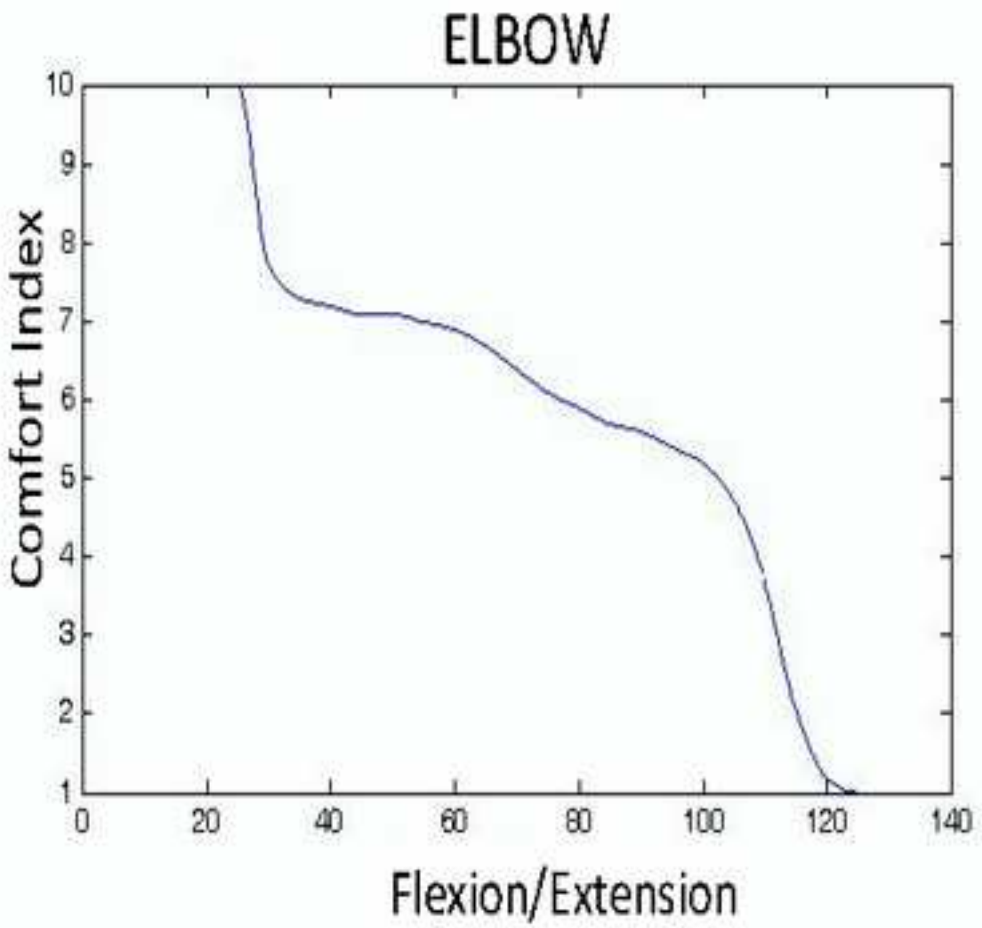


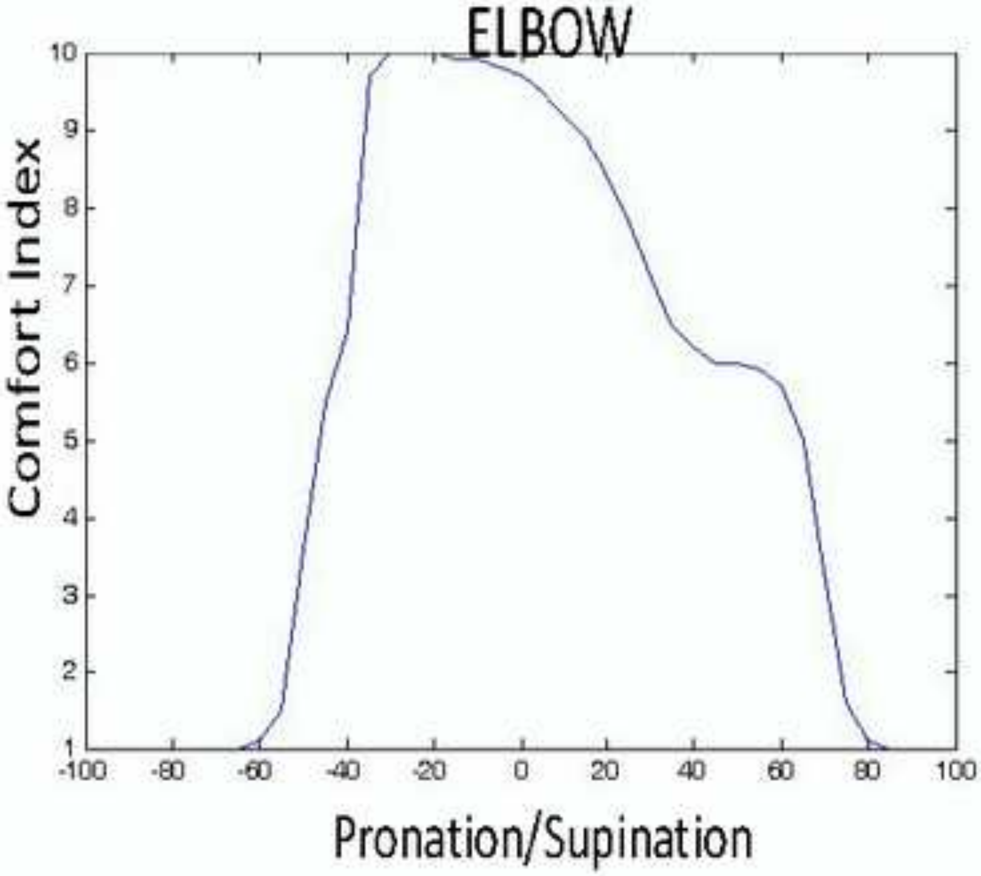

NECK
Comfort Index
10
9
8
7
6
5
4
3
2
1
-50
-40
-30
-20
-10
0
10
20
30
40
50
Lateral Flexion

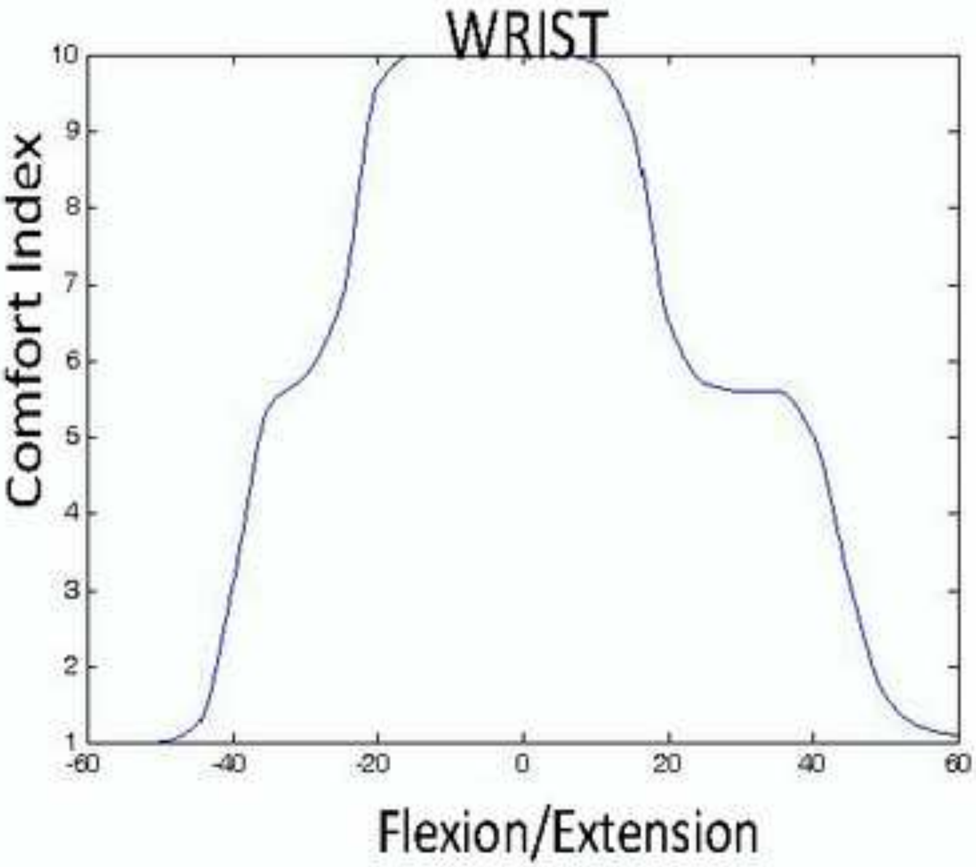

NECK
Comfort Index
10
9
8
7
6
5
4
3
2
1
-50
-40
-30
-20
-10
0
10
20
30
40
50
Rotation

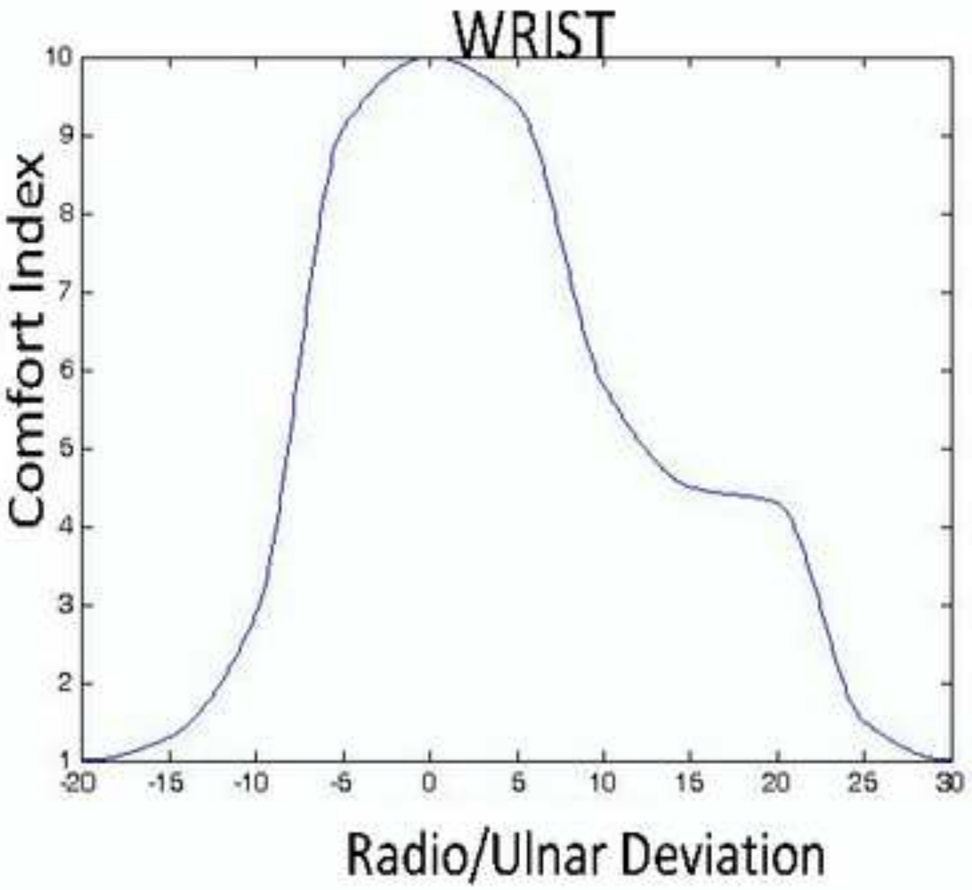

SHOULDER
Comfort Index
Flexion/Extension
10
9
8
7
6
5
4
3
2
1
-60
-40
-20
0
20
40
60
80
100
120
140


SHOULDER
Comfort Index
Adduction/Abduction
10
9
8
7
6
5
4
3
2
1
0
20
40
60
80
100
120
140
160
180


ELBOW
Comfort Index
10
9
8
7
6
5
4
3
2
1
0
20
40
60
80
100
120
140
Flexion/Extension


ELBOW
Comfort Index
10
9
8
7
6
5
4
3
2
1
-100
-80
-60
-40
-20
0
20
40
60
80
100
Pronation/Supination

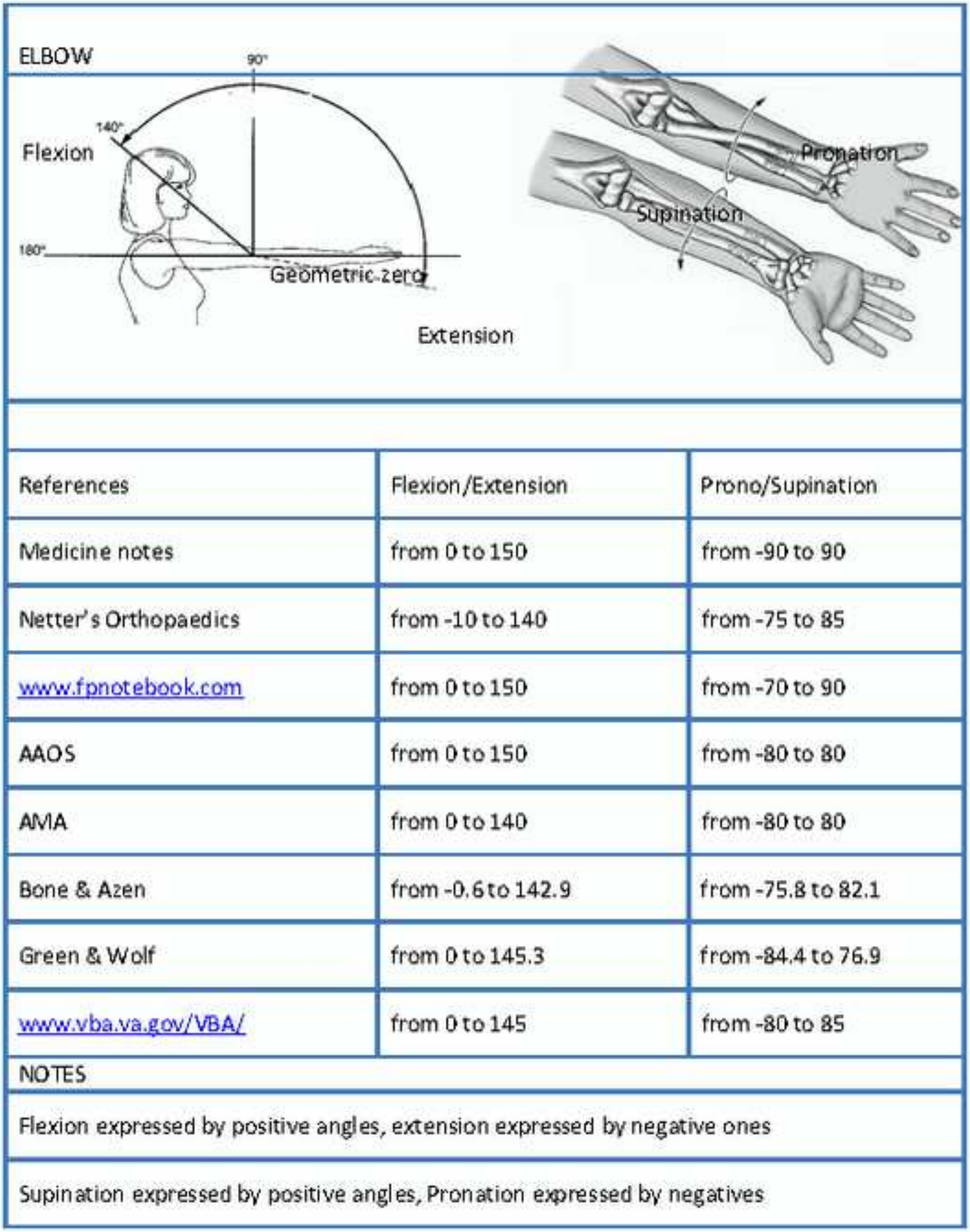

WRIST
Comfort Index
10
9
8
7
6
5
4
3
2
1
-60
-40
-20
0
20
40
60
Flexion/Extension


WRIST
Comfort Index
10
9
8
7
6
5
4
3
2
1
-20
-15
-10
-5
0
5
10
15
20
25
30
Radio/Ulnar Deviation


α=5°
α=50°
α=26°


α=7°
α=21°
α=108°


α=5°
α=28°
α=76°



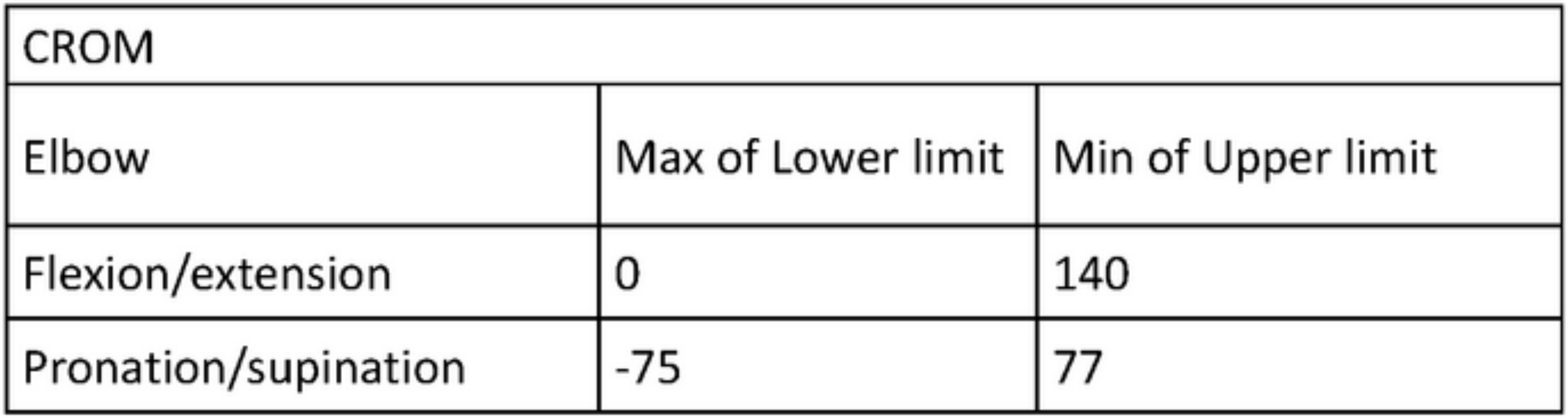
ELBOW

References	Flexion/Extension	Prono/Supination
Medicine notes	from 0 to 150	from -90 to 90
Netter's Orthopaedics	from -10 to 140	from -75 to 85
www.fpnotebook.com	from 0 to 150	from -70 to 90
AAOS	from 0 to 150	from -80 to 80
AMA	from 0 to 140	from -80 to 80
Bone & Azen	from -0.6 to 142.9	from -75.8 to 82.1
Green & Wolf	from 0 to 145.3	from -84.4 to 76.9
www.vba.va.gov/VBA/	from 0 to 145	from -80 to 85

NOTES

Flexion expressed by positive angles, extension expressed by negative ones

Supination expressed by positive angles, Pronation expressed by negatives



CROM		
Elbow	Max of Lower limit	Min of Upper limit
Flexion/extension	0	140
Pronation/supination	-75	77

Table(s)

<table>
<tr><th colspan="5">ELBOW</th></tr>
<tr><td colspan="5">Flexion/Extension</td></tr>
<tr><td>0</td><td>30</td><td>60</td><td>90</td><td>135</td></tr>
<tr><td colspan="5">Pronation/Supination</td></tr>
<tr><td>-90</td><td>-45</td><td>0</td><td>45</td><td>90</td></tr>
</table>

Table(s)

NECK				
Flexion/Extension				
-45°	-22,5°	0°	22,5°	45°
Lateral Flexion				
-45°	-22,5°	0°	22,5°	45°
Rotation				
-45°	-22,5°	0°	22,5°	45°
SHOULDER				
Flexion/Extension				
-45°	0°	45°	90°	135°
Abduction/Adduction				
0°	45°	90°	135°	170°
ELBOW				
Flexion/Extension				
0°	30°	60°	90°	135°
Prono/Supination				
-90°	-45°	0°	45°	90°
WRIST				
Flexion/Extension				
-60°	-30°	0°	30°	60°
Radio/Ulnar Deviation				
-20°	-10°	0°	15°	30°

Table(s)

		Posture 1		Posture 2		Posture 3	
		Angle	Comfort	Angle	Comfort	Angle	Comfort
NECK	Flexion/Extension	-5	10	-7	10	-5	10
	Lateral Flexion	0	9.9	0	9.9	0	9.9
	Rotation	0	10	0	10	0	10
SHOULDER	Flexion/Extension	50	6.9	21	9.4	28	8.0
	Abd/Adduction	0	10	0	10	0	10
ELBOW	Flexion/Extension	26	10	108	3.7	76	6.1
	Prono/Supination	0	9.7	0	9.7	0	9.7
WRIST	Flexion/Extension	0	10	0	10	0	10
	Radio/Ulnar Deviation	-11	2.9	-11	2.9	5	9.4
SUM			79.4		75.6		83.1