Ergonomic risk analysis inherent in neonate bathing activity performed by nurses using the REBA methodology through kinect depth sensors

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ABSTRACT

The absence of quantitative parameters to determine the mobility of the body segments required by functional assessment scales such as Rapid Entire Body Assessment (REBA) reduces its reliability by identifying risks based only on postural observation. This work measures the ergonomic risk associated with the neonatal bathing activity performed by nurses, the influence of the introduction of Kinect sensors, and their marker-less skeleton tracking function in conjunction with the postural analysis tool REBA to reduce the inter-observer variability and the subjectivity of the results. Many people without injuries reproduced the sequence of movements of a baby's body wash task, selected as the most critical within the activity. The use of a reference motion capture system, such as photogrammetry, was used to check the validity of Kinect as a measurement instrument and its precision. Variables such as the recording frequency of the sensors, and their location to the participants, influence the detection of body positions. This paper demonstrates the need for improving the nurses' posture because it is associated with an intermediate level of ergonomic risk and requires intervention.

Keywords: Functional assessment, Ergonomic risk, Kinect sensors, REBA, Photogrammetry

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1. Introduction

Functional assessment at an ergonomic level focuses on evaluating the body systematically when adopting certain postures, forced extensions, and repetitive movements, which are carried out when performing a work activity. Understanding posture as the biomechanical alignment of the body and its relationship with the environment. Correct postural alignment implies maximum physiological and biomechanical efficiency with little overhead in the support structures [1]. An appropriate and timely ergonomic assessment provides relevant information to health specialists, responsible for treating problems caused by work that can cause injuries and musculoskeletal disorders (MSDs) [2]. Within the occupational health area, MSDs cause issues that go beyond health problems, including losses in economic, professional, and productive fields. [3]. Studies from [4] suggest that lumbar MSDs will affect between 60% and 90% of people during their professional lives. Agricultural, construction, and health workers show the highest prevalence rates. Among healthcare personnel, nursing is the second riskiest profession after heavy industry [5], [6].

Currently, the need for on-site ergonomic evaluations leads to the application of highly sensitive methods to control unpredictable work postures become one of the most widely used tools in industries. Qualitative postural assessment based on visual inspection is the most common approach used to evaluate posture. However, the methodology is subjective, increases the possibility of errors among inspectors, and makes it difficult to identify subtle postural changes, presenting low reliability compared to quantitative approaches [1], [7]. For this reason, qualitative risk scales, specifically Rapid Entire Body Assessment (REBA), are presented as useful mechanisms to evaluate the whole body rapidly, and MSD risks associated with the job task being evaluated [8], [9]. The use of motion capture techniques such as photogrammetry and depth sensors allow the extraction of information to characterize the activity performed by a person at work considering the positions and movements involved in it. The advantage of the system used by Kinect sensors is that no contact with users is required, interaction occurs through the markerless motion capture function without calibration, making it possible to measure 3D postures in real-time, where the location of an object is defined by three-dimensional coordinates (x, y, z) in international system units (SI) [10], [11].

Assessing the potential risks for musculoskeletal disorders at real workstations is challenging, especially in cluttered spaces, making it difficult to assess working postures with accuracy. The use of Kinect depth sensors can provide more reliable REBA scores even in suboptimal conditions induced by the work environment [12]. Despite this, Kinect sensors were designed as a gaming accessory to track body parts and derive joint angles, it means the subjects are always observed from a frontal view. This assumption will result in a loss of tracking points due to occluded body parts [13]. This is the main disadvantage of using commercial depth sensors for postural evaluation despite its portability and low cost [14]. On the other hand, photogrammetry systems, which are capable of accurately differentiating joint movements, require multiple cameras, markers located on anatomical body landmarks, and controlled conditions, as well as experience to operate and interpret the results [15], [16]. For these reasons, this study aims to carry out a validation process for the results through kinematic analysis of the angles required by REBA. For the ergonomic risk evaluation, the most critical task involved in the newborn bath activity performed by nurses corresponds to the baby's body wash. The angles are calculated from the 3D coordinates of body joints using Kinect depth sensors, and the photogrammetry motion capture system as a reference under laboratory conditions simultaneously. Thus, they can be compared by their error rates.

2. Material and methods

2.1. REBA postural analysis

The application of the REBA methodology implies the division of the body into segments to which it provides a scoring system based on a series of static, dynamic, repetitive, and unstable postures [6]. A specific posture, generally the most critical produced during the work task, is analyzed to obtain an overall score. Fig. 1 corresponds to the REBA evaluation system, which contains the analyzed segments and the values they can take. Two groups can be identified (A and B) from which partial and final scores are obtained that allow establishing the risk level [17]. The score is based on the joint angle values from the trunk, neck, legs, arms, forearms, and wrists [14]. Additionally, this methodology considers adjustments that evaluate load handled, coupling type, etc. Adding points when there are conditions that worsen the nature of the posture and removing them when something contributes to reducing the impact of loads over the body [18].

2.2. Study sample

Five young participants (4 women and 1 man) aged between 20 and 45 years were selected for executing the task. They should not present injuries or pain at a muscular or osseous level that limit the mobility required for the execution of the activity of the newborn bath.

2.3. Procedures

The Kinescan/IBV photogrammetry system available in the Biomechanics Laboratory at EPN allows the analysis of motion through kinematic parameters and was considered as the reference. It consists of 6 infrared cameras and reflective markers which were placed on the participants according to the Kinect anatomical model and the anatomical references recommended by the ISB (International Society for Biomechanics). Due to the prevalence of occlusions in the middle fingers and thumb, it was decided to remove them and simplify the model to 21 body points, consequently, the wrist flexion angle will be considered a manual entry parameter.

A. Neck, Trunk and Leg Analysis

Step 1: Locate Neck Position
+1 0-20° +2 20°+ +2 in extension
Neck Score

Step 1a: Adjust...
If neck is twisted: +1
If neck is side bending: +1

Step 2: Locate Trunk Position
+1 0° +2 0°-20° +3 20°-60° +3 in extension >20° +4 60°+
Trunk Score

Step 2a: Adjust...
If trunk is twisted: +1
If trunk is side bending: +1

Step 3: Legs **Adjust:**
+1 Both legs down +2 One leg raised +1 30°-60° +2 60°+
Leg Score

Step 4: Look-up Posture Score in Table A
Using values from steps 1-3 above,
Locate score in Table A
Posture Score A

Step 5: Add Force/Load Score
If load < 11 lbs. : +0
If load 11 to 22 lbs. : +1
If load > 22 lbs.: +2
Adjust: If shock or rapid build up of force: add +1
Force / Load Score

Step 6: Score A, Find Row in Table C
Add values from steps 4 & 5 to obtain Score A.
Find Row in **Table C**.
Score A

Scoring
1 = Negligible Risk
2-3 = Low Risk. Change may be needed.
4-7 = Medium Risk. Further Investigate. Change Soon.
8-10 = High Risk. Investigate and Implement Change
11+ = Very High Risk. Implement Change

Scores

Table A — Neck

		1				2				3		
	Legs	1	2	3	4	1	2	3	4	1	2	3	4
Trunk Posture Score	1	1	2	3	4	1	2	3	4	3	3	5	6
	2	2	3	4	5	3	4	5	6	4	5	6	7
	3	2	4	5	6	4	5	6	7	5	6	7	8
	4	3	5	6	7	5	6	7	8	6	7	8	9
	5	4	6	7	8	6	7	8	9	7	8	9	9

Table B — Lower Arm

		1			2		
	Wrist	1	2	3	1	2	3
Upper Arm Score	1	1	2	2	1	2	3
	2	1	2	3	2	3	4
	3	3	4	5	4	5	5
	4	4	5	5	5	6	7
	5	6	7	8	7	8	8
	6	7	8	8	8	9	9

Table C

Score A	Score B											
	1	2	3	4	5	6	7	8	9	10	11	12
1	1	1	1	2	3	3	4	5	6	7	7	7
2	1	2	2	3	4	4	5	6	6	7	7	8
3	2	3	3	3	4	5	6	7	7	8	8	8
4	3	4	4	4	5	6	7	8	8	9	9	9
5	4	4	4	5	6	7	8	8	9	9	9	9
6	6	6	6	7	8	8	9	9	10	10	10	10
7	7	7	7	8	9	9	9	10	10	11	11	11
8	8	8	8	9	10	10	10	10	10	11	11	11
9	9	9	9	10	10	10	11	11	11	12	12	12
10	10	10	10	11	11	11	11	12	12	12	12	12
11	11	11	11	11	12	12	12	12	12	12	12	12
12	12	12	12	12	12	12	12	12	12	12	12	12

Table C Score + Activity Score = REBA Score

B. Arm and Wrist Analysis

Step 7: Locate Upper Arm Position:
+1 20°-20° in extension +2 20° +2 20°-45° +3 45°-90° +4 90°+
Upper Arm Score

Step 7a: Adjust...
If shoulder is raised: +1
If upper arm is abducted: +1
If arm is supported or person is leaning: -1

Step 8: Locate Lower Arm Position:
+1 60°-100° +2 0°-60° +2 100°+
Lower Arm Score

Step 9: Locate Wrist Position:
+1 15°-15° +2 15°+ +2 15°+
Wrist Score

Step 9a: Adjust...
If wrist is bent from midline or twisted : Add +1

Step 10: Look-up Posture Score in Table B
Using values from steps 7-9 above, locate score in Table B
Posture Score B

Step 11: Add Coupling Score
Well fitting Handle and mid range power grip, *good: +0*
Acceptable but not ideal hand hold or coupling
acceptable with another body part, *fair: +1*
Hand hold not acceptable but possible, *poor: +2*
No handles, awkward, unsafe with any body part,
Unacceptable: +3
Coupling Score

Step 12: Score B, Find Column in Table C
Add values from steps 10 &11 to obtain
Score B. Find column in **Table C** and match with
Score A in row from step 6 to obtain Table C Score.
Score B

Step 13: Activity Score
+1 1 or more body parts are held for longer than 1 minute (static)
+1 Repeated small range actions (more than 4x per minute)
+1 Action causes rapid large range changes in postures or unstable base

Original Worksheet Developed by Dr. Alan Hedge. Based on Technical note: Rapid Entire Body Assessment (REBA), Hignett, McAtamney, Applied Ergonomics 31 (2000) 201-205
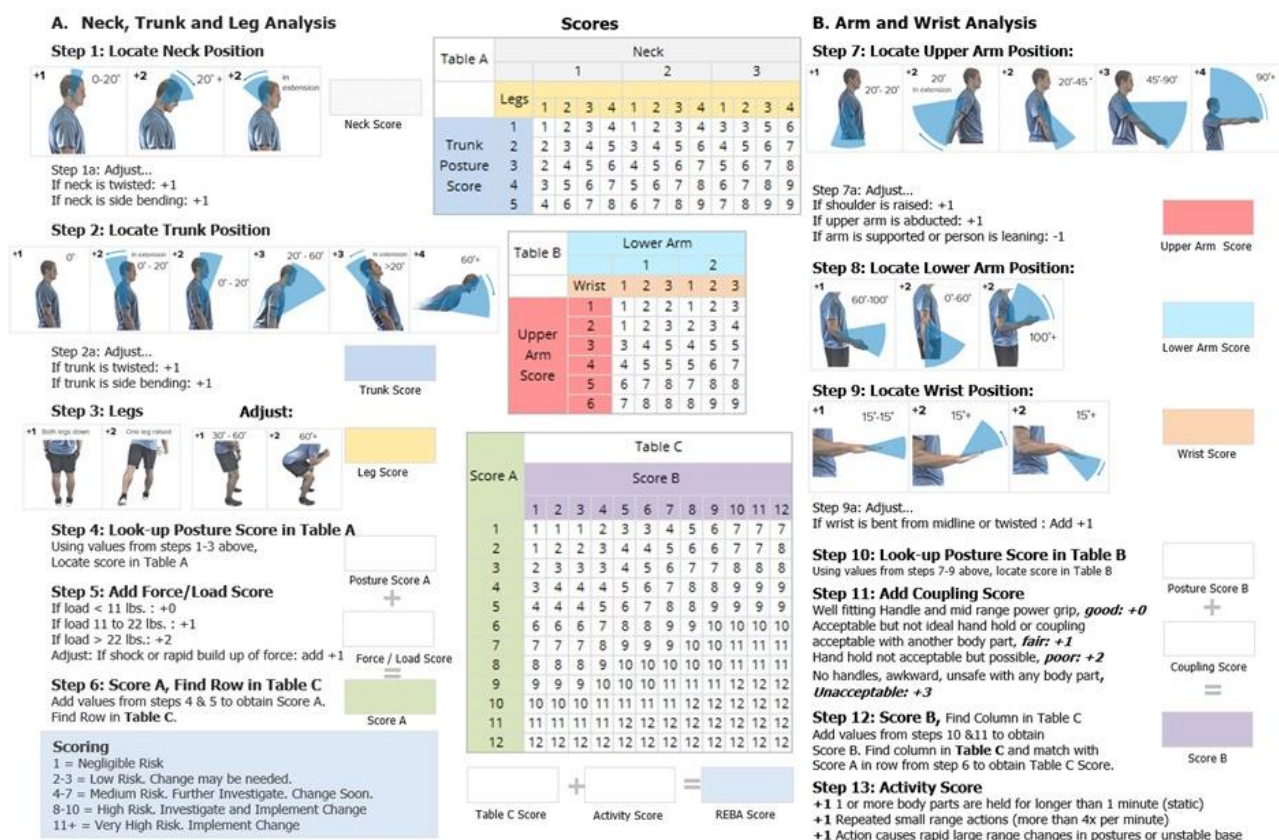
Figure 1. Segments and scoring system of the REBA rating scale [8]

Two Kinect sensors were used, and their performance was evaluated by positioning them on tripods at a height of 1 m and 2 m distance from the participant in two arrangements. The first at 30 ° to the right and 30 ° to the left, the second at 30 ° to the right and frontally at 90 °. The task of washing the body of a baby, selected as the most critical according to the indicators of intensity, frequency, and duration related to posture, force production, repetitive movements, and static work was analyzed [19]. A cuddly toy with characteristics like those of a neonate in dimensions and weight (2.4 kg) was used. Participants were instructed to perform the movements of (1) holding the baby with the left arm and adopting the anatomical position, (2) bending the trunk approximately 45 °, (3) from a neutral shoulder position and with the elbows fully in extension, flex the arms at approximately 30 ° followed by elbows flexion and abduction left at 90 ° and right at 100 ° in such a way that the forearm is parallel to the chest, (4) the baby should rest on the left forearm, make a slight flexion and rotation of the neck with the look towards the baby as shown in Fig. 2. The posture achieved with the sequence of movements should be maintained for 40 s, avoiding knee flexion. The anatomical position consists of standing upright, opening the feet at shoulders level, limbs in extension, and palms facing outwards. It is adopted for 5 s at the beginning and end of the movement, it allows to verify markers detection. During the validation process, one of the participants reproduced the complete movement sequence with the baby and additionally the movements of the left and right arm separately including the trunk flexion without using the baby. All tests were conducted three times. For the ergonomic risk tests, the validation results regarding the location of sensors were considered.

2.4. Data acquisition

The information provided by the Kinect V2 sensor was obtained using the Kinect for Windows Software Development KIT (SDK), through MATLAB with its components: Image Acquisition Toolbox Support Package for Kinect For Windows Sensor and the Kinect 2 Interface for MATLAB (Kin2) application, developed by [20] available on GitHub that allows the development of research applications in MATLAB from image acquisition, coordinate mapping, body tracking, facial processing, and 3D reconstruction data without the need to delve into programming languages such as C# or C++. Inside the body demo resource, part of Kin2 a counter was implemented to store the body joints coordinate information with its components

(X = medial/lateral, Y = vertical, Z = anterior/posterior) in each frame within a matrix during the recording period. Data acquisition was performed at Kinect nominal available frequency of 30 Hz.
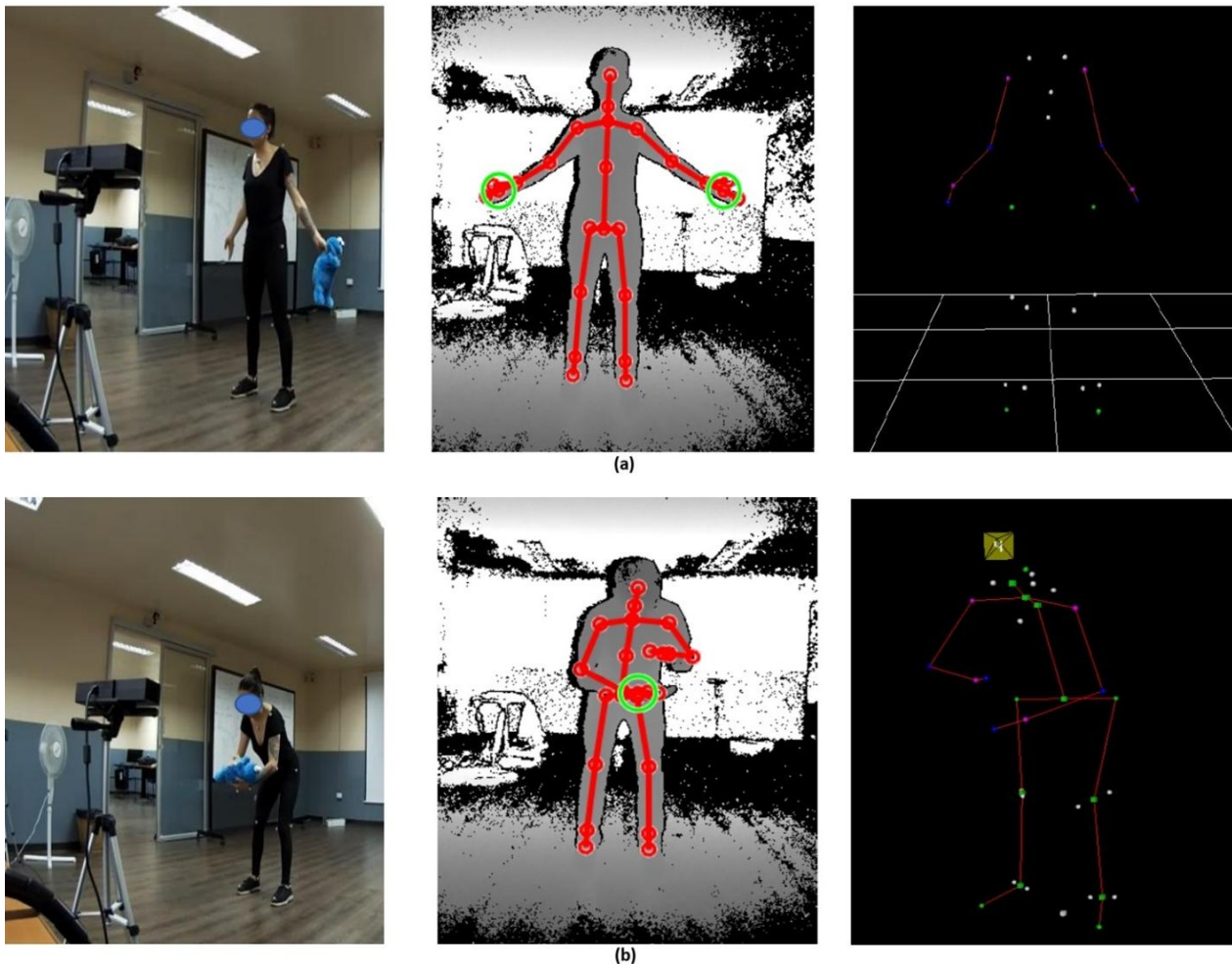

Figure 2. (a) Anatomical position captured by Kinect sensor and Kinescan, (b) Analyzed posture captured by Kinect sensor and Kinescan motion capture system

2.5. Data processing

Data processing is carried out systematically in two parts. First validation, then ergonomic risk analysis with REBA. The information obtained with depth sensors and the photogrammetry system is stored in arrays which must comply with the dimension, positioning, and coordinate reference system features of the model set by Kinect, as follows: $M = \left(M_{ij}\right)_{n \times 21}$, where n is the number of frames acquired during recording and 21 the joints detected by the sensor. The Kinescan system employs an (X, Z, Y) axis system therefore its array was restructured into a model analogue to Kinect's (X, Y, Z) coordinate system. The recording frequency of depth sensors is unsteady approximately 3 times lower than that of photogrammetry which remains stable at 30 Hz. To maintain constant sampling intervals, the downsampling function was used, which reduces the sampling rate by an integer factor of 3 through linear interpolation. According to [21], [22] in systems based on multiple sensors, data must be synchronized and normalized. The change of movement detected when anatomical position ends and the activity starts is used to align the signals, meanwhile, with normalization, the data acquired in time series is scaled again in a range of values from 0 to 100 % that represent the beginning and end of the activity. The Savitzky-Golay (SG) filter was implemented. It is a piecewise polynomial fit applied to a polynomial function, which corresponds to the original signal using the least-squares error method [23]. Being known the positions of the 21 available body joints it is possible to determine the angles required by REBA. Therefore, the trunk arms, forearms segments were calculated from the anatomical reference coordinates using the angle between bars in accordance with the global coordinate system by establishing joint axes for each segment. Due to the complexity of the analyzed posture, anatomical planes were generated for

the calculation of the leg's flexion angle, employing the projection of vectors on those planes. The joint angle is formed by the longitudinal axes of its adjacent body segments [24]. The value of the angle between bars is defined by (1).

$$\theta_{p1,p2} = \cos^{-1} \frac{\overrightarrow{p_1 r} \cdot \overrightarrow{r p_2}}{\|\overrightarrow{p_1 r}\| \|\overrightarrow{r p_2}\|} \tag{1}$$

$\theta_{p1,p2}$ represents the angle formed by two vectors $\overrightarrow{p_1 r}, \overrightarrow{r p_2}$, and $\|\overrightarrow{p_1 r}\|, \|\overrightarrow{r p_2}\|$ represents its module. It is necessary to know the spatial coordinates of three points p_1, p_2 y r. The point of origin r shared by vectors also represents the joint from which results will be obtained.

2.6. Statistical analysis

The average values of calculated angles from the provided information by Kinect depth sensors and Kinescan were analyzed using the standard deviation to know the dispersion in comparison with the mean. Thus, the systematic error was also used to evaluate whether the measurement method is appropriate and valid, while the Standard Error of Measurement (SEM) is linked to the existing variability within the errors.

3. Results and discussion

3.1. Sensor validation in critical segments

Table 1 shows the information corresponding to systematic error and (SEM) for the left arm and right arm sequences, it can be observed that the best results are obtained when using the frontal - lateral sensor arrangement. Systematic errors represent the difference in degrees between the reference value and the results measured with the Kinect sensors.

Table 1. Systematic error and SEM for left and right arm sequence

	Left Arm Only Sequence								Right Arm Only Sequence							
	Sensor arrangement Side 30 °				Sensor arrangement Side 30 °				Sensor arrangement Side 30 °				Sensor arrangement Side 30 °			
	Systematic error [°]		SEM [°]		Systematic error [°]		SEM [°]		Systematic error [°]		SEM [°]		Systematic error [°]		SEM [°]	
	30 ° Left	30 ° Right	30 ° Left	30 ° Right	90 °	30 ° Right	90 °	30 ° Right	30 ° Left	30 ° Right	30 ° Left	30 ° Right	90 °	30 ° Right	90 °	30 ° Right
Trunk	20.90	9,47	5,45	4,03	8,10	3,50	3,60	0,15	8.34	6.91	5.15	5.38	15.60	3.16	0.74	0.61
Neck	2.76	2,39	1,79	1,47	5,25	7,03	1,74	0,80	8.74	22.30	2.27	8.09	4.31	3.40	0.93	0.69
Leg Right	6.20	3,95	1,83	1,80	6,50	1,48	0,64	0,16	8.81	6.11	0.83	1.83	6.27	2.37	0.15	0.43
Left Leg	5.25	8,02	2,59	1,54	3,81	1,63	0,57	0,39	9.15	2.46	1.73	1.51	6.20	8.00	0.13	0.23
Elbow Left	27.40	13,40	12,70	8,70	16,00	5,95	5,42	1,25	38.70	33.20	14.50	14.70	35.50	51.30	3.35	2.10
Left Arm	32.60	7,16	8,13	5,95	8,62	2,53	1,27	0,55	6.10	20.20	3.82	4.34	5.88	14.80	0.70	1.45

In a deeper analysis it can be noticed that errors vary segment by segment, so the points that appear to be problematic due to the lack of accuracy in their measurements are the left elbow with an error of 16 ° with the frontal sensor, and the right elbow with an error of 35 and 51 ° with the sensors in frontal and lateral position respectively. This is primarily due to the nature of the movements analyzed, joints occlusion, and the variability of the sampled signals. Achieving mitigation of these defects is one of the reasons for using multiple sensors where the location of the articular joints is captured from different points of view, thus selecting the optimal ones for the study. For this selection, the SEM error is also taken into consideration, where the lower its value the greater reliability its results.

The difference in acquired frames by the two systems is representative. The actual recording frequency of the depth sensors oscillates in a range of 8 to 10 Hz according to Kinect. It provides arrays with dimensions between 550×21 and 950×21.

Table 2 shows the results of the evaluation of the complete movement where the values of the mean and standard deviation of all the tests carried out for each joint analyzed are summarized. Segments that imply

constant movement during the analysis present high variability, with a standard deviation greater than 5 ° corresponding to the elbows. In the rest of the joints, the standard deviation takes values between 0.17° and 4.02°, which is considered an acceptable range. In measurements made with the sensor in the lateral position, the standard deviation is much lower than that obtained with the front sensor because of a reduced amount of noise due to the decrease of occlusions. The systematic error tends to increase when analyzing a complex movement. The inconveniences in elbows and arms prevail as shown in Table 3.

Table 2. Average and standard deviation of values obtained for the complete sequence of movements

Complete Sequence with Baby					
Front sensor arrangement - Right side					
	Mean [°]			Standard deviation [°]		
	90 °	30 °	Kinescan	90 °	30 °	Kinescan
Trunk	49.53	56.47	50.95	5.69	0.45	1.75
Neck	10.76	25.47	24.30	2.00	1.00	0.58
Leg Right	9.15	4.55	4.48	3.12	0.29	0.06
Left Leg	9.13	4.46	5.76	2.16	0.27	0.18
Left Elbow	88.63	104.20	96.95	8.35	9.16	0.11
Right Elbow	82.80	76.07	114.00	7.06	4.95	0.22
Left Arm	31.73	29.93	21.10	0.91	0.80	0.27
Right arm	34.77	30.60	25.05	1.88	0.97	0.56

Table 3. Systematic error and SEM for the complete sequence of movements

Complete Sequence with Baby				
Front sensor arrangement - Right side				
	Systematic Error [°]		SEM [°]	
	90 °	30 °	90 °	30 °
Trunk	5.19	4.38	4.25	0.41
Neck	13.10	2.13	2.31	0.79
Leg Right	4.79	0.84	2.71	0.29
Left Leg	3.38	1.15	1.79	0.26
Left Elbow	11.10	9.72	5.09	6.51
Right Elbow	32.10	38.10	3.84	4.91
Left Arm	10.40	8.91	1.04	0.86
Right arm	9.15	6.13	1.78	0.91

3.2. Trunk flexion angle

Additionally, to determine which sensor provides the best information for each joint, it should be taken into account that when monitoring joints, characteristics such as observable trends in the signals are important because the reference frameworks for decision making are based on them. Joint by joint analysis in Fig. 3 illustrates that during trunk flexion with the camera located frontally, the standard deviation is higher, which is reflected in the oscillations of the value of the angles. This is mainly since with the sensor in this position, trunk flexion and arms movement tend to interfere with the detection of corporal points used to calculate this angle. Thus, the best alternative to evaluate this segment is the sensor located laterally in whose graph it is observed that before the signal stabilizes there is a variation in the slope, which represents the change in position of the trunk from upright to flexed. By [25] this difference between the Kinescan reference curve and those of the Kinect is mainly due to the variation in recording frequency and time delays in the Kinect's tracking algorithms and its effect is more noticeable in segments with greater movement in this study particularly elbows, arms, and trunk.
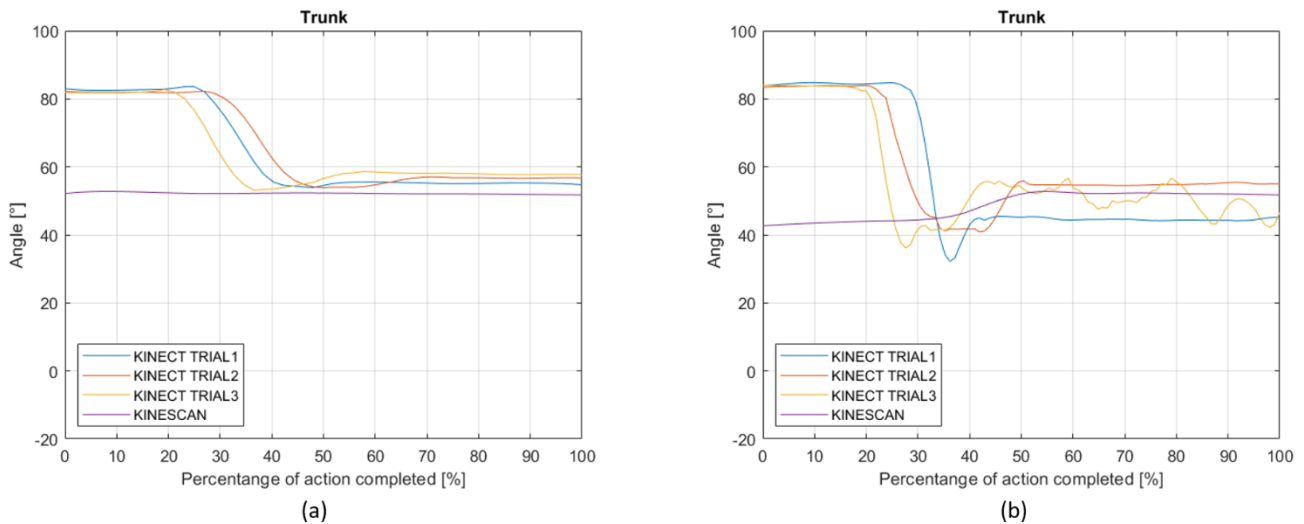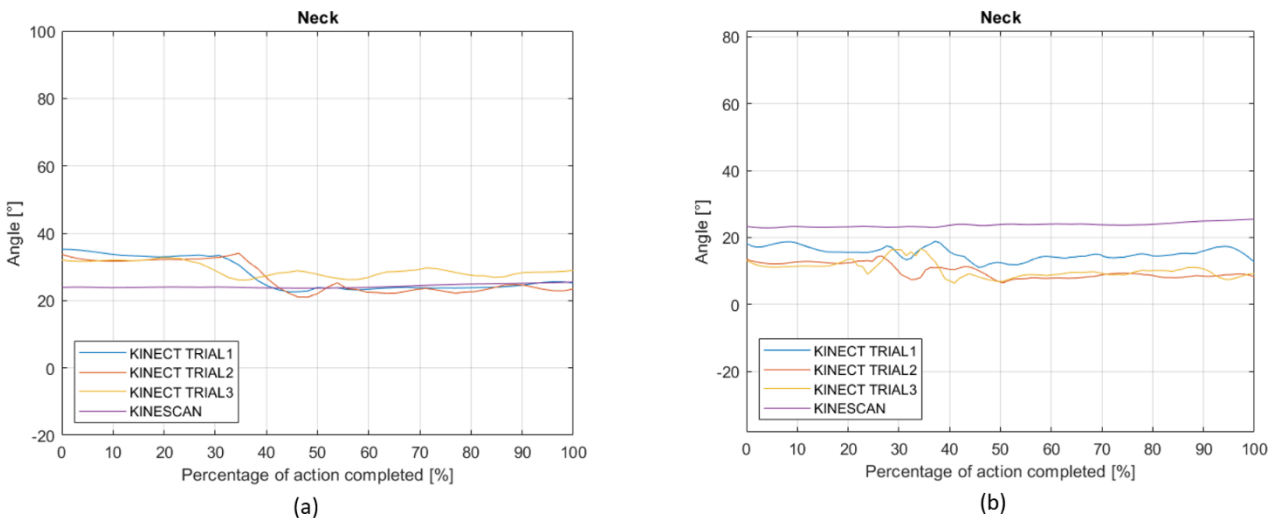
Figure 3. Trunk flexion angle (a) lateral sensor [°] vs. percentage of movement completed (b) front sensor [°] vs. percentage of movement completed

3.3. Neck flexion angle

In Fig. 4 the graphs of the neck flexion angle are shown as a function of the percentage of the action completed with the cameras located laterally and frontally. In both cases, there are oscillations in the signal throughout the movement. However, the results of the lateral sensor present a lower standard deviation and a trend that is closer to the reference which is related to the fact that the plane in which the movement is developed corresponds to the sagittal or anteroposterior. Due to this, the data obtained by the lateral sensor is used, which is the one with the best point of view of that plane.
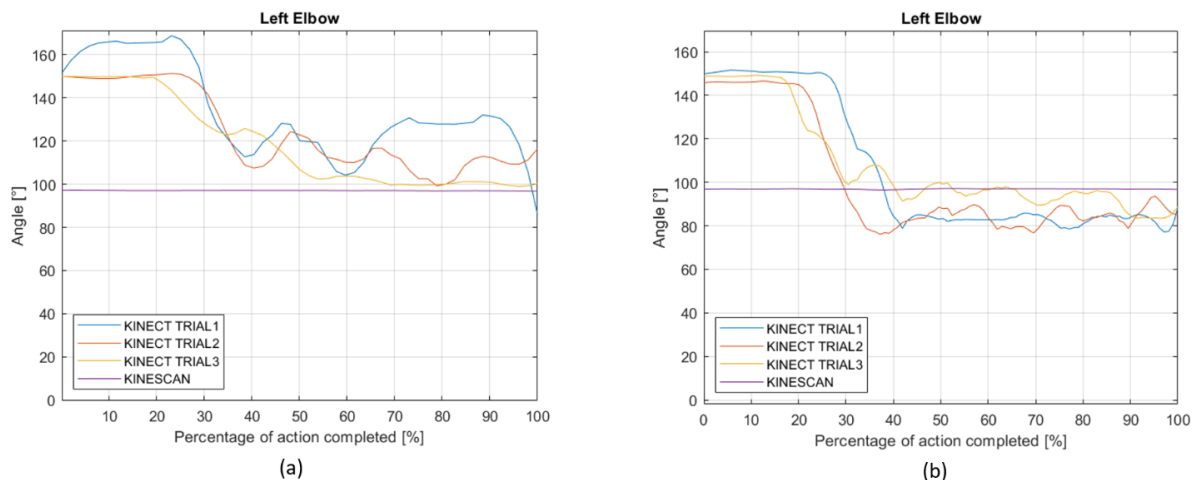

Figure 4. Neck flexion angle (a) lateral sensor [°] vs. percentage of movement completed (b) front sensor [°] vs. percentage of movement completed

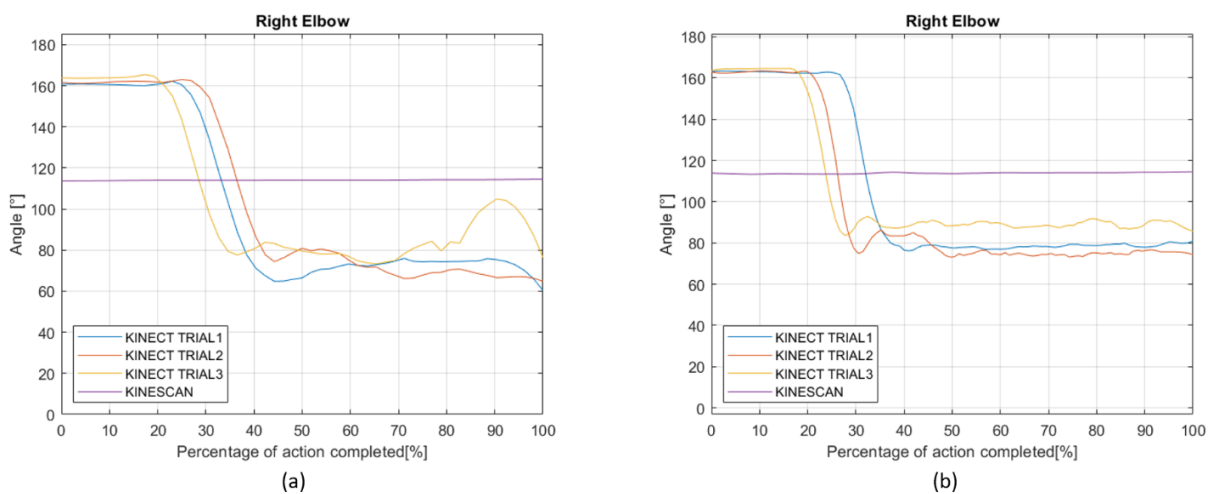### 3.4. Elbows flexion angle

The noise in the signals is shown as a predominant effect in the evaluation of joints that involve complex sequences of movement, as in the left elbow Fig. 5. Or constant movement as in the right elbow Fig. 6. In both cases, the oscillations in Kinect curves prevail throughout the sequence. It comes to the segments with the highest standard deviation, which means greater dispersion in their results. The behavior of the curves that represent these angles is most appropriately captured with the frontal sensor, which has a better field of view of the transverse plane, which is where these joints move, and a lower standard deviation in its results. Particularly in the right elbow, the experimental data deviates considerably from the reference with a systematic error of 32° also related to the time delay in the processing of information by the reduction in the sampling frequency. The calculation of the angle of the right forearm associated with the elbow flexion required for postural evaluation in this study must consider the inter-participant variability factor when

reproducing a movement. Specifically, in the joint of the right elbow, the spectrum of results of the angular displacement during the body wash of the neonate is wide (80° to 120 °). Although the capacity of the sensor is not sufficient to estimate this angle with good precision, it can detect the change of movement in this segment appropriately to assess with REBA, whose score for the forearm requires to determine if the flexion corresponds to an angle greater or less than 100 °.

3.5. Legs bending angle

The results of the left and right leg flexion are presented in Fig. 7 and Fig. 8 respectively. This movement also takes place in the anteroposterior plane. Also, due to the flexion of the trunk, the points of the hips and knees tend to occlude with the front camera, and certain fluctuations in the signal are introduced, thus the sensor located in the lateral position is used, which is the one that provides information with the lower standard deviation and a trend very close to the Kinescan reference curve.

3.6. Arms flexion angle

The left and right arm flexion results shown in Fig. 9 and Fig. 10 respectively, present similar trends with the cameras in the lateral and front positions. Despite this, the sensor with the best view of the plane in which the movement takes place is also the one that provides the best results. In this segment, the action is performed on the anteroposterior plane. Consequently, the lateral sensor information is used which also has a lower standard deviation.

Figure 5. Left elbow flexion angle (a) lateral sensor [°] vs. percentage of movement completed (b) front sensor [°] vs. percentage of movement completed
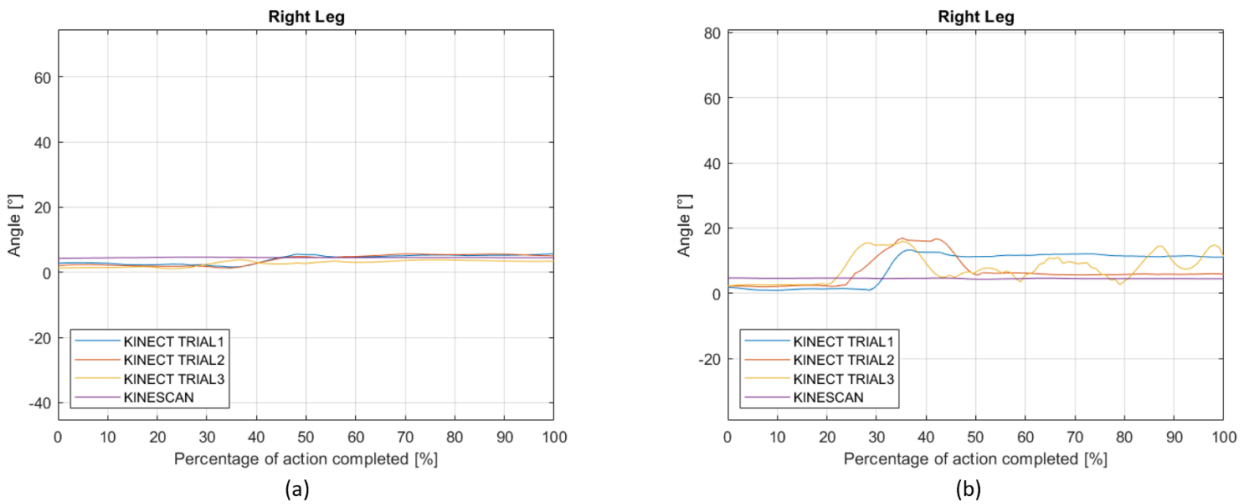

Figure 6. Right elbow flexion angle (a) lateral sensor [°] vs. percentage of movement completed (b) front sensor [°] vs. percentage of movement completed
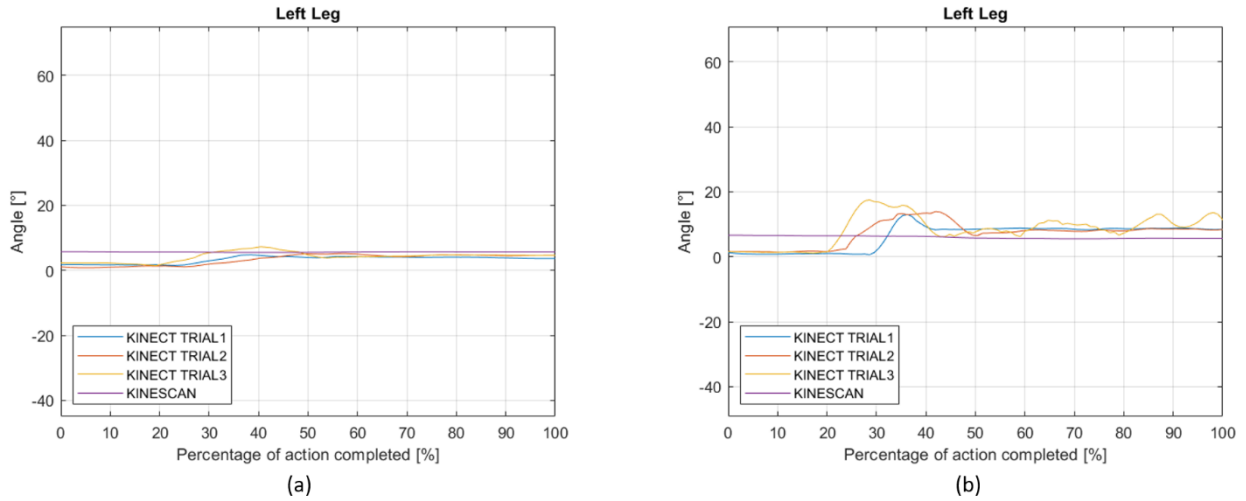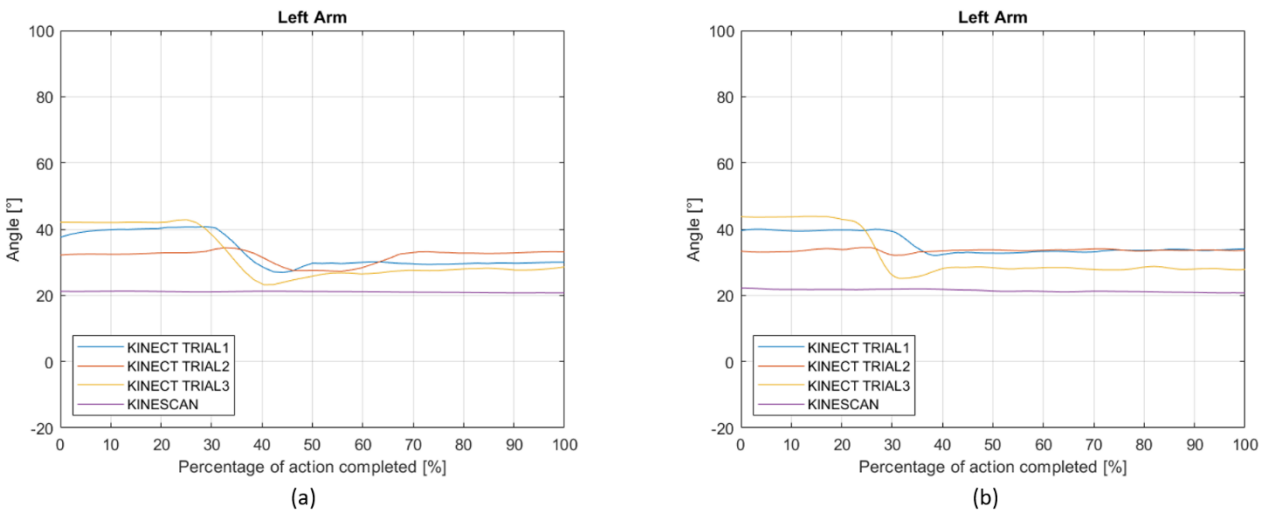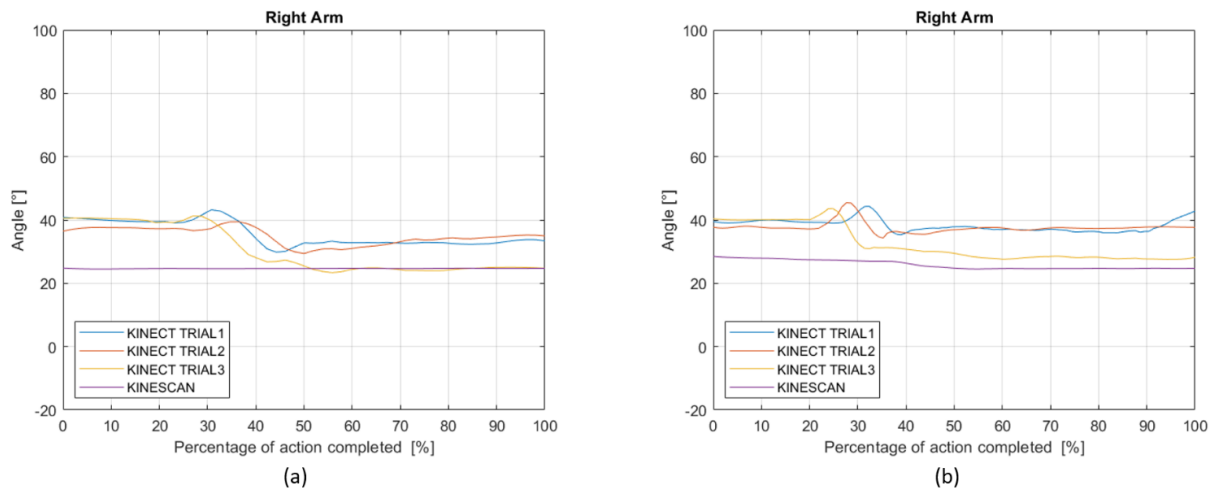
Figure 7. Left leg flexion angle (a) lateral sensor [°] vs. percentage of movement completed (b) front sensor [°] vs. percentage of movement completed

Figure 8. Right leg flexion angle (a) lateral sensor [°] vs. percentage of movement completed (b) front sensor [°] vs. percentage of movement completed

Figure. 9 Left arm flexion angle (a) lateral sensor [°] vs. percentage of movement completed (b) front sensor [°] vs. percentage of movement completed

Figure. 10 (a) Right arm flexion angle (a) lateral sensor [°] vs. percentage of movement completed (b) front sensor [°] vs. percentage of movement completed

3.7. Results of risk assessment with REBA

This section shows the results of the ergonomic risk assessment of the most critical motion sequence corresponding to the baby's body wash carried out by nurses during the newborn bath using REBA methodology and Kinect sensors. As well as the determined risk trends, and the influence of the calculated data obtained from the depth sensor information and the manual input parameters on the results. Table 4 shows the ergonomic risk on the REBA scale of the evaluation corresponding to the right and left sides of each study participant's body. It means that 4 of the 5 cases present medium risk (values between 4 and 7) while only one case has a high risk (values between 8 and 10). In 2 cases a higher score was obtained on the left side, in 2 cases the result is equal on both sides, and only on one occasion, the score on the right side exceeded the left side. This because the left side bears the weight of the baby with the arm during the bath. Considering the average results of the ergonomic evaluation it can be said that the activity of the newborn bath in its most critical task corresponding to the washing of the body of the baby presents average risk consequently corrective measures are necessary to avoid the adoption of forced postures and the appearance of injuries.

Table 4. REBA evaluation results

	Ergonomic Risk Results		
	REBA Left Side	REBA Right Side	Level of Action
Subject 1	6	5	It is necessary
Subject 2	5	6	It is necessary
Subject 3	8	8	It is necessary as soon as possible
Subject 4	6	5	It is necessary
Subject 5	7	7	It is necessary
Average	6,4 ~ 6	6,2 ~ 6	It is necessary

3.8. Influence of angles calculated from kinect sensor information

For a greater understanding of the variation in risk results, a statistical analysis was performed taking into account the mean and standard deviation of the angles used in the study. In Table 5 segments with the greatest dispersion are the elbows. The fluctuation presented in these values is due to the movement associated with those segments during task reproduction. In general, it should be considered that despite the existence of a protocol to execute the movements the physical and biomechanical conditions of each person introduce an effect of inter-participant variability. However, this is only relevant when there are values greater than 20° in the neck segment, and values less than 100° in the elbows since they represent an increment and reduction of one point respectively in the score assigned to those segments. On the other hand, these variations in risk results do not significantly influence their characterization since in 80% of cases the risk associated with the

activity is medium, and only in a case representing the remaining 20% a value that implies high risk was obtained.

Table 5. Average and standard deviation values of angles used in the REBA assessment

	REBA angles					
	Average [°]					St Dev
	Subject 1	Subject 2	Subject 3	Subject 4	Subject 5	
Trunk	62.1	64.3	60.9	63.6	59.5	1.95
Neck	11.86	15.8	20.2	12.2	26.6	6.18
Leg Right	3.74	3.63	7.35	2.4	3.96	1.85
Left Leg	1.36	15.2	4.9	4.64	7.5	5.22
Left Elbow	103	96.7	115	102	102	6.76
Right Elbow	89.6	112	114	97.5	101	10.19
Left Arm	23.3	34.9	20.3	21	29.7	6.28
Right arm	39.7	33.4	26.1	34.7	31.4	4.95
Support Feet	0.0207	0.01	0.0129	0.0469	0.00759	0.02

3.9. Influence of manual input parameters and settings

The presence of manual input parameters and adjustments obtained by observation can cause significant changes in the score. Despite this, the settings used in REBA are quite specific and easy to identify. Thus, all these parameters were defined for the entire study. Simultaneously, taking into account the variability in how the task movements between each participant are executed, it is beneficial to verify how the defined parameters adapt to each participant particular conditions, and it can be concluded that the adjustments considered remain unchanged. For that reason, through the case study, they did not alter the scores of each segment. In the case of corrections by the type of muscle activity, it should be emphasized that these conditions can increase the final REBA score by up to a value of 3. In this study, the existence of static postures increases the final result of all participants by 1 point.

3.10. Discussion

Based on the results obtained, especially in the calculation of angles, it is possible to conclude that Kinect sensors have good characteristics to be introduced as complementary tools in postural evaluation and motion analysis without markers. Despite this, it is very sensitive to the conditions of the environment which is presented as a strong limitation in terms of its use as a measuring instrument. However, it is appropriate for evaluating and distinguishing ranges of motion. Precisely qualitative ergonomic risk assessment scales set their different scoring levels based on fairly flexible mobility ranges, i.e., they involve a considerable change in movement as well: in REBA for the score of a segment to increase by 1 point there must be a variation in the angle measured between 20° to 40° depending on the segment.

The results obtained are consistent and comparable to motion capture systems using markers. Low recording frequency is a limiting condition even for the photogrammetry system whose nominal value was set at 30 Hz to reach analog data acquisition conditions on both Kinect and Kinescan systems. Additionally, it should be noticed that the actual sample rate of depth sensors decreases dramatically, approximately 3 times lower causing the acquired data to be drastically reduced. Despite this, the trend in terms of its value remains similar. The presence of sudden movements or their rapid onset introduces noise to signals in both cases and causes digitization problems in Kinescan. The presence of measurement errors is mainly due to the technical characteristics of Kinect depth sensors and the type of movements that are part of the activity analyzed. Therefore, the use of a multi-camera array and the study of their location is a way to achieve better results in an ergonomic risk assessment as body movement develops across multiple planes.

The introduction of qualitative parameters in ergonomic risk analysis allows for significant improvements in results by reducing interobserver variability using Kinect depth sensors and markerless skeletal tracking. Results in similar studies are promising and show that the depth sensor is accurate enough to assess 3D positions in work environments.

Finally, regarding the levels of action, it can be concluded that all participants require an intervention. There is evidence of a strong relationship between the adoption of forced postures and the appearance of

musculoskeletal disorders, but the mechanism of action has not been accurately determined. There is no reasonably understandable model for establishing design criteria to prevent disorders [26]. However, considering that neonate bathing activity involves load management and flexion/extension of segments in the upper limb, the application of specific workplace conditioning strategies can reduce the possibility of suffering injuries or musculoskeletal disorders as long as it focuses on reducing the adoption of muscle-overloading, and postures, postures that generate asymmetric loads on joints, as well as preventing one or more anatomical regions from no longer being in a natural position of comfort to reach forced postures, generating hyperextensions, hyperflexions and/or osteoarticular hyper rotation that can trigger overload injuries [26].

4. Conclusions

By identifying positions whose execution involves repetitive or prolonged adoption, and require important physical efforts, it is possible to establish the most critical motion sequences of activity, associated with possible analysis scenarios where finally only the worst case is considered.

Ergonomic valuation carried out using the REBA postural analysis method and Kinect depth sensors together allowed quantitative parameters to be included when calculating the angles of the segments of interest for evaluation. The risk results obtained present a marked trend taking values of 5 and 6, thus showing a reduction in the subjectivity of qualitative valuation scales, and errors caused by inter-observer variability.

Technical specific features of depth sensors such as the low available recording frequency make them highly sensitive to environmental conditions, foreign bodies detection, and sudden movement execution. Therefore, despite having great potential in markerless motion analysis their results need to be validated in terms of accuracy, this is achieved through comparative processes with other technologies.

The validation process was performed with photogrammetry where the error in the calculated angular measurements was estimated using the information provided by Kinect and Kinescan. Indeed, it can be concluded that the quality of the data provided by the sensor is adequate to carry out postural assessments in combination with qualitative methods of risk analysis where the value ranges of the angles established for the assignment of a score must vary between 15 and 20 degrees to increase their value by 1 point. This considering that the systematic error obtained is less than $5°$ except for the right arm and left forearm segments that are affected by the introduction of artifacts by movement and the use of a doll to simulate the baby. The use of two sensors in conjunction with the study of their location in the workspace allows mitigating noise effects, artifact errors as well as the possibility to choose the best data of each sensor.

The task of washing a baby's body carried out by nurses as part of the newborn bathing process is shown as the most critical presenting an intermediate associated risk corresponding to the scores of 4 and 5 obtained with REBA an intervention is necessary, which includes a more detailed analysis of the physical conditions of those who perform this activity and the workplace conditions.

The intermediate-risk score presented in neonate bathing activity is related to the existence of risk factors in terms of postural load and working environment, reducing them also mitigates the appearance of TMEs.

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