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The Development of Exercise Accuracy Measurement Algorithm Supporting Personal Training's Exercise Amount Improvement

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Abstract

The demand for personal training (PT), through which high exercise effects can be achieved within short-term, has recently increased. PT can achieve an exercise amount improvement effect, only if accurate postures are maintained upon performing PT, and exercise with inaccurate postures can cause injuries. However, research is insufficient on exercise amount comparisons and judging exercise accuracy on PT. This study proposes an exercise accuracy measurement algorithm and compares differences in exercise amounts according to exercise postures through experiments using a respiratory gas analyzer. The exercise accuracy measurement algorithm acquires Euler angles from major body parts operated upon exercise through a motion device, based on which the joint angles are calculated. By comparing the calculated joint angles with each reference angle in each exercise step, the status of exercise accuracy is judged. The calculated results of exercise accuracy on squats, lunges, and push-ups showed 0.02% difference in comparison with actually measured results through a goniometer. As a result of the exercise amount comparison experiment according to accurate posture through a respiratory gas analyzer, the exercise amount was higher by 45.19% on average in accurate postures. Through this, it was confirmed that maintaining accurate postures contributes to exercise amount improvement.

Keywords: *Exercise Accuracy, Personal Training, Exercise Amount, measurement Algorithm*

1. Introduction

As interest in health increases, people participating in sports activities increase as well [1]. Demand for personal training (PT) that can help body balance, as well as health retention, muscle strength consolidation, and weight decrease is on the rise [2, 3]. PT presents an exercise method for safe and efficient exercise to be carried out in line with personal physical characteristics [4]. PT can consist of various motions (exercises) stabilizing physical movements, balancing body, and consolidating core muscles [5]. Such PT motions (core exercises) have a merit that can maximize the effects of exercise within short term [6]. Accurate postures in

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exercise enhance muscle activity and increase calorie consumption [7, 8]. Meanwhile, exercise effects become amiss due to inaccurate postures, and the risk of injury is caused [9]. As the importance of accurate postures becomes pronounced, research to ascertain accurate postures must be carried out [10, 11]. Existing research includes a method using Kinect sensor, whereas motion recognition is possible only within limited space. The SVM(Support Vector Machine) method using the acceleration sensor has limitations in judging various motions' accuracies [12, 13]. Research measuring exercise amount, according to exercise, must measure energy consumption on walking, jumping, and running using an acceleration sensor. It must also evaluate exercise amounts in consideration of the weight upon lifting weights and the number of lifting weights [14]. As such, exercise with movement distance or resistance exercise lifting weights have tried various attempts to measure exercise amounts. However, research is lacking on measuring exercise amounts on PT as carried out by without a tool. PT is an exercise maintaining the angle of each body part operated by exercise motion, with the exercise effects being demonstrated only if the movement of the joint parts is accurately carried out [15, 16]. In this regard, research comparing differences in exercise amounts, according to accurate postures, is required.

This study proposes the exercise posture accuracy judgment algorithm that can judge accurate motions in PT. The proposed method is to attach 9-axis motion sensors to major body parts and acquire a user's motion data. Motion data include Euler angles calculated on the basis of acceleration, gyro, each geomagnetic axis data, and quaternion value. Joints' bending angles according to sensor's attachment positions are calculated using Euler angles, and exercise's accuracy is judged in comparison with reference angles of pre-set joint angles in each joint part. Concerning the bending angles of joints, 0-145° for knee and 0-130° for elbow are set as thresholds of effective bending angles [13, 17]. The accuracy of exercise postures is judged by comparing the bending angles of joints in terms of user-selected exercise. The bending angle becoming the standard of judgment is set by referring to the existing research cases. In existing research, push-up was defined as 90° in elbow angle in the elbow and wrist-bent state in the intermediate step. Squat was defined as 70-100° with knee-bent angle in the intermediate step. Lunge was defined as 90° in knee angle with held out knee and not held out knee in the intermediate step [7, 18, 19]. In this study, the reference angle was set as 90° of elbow in push-up, and 90° of knee angle in squat and lunge. Afterwards, exercise amounts were measured, compared, and evaluated by measuring exercise amounts according to exercise postures through the respiratory gas analyzer.

2. Exercise Posture Accuracy measurement Algorithm

This study used acceleration, gyro, and geomagnetic values on a user's exercise postures, and the quaternion data calculated and offered based on those using the motion sensor device in order to judge whether accurate postures are maintained upon a user's exercise. Finally, accuracy was extracted through the exercise posture accuracy judgment algorithm. As for the algorithm, joint bending angles were calculated after extracting quaternion-based Euler angles. Afterwards, exercise posture accuracy was calculated(judged). Figure 1 shows the main process flow of exercise posture accuracy judgement.

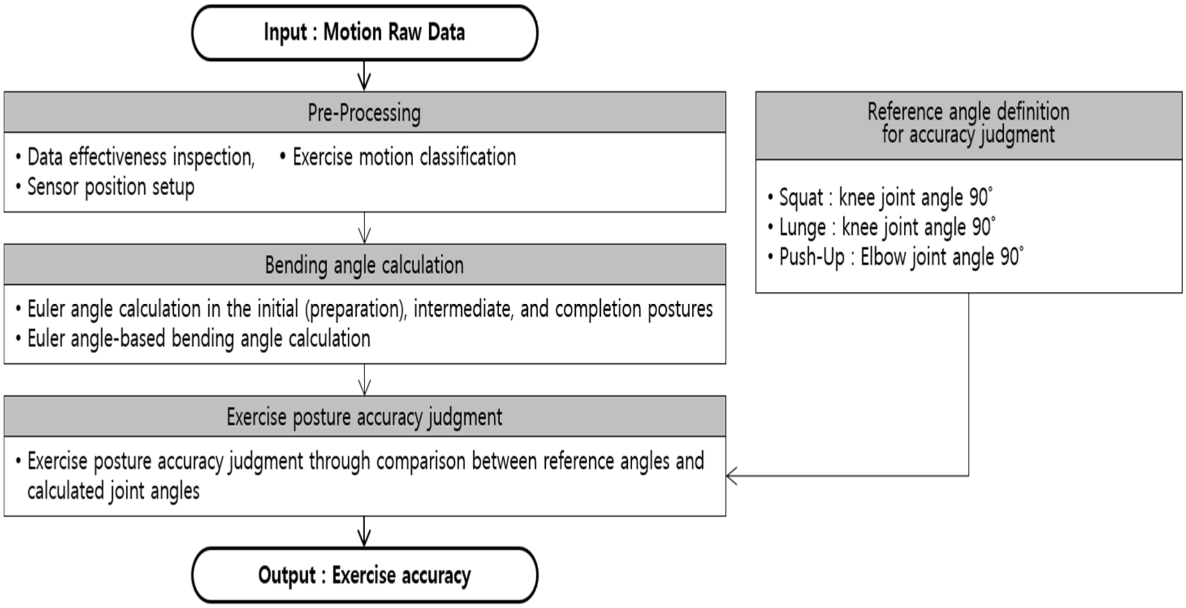


Figure 1. Main process flow of exercise posture accuracy judgement.

2.1 Motion Data Acquisition (Euler Angle Extraction)

For accuracy judgment of PT exercise motions, a user's motion data need to be acquired. This study acquired raw motion data on a user's exercise through a motion device (3.6*3.6*0.7cm) developed by P Company(Prochild, Korea). As for the motion device, 9-axis motion device (MPU9250) developed by I Company(InvenSense, America) was applied by measuring acceleration, gyro, and geomagnetic values on x, y, and z axes, based on which each measured value and quaternion data were calculated and offered. The motion transmits output values through gateway since a bluetooth low energy (BLE) communications module is installed. Out of the transmitted values, the Euler angles were calculated in the sensor attachment positions using the quaternion value. Figure 2 shows the summary of Euler angles for accuracy judgment. The Euler angles refer to three angles adopted to indicate the 3D space in the direction where rigid body was located. The rotations of the X, Y, and Z axes are referred to as roll, pitch, and yaw, respectively. Formula 1 is the functional formula applied for quaternion data-based Euler angle calculation. In quaternion data, while calculating the Euler angle, two axes overlap and one axis is lost when a specific axis is rotated at a particular angle. This case is called 'Gimbal-lock' and is the reason expressing all angular transformations is limited. To compensate for this limitation, Euler angles were calculated using Equation 1 and the quaternion data, which employ the scalar value w and the vector values on the x, y, and z axes.

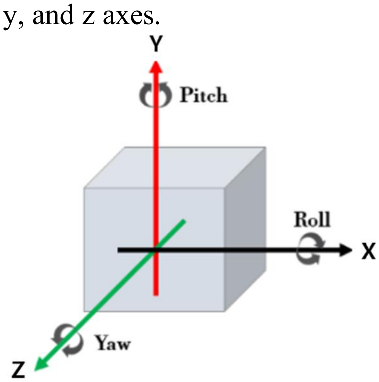


Figure 2. Overview of Euler Angle

$$roll = \left(Atan2\left(2.0 \times (y \times z + x \times w), (-x^2 - y^2 + z^2 + w^2)\right) \times \pi\right),$$
$$pitch = \left(Asin\left(-2.0 \times (x \times z + y \times w)\right) \times \pi\right), \tag{1}$$
$$yaw = \left(Atan2\left(2.0 \times (x \times y + z \times w), (x^2 - y^2 - z^2 + w^2)\right) \times \pi\right), \qquad \pi\ is\ the\ ratio\ of\ circumference$$

According to existing study, the body part where body surface area is extended by less than 20% is recommended upon exercise in terms of sensor attachment positions for body movement measurement [20]. Based on the angle measuring experiences of the body joint parts on three exercises, namely push-up, squat, and lunge, this study selected the upper and lower limbs, judged to be favorable to joint angle measurement, upon targeting the subjects in this study. Concerning sensors, they were attached to 10cm above and below the knees of both legs, and 10cm above and below elbows, whereas selective attachment was made possible by each exercise type. Figure 3 shows the attached motion device for a sensor's direction setup and each joint angle measurement.

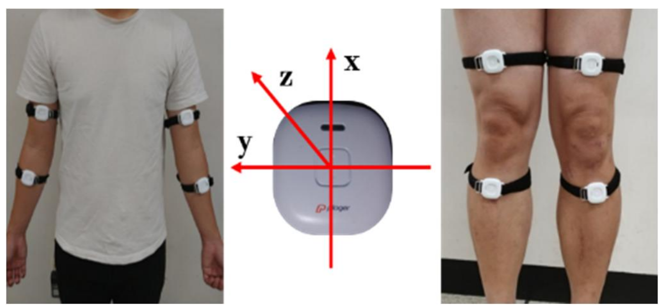


Figure 3. Angle Examples of Sensor Direction Setup and Attachment

2.2 Joint Bending Angles Calculation

This study calculated joint bending angles to judge the accuracy of squat, lunge, and push-up motions out of PT core exercises. Squat and lunge motions used knee-bending angle as an exercise accuracy judgment factor, and push-up motion used elbow bending angle. Each motion classified the state of vertical suspension of operated legs and arms by exercise on the floor plane into preparation, and intermediate step, where joints are bent maximally, and completion step where the state returns to preparation posture again. Although each step is carried out in sequence, it was acknowledged as one time, but the case in which lunge motion was carried out to the left and right, respectively, was regarded as one time.

Joint angle was initialized as 0 in terms of preparation step angle, and motion data were acquired in the intermediate step of each exercise. Out of the acquired Euler angles, pitch values, which considered sensor attachment directions and rotation motions, focused on specific X axis, as important motions, were used. Figure 4 is the method to measure knee joint angles.

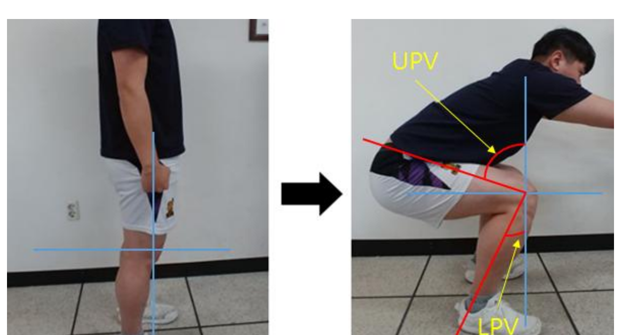


Figure 4. Joint Angle Measuring Method in the Intermediate Exercise Step

For joint angle extraction, this study calculated the sum of angles' change values of upper and lower limbs. The bending angles of knee and elbow could be extracted through a pitch component's change amount out of the Euler angles. Formula 2 aims to extract joint angles in real time.

$$B.A = |U.P.V| + |L.P.V|, \quad (B.A: Bending\ Angle, U.P.V: Upper\ of\ Pitch\ Variation, L.P.V: Lower\ of\ Pitch\ Variation) \tag{2}$$

2.3 Exercise Posture Accuracy Calculation

The exercise posture accuracy was calculated by comparing consistency rate with the reference angle in the intermediate step (Step 1) on user's motions carried out in the preparation step (Step 0), intermediate step (Step 1), and completion step (Step 2) by each exercise. Motion data (Euler angles) were received through the device attached to major body parts, and an effectiveness inspection to check whether the data are without errors in communication was conducted. In this process, data were acquired again, in case abnormal data were received due to communication errors or measurement failure. In the case of being confirmed as effective values, the sensor attachment position was confirmed, and joint bending angle of each position was calculated in case no abnormality was found. The effective angle evaluation inspecting whether the calculated angles are those within the normal range was carried out, and they were confirmed as the joint angles in the initial posture.

Through the same process, the joint angles in the intermediate and completion steps were calculated. The available range of each joint for effective angle evaluation is that the operation ranges of the elbow and knee were set as 0°-145° and 0°-130°, respectively. When each exercise step was carried out in sequence, it was regarded as one time of exercise was completed, and then exercise accuracy was calculated. Figure 5 shows the sequence diagram of the exercise posture accuracy judgment algorithm.

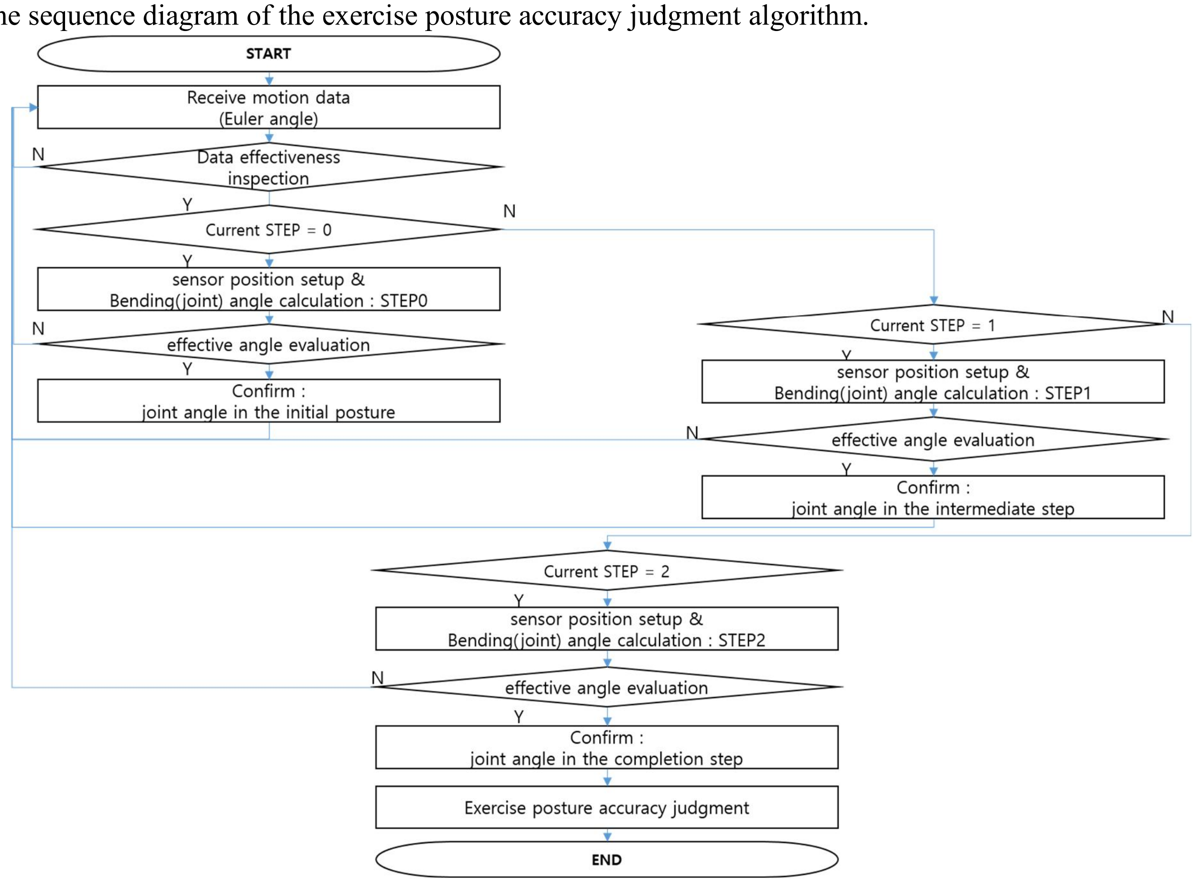


Figure 5. Algorithm of Exercise posture accuracy judgement

Regarding exercise accuracy, each motion accuracy and each exercise accuracy were calculated. Exercise accuracy upon one time of each exercise was calculated using the joint bending angles measured in real time, as well as reference angles in each step, and Formula 3 shows this.

$$A.M = 100 - \left(\frac{S.A - M.A}{S.A} \times 100\right), \tag{3}$$
$(A.M$: Accuracy of Motion, S.A: Standard Angle, M.A: Measured Angle)

Each exercise accuracy was calculated as cumulative accuracy calculation result on each motion and as mean value divided by total number of motion implementation (Formula 4).

$$Accuracy = \frac{\sum_{i=1}^{n} A.M}{n}, \quad n = Number\ of\ Exercise \tag{4}$$

3. Experiment and Evaluation

This study carried out an experiment to check exercise accuracy and calorie consumption differences, according to accurate exercise postures in relation with some motions out of PT's core exercises.

3.1 Comparison with Actually Measured Exercise Accuracy

Actual measurement was conducted to check the accuracy of the data calculated as joint bending angles in 2.2. Figure 6 shows goniometer attachment to the knees and elbows to measure joint angles. To check the exercise accuracy measurement algorithm performance presented in this study, actual measurement was conducted using a manual measuring equipment, which is a goniometer, and exercise accuracy was compared. Concerning the joint bending angle measurement experiment, exercise accuracy was calculated by exercise posture targeting four trained people. The experimenters carried out five reps of squat, lunge, and push-up, respectively, and Table 1 shows the compared results calculated on the basis of actually measured joint angles through the goniometer, as well as the motions accuracy calculated through the exercise accuracy measurement algorithm.

Figure 6. Joint Angle Measurement Experiment Method

Table 1. Exercise Accuracy Results Compared with Actual Measurement

Movement classification	Measurement method	Exercise Posture Accuracy (%)				
		Person1	Person2	Person3	Person4	Average
Squat	Proposed method	99.30	98.70	98.30	97.60	98.48
	Goniometer	99.20	98.80	97.60	97.90	98.38
Lunge	Proposed method	98.48	99.16	98.42	98.38	98.61
	Goniometer	98.80	98.80	98.80	98.60	98.75
Push-Up	Proposed method	97.42	99.10	98.06	98.36	98.24
	Goniometer	98.40	98.40	98.40	97.80	98.25

Average	Proposed method	98.40	98.99	98.26	98.11	98.44
	Goniometer	98.80	98.67	98.27	98.10	98.46

The results of each motion carried out in line with the reference angle (90°) showed 98.48%, 98.61%, and 98.24% of accuracy in squat, lunge, and push-up, respectively, and the results actually measured with the goniometer were 98.38%, 98.75%, and 98.25%, respectively. Therefore It was confirmed that exercise accuracy measured through the proposed algorithm was 98.44%, and the actually measure result with the goniometer was 98.46% on comprehensive mean value in exercises, and thus no significant difference was confirmed.

3.2 Consumption according to Exercise Posture Accuracy

A total of 10 experimenters participated in the experiment, and they carried out PT's typical exercises, namely push-up, squat, and lunge in the state of attaching the respiratory gas analyzer and motion device. The experimenters' mean age was 25±5, and they consisted of six males and four females. The male experimenters' mean weight was 75±10kg and their mean height was 172±10cm. The female experimenters' mean weight was 55±10kg and their mean height was 160±5cm. After they practiced each exercise for a week in order to be familiar with accurate postures of each exercise, they participated in the experiment. The energy consumption(calorie consumption) comparison experiment according to exercise accuracy was carried out through the cardiopulmonary exercise test system, and the respiratory gas analyzer Quark CPET (COSMED, Italy) equipment connected with the system was used. Figure 7 shows the subjects to whom the respiratory gas analyzer and equipment were attached.

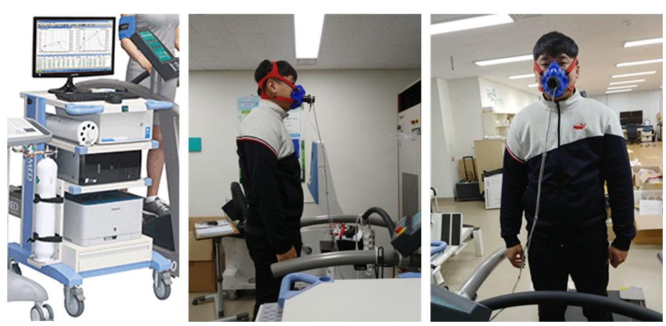
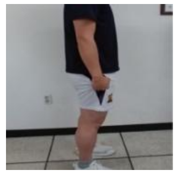


Figure 7. Attachment of Cardiopulmonary Exercise Test System and Respiratory Gas Analyzer

Table 2 described accurate exercise posture criteria and accurate motions in relation with squat, lunge, and push-up. For squat and lunge, this study set a knee bending angle of 90° as an accurate posture in the intermediate step. For push-up, this study set an elbow bending angle of 90° as an accurate posture in the intermediate step. If the preparation, intermediate, and completion postures were carried out in sequence, respectively, it was acknowledged as carrying out one time of motions.

Table 2. Criteria and Performing Postures of Squat, Lunge, and Push-up and Motion Description

Classification	Accurate posture criteria	Preparation (Step 0) and completion (Step 2) postures	Intermediate (Step 1) posture	Description of motions on accurate exercise postures

Squat	Knee joint angle of 90°			After spreading legs as wide as shoulder width, knees should be bent at 90°. Upon squat exercise, muscles should be contracted quickly, and motion should be slowly released upon relaxation.
Lunge	Knee joint angle of 90°			After spreading legs as wide as shoulder width, one leg should be held out by 70-100cm, and the other leg's heel should be lifted. The held out leg should be bent by 90°, and the lower body should touch the floor in the state of stretching back.
Push-up	Elbow joint angle of 90°			After spreading arms as wide as shoulder width, the back and legs should make a straight line. Bending and stretching arms until elbow becomes 90° should be repeated.

This study set each exercise's performing criteria for exercise measuring experiment. For squat, one set means 20 reps for a minute. Regarding lunge, one set means 10 reps for a minute, and cross performance to the left and right should be completed to be counted as one time. Concerning push-up, 20 reps for a minute were regarded as one set. Four sets were carried out for each exercise, and break time was offered for one minute between the sets. To carry out each experiment, training was conducted so that the experimenters could be aware of each motion in advance. For inaccurate posture, it was intentionally instructed to perform under the condition of less than 20% of the criteria in terms of joint bending angle. Also, calorie consumption on each motion was measured. Table 3 shows the measured calorie consumption by accuracy in the each exercise posture.

Table 3. Total Calorie Consumption by Exercise Accuracy

Person	Posture classification	Squat		Lunge		Push-Up		Average	
		Exercise posture accuracy	Calorie consumption	Exercise posture accuracy	Calorie consumption	Exercise posture accuracy	Calorie consumption	Exercise posture accuracy	Calorie consumption
Person1	Accurate	99.30	52.13	98.80	37.95	96.80	34.07	98.30	41.38
	Inaccurate	71.60	35.03	74.50	24.44	65.50	25.41	70.53	28.29
Person2	Accurate	97.60	52.42	99.30	41.83	96.60	31.09	97.83	41.78
	Inaccurate	66.30	47.15	71.60	30.01	75.90	23.35	71.27	33.50
Person3	Accurate	99.70	49.91	98.60	50.18	99.20	39.87	99.17	46.65
	Inaccurate	72.10	35.52	65.00	36.09	70.90	29.03	69.33	33.55
Person4	Accurate	99.50	39.65	98.20	41.37	98.30	22.99	98.67	34.67
	inaccurate	76.10	29.87	62.00	36.63	73.80	17.97	70.63	28.16
Person5	Accurate	99.00	30.40	96.00	27.22	98.80	25.41	97.93	27.68
	Inaccurate	75.30	14.91	64.00	14.09	70.30	18.48	69.87	15.83
Person6	Accurate	98.20	33.19	98.50	29.61	98.00	17.73	98.23	26.84
	Inaccurate	74.10	30.49	71.10	22.51	65.70	14.01	70.30	22.34
Person7	Accurate	96.00	54.32	98.10	46.02	98.70	29.34	97.60	43.23

	Inaccurate	64.00	27.59	75.70	39.57	78.90	22.84	72.87	30.00
Person8	Accurate	99.90	48.24	98.60	54.44	98.70	32.47	99.07	45.05
	Inaccurate	71.10	31.30	80.00	24.09	74.90	20.70	75.33	25.36
Person9	Accurate	97.70	33.55	96.10	26.91	99.20	17.17	97.67	25.88
	Inaccurate	75.70	18.40	61.20	17.62	76.10	11.16	71.00	15.73
Person10	Accurate	98.60	69.88	97.70	51.39	97.60	26.23	97.97	49.17
	Inaccurate	68.10	33.22	76.00	39.85	65.90	18.65	70.00	30.57
Average	Accurate	98.55	46.37	97.99	40.69	98.19	27.64	98.24	38.23
	Inaccurate	71.44	30.35	70.11	28.49	71.79	20.16	71.11	26.33

Through the experimental results of Table 3, it was confirmed that more efficient exercise amount could be achieved in accurate exercise postures, compared with the case in which experimenters performed exercises in inaccurate exercise postures. Figure 8 shows statistics on actually measured exercise amounts according to exercise posture accuracy.

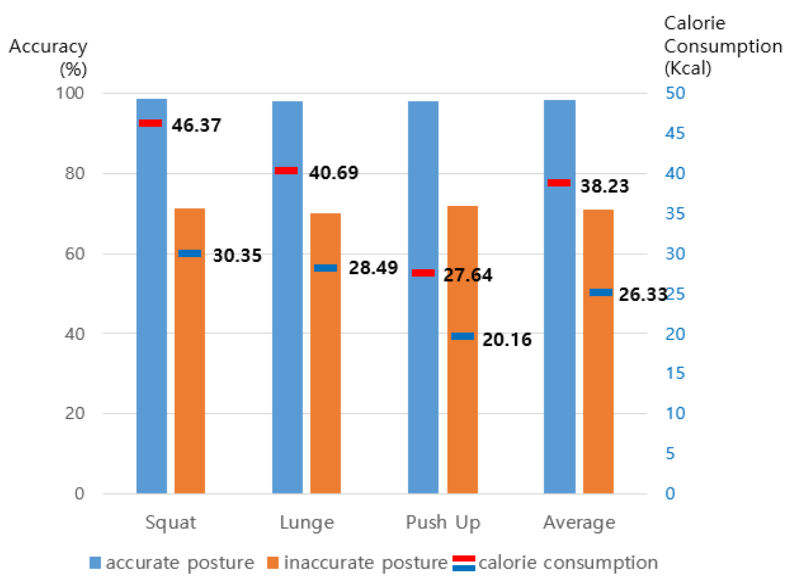


Figure 8. Comparison of Exercise Amounts according to Exercise Posture Accuracy

As for squat, the mean calorie consumption of accurate and inaccurate postures was 46.37kcal and 30.35kcal, each. In lunge, the mean calorie consumption in accurate and inaccurate postures was confirmed to be 40.69kcal and 28.49kcal, respectively. Concerning push-up, the mean calorie consumption in accurate and inaccurate postures was 27.64kcal and 20.16kcal. Consequently, it was identified that exercise efficiency can be enhanced by maintaining accurate motions upon PT.

4. Conclusion

This study developed the exercise posture accuracy judgment algorithm to judge whether accurate motions have been carried out in various core exercises of personal training (PT). To apply the proposed algorithm, the knee and elbow joint angles mainly operating upon a user performing squat, lunge, and push-up core exercises were measured. To extract Euler angles, a motion device developed by P Company was used. To measure joint angles, motion devices were attached to the experimenters, 10cm above and below both legs' knees in terms of knee joint angles. In the case of elbow bending angle, each motion device was attached 10cm above and below elbow. In the exercise posture accuracy judgment algorithm, the effectiveness test on each Euler angle value, which can be the received sensor data value, was conducted. In case data went beyond the effective range through transmitted data, by which measurement and communications errors can occur, they were ignored, and user's sensor attachment position was checked, only if they were confirmed as effective values. In consideration of a sensor's attachment positions, this study acquired the Euler angles of the joints concerned used for the exercises, calculated the sum of Euler angles of upper and lower limbs, and calculated joint bending angles. As for joint bending angles, knee bending angle and elbow bending angle, namely 0-145° and 0-130° were set as the thresholds of effective bending angles, each. Concerning the exercise posture accuracy, joint bending angles on the users' selected exercises were compared with and judged. Exercise postures were classified as the preparation, intermediate, and completion steps, and bending angles in each step were compared with. The intermediate step's reference angle for motion accuracy measurement referred to existing study cases, and thus it was set as 90° in terms of elbow bending angle in push-up, and as 90° in terms of knee bending angle in squat and lunge. Upon a user's exercise, exercise accuracy was calculated comparing joint bending angles calculated through the proposed algorithm. Regarding accuracy per set, accuracy by each set was summed up, and the summed up value was divided by the total number of exercise performance.

As a result of comparing the exercise posture accuracy proposed in this study and actually measured goniometer results, this study confirmed that they matched up to one decimal place. This study also compared the exercise amounts between accurate postures and inaccurate postures in squat, lunge, and push-up exercises. For exercise amount comparison, this study used the respiratory gas analyzer Quark CPET (COSMED, Italy) connected with the cardiopulmonary exercise test system. The experiment targeted 10 male and female university students (25±3 years). As a result of the experiment, the exercise amount in the accurate postures was 38.23Kcal, while in the inaccurate postures it was 26.33Kcal. The exercise amount in the accurate posture was 45.19% higher on average, and thus it was confirmed that maintaining accurate postures contributes to exercise amount improvement. Upon personal training exercise, it was identified that a system supporting coaching service is needed. In the future, a study is required to generalize algorithm to apply it to more diverse exercises, to connect the heart rate sensor under an environment where the respiratory gas analyzer is excluded, and to develop other exercise amount measuring methods.

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