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Comparison of Range-of-motion test methods for measuring Clothing Mobility

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의복의 기능성 측정을 위한 관절각도법에 관한 비교연구

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Abstract

본 연구의 목적은 의복의 기능성 측정의 객관적 평가를 위한 관절각도측정의 방법들 간에 상관관계를 분석하고, 컴퓨터를 이용한 측정방법을 개발, 이를 기존의 방법과 비교, 분석함으로써, 의복의 기능성 측정 및 기능적 디자인 개발에 기여함에 있다.

미국 Kansas 지역의 전문 소방수를 대상으로, 선택된 10가지 실험동작에서의 관절각(range-of-motion)을 computer-aided method, Leighton flexometer, goniometer를 사용하여 측정하였으며, 측정순서는 무작위 순서(random order)로 하였다. 독립변인으로는 3종류의 측정방법(computer-aided method, flexometer, goniometer)이며, 종속변인으로는 선택된 동작에서의 관절각(range-of-motion)이다. 또한 상관분석(correlation analysis)을 실시하여, 상관계수(correlation coefficient)를 측정한 통계처리결과, 각 측정방법들 간에 긍정적이며 유의적인 상관관계가 있는 것으로 나타났다.

Key words: range-of-motion, clothing mobility; 관절각도, 의복의 기능성

I. Introduction

Working clothing must fit satisfactorily in both static and dynamic body movement situation for worker satisfaction. Static fit describes that which accommodates the dimensions of the stationary body, and dynamic fit describes the fit that accommodates the body during motion and activities of the wearer(Keeble, prevatt, & Mellian, 1992).

Range-of-motion is usually measured for evaluating dynamic fit of clothing(clothing mobility)(Adams, 1993; Huck, 1988, 1991; Nicoloff, 1957; Saul & Jaffe, 1955).

Nicoloff(1957) defined range-of-motion as the quality of being flexible, the ability to bend and yield, or simply the amount of movement possible in a joint. Measurement of range-of-motion became important after World War I when pension boards demanded physicians provide an accurate estimate of a veteran's disability. A great variety of methods of measurement, instruments of measurement, and nomenclature resulted from this need to determine disability(Nicoloff, 1957).

Brown(1954) studied the effect of clothing(clothing restriction and mobility) by taking range-of-motion measurements in the arm and shoulder girdle while subject was wearing jacket. Soul and Jaffe(1955) determined the usefulness of 28 range-of-motion movements to determine the restriction of clothing and equipment for military personnel. Nicoloff(1957) measured several range-of-motion movements which were carried out by ROTC students with and without an arm and shoulder harness that simulated clothing restriction. Decrements in range-of-motion were found resulting from the resultant restriction

of clothing.

Huck(1988) evaluated clothing mobility of fire fighter turnout coats by taking measurement of eight range-of-motion movements which represented the types of physical activities a fire fighter might make during the course of performing fire fighting duties. Huck(1991) also measured five selected range-of-motion movements to determine restriction of clothing mobility between traditional and alternative sleeve designs in fire fighter turnout clothing ensembles. Huck et al.(1997) analyzed four range-of-motion movements to evaluate the garment design and fit of protective overalls. Adams et al.(1993) compared three methods(a universal goniometer, a Leighton Flexometer, and an electrongoniometer) for objectively measuring range-of-motion while workers were wearing protective clothing.

Relatively few studies have focused development of measuring method for range-of-motion movements. Until now, in most research, traditional methods have been used for measuring range-of-motion movement. Although, traditional method for measuring range-of-motion movement was very useful, there was some inconvenience(i.e., restriction of movement from equipment etc...). Therefore, in this study, the development of measuring method of range-of-motion movement using computer equipment was researched. The purpose of this research was to determine the relationship among instruments(a Leighton flexometer, goniometer and computer-aided method) for measuring range-of-motion, to develop more convenient method for measuring clothing mobility using computer equipment, and finally, to provide basic data for researching functional working clothing. Independent variable was three different equipments(a Leighton flexo-meter, goniometer and computer-aided method). Depen-dent variable was range-of-motion measurement in the selected joint movements.

II. Methodology & Procedure

1. Test procedure

Ten male fire fighters in Kansas, USA were participated as subjects. Subject's physical characteristics and body measurements were reported(Table 1, 2). The subject was asked to dress T-shirts and jean pants provided by researcher. He was told to complete a pre-exercise routine so that his muscles were relaxed and warm. Then, he was asked to don his coverall over the T-shirts and jean pants. Range-of-motion(Fig. 4) of selected movements(shoulder adduction/abduction, shoulder flexion/extension, trunk flexion/extension on standing position, hip flexion/extension(knee), hip flexion/extension(trunk), upper leg flexion, trunk lateral flexion, hip adduction, trunk flexion/extention on sitting position, upper leg adduction) was measured using a Leighton flexometer, goniometer and computer-aided method. In order to reduce internal validity of testing, the order of testing was randomized.

A Leighton Flexometer(Fig. 1) was strapped to the

Table 1. Subject's Physical Characteristics

Subject No.	Age	Height (cm)	Weight (Kg)
1	54	180.3	77.2
2	42	180.3	84.8
3	45	172.7	86.5
4	29	172.7	77.2
5	35	177.8	113.5
6	33	172.7	83.9
7	41	175.3	72.6
8	44	167.6	74.9
9	41	182.9	113.5
10	29	177.8	93.1
Mean	39.3	176.0	87.6
Std.	7.8	14.9	3.6

Table 2. Subject's body measurements

Measurements	Mean (cm)	S.D. (cm)	Min (cm)	Max. (cm)
Chest circumference	106.2	8.9	91.5	119.4
Waist circumference	105.7	11.0	91.5	124.5
Back waist length	46.5	2.5	43.2	50.0
Shoulder length	15.0	1.5	12.7	17.8
Hip circumference	106.9	6.4	97.8	119.4
Vertical trunk circumference	170.2	10.7	158.0	186.7
Crotch depth	24.4	2.3	21.8	28.7
Full pants length	100.5	4.3	93.0	108.0
Sleeve length	60.2	1.8	58.4	63.5
Crotch length	85.3	6.4	0.9	8.6

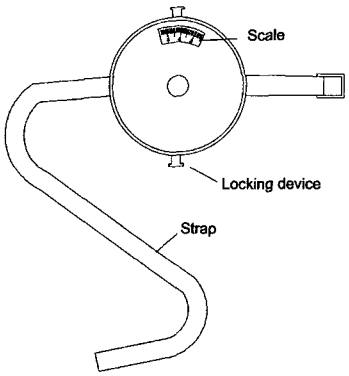


Fig. 1. Leighton flexometer.

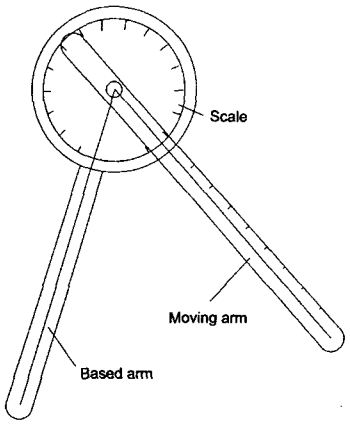


Fig. 2. Goniometer.

appropriate body location of selected range-of-motion movements. The subject was instructed to take the appropriate body position indicated(solid line, Fig. 4). The weighted dial of the Leighton Flexometer was locked in the zero position. He was then directed to move the fullest extent possible without straining(dotted line, Fig. 4). While he was moving, the scale of Leighton Flexometer was moving and pointing. When he stopped moving, the locking device of the Leighton Flexometer was locked and a reading was taken.

The subject was requested to take the appropriate body position of selected range-of-motion movements (solid line, Fig. 4). Goniometer(Fig. 2) was positioned at the joint center. Based arm was aligned at the appropriate body position, and he was told to move the fullest extent possible without straining(dotted line, Fig. 4). The moving arm of goniometer was widen and

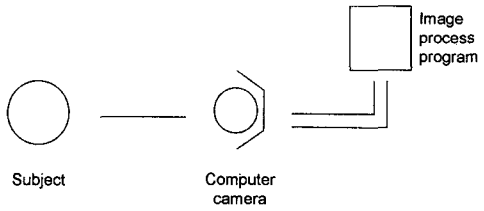


Fig. 3. computer-aided method.

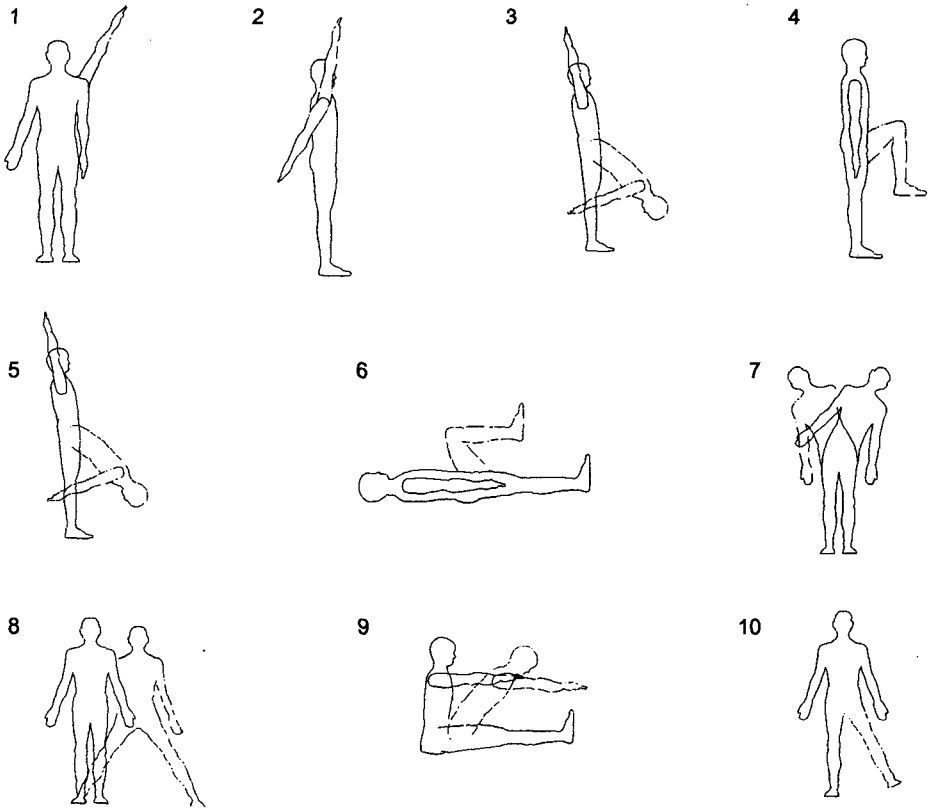
aligned with the adjoining body limb and a reading was taken.

The subject was asked to take the appropriate body position of selected range-of-motion movements(solid line, Fig. 4). The first position was captured by computer camera(Fig. 3). After that, he was instructed to move the fullest extent possible without straining (dotted line, Fig. 4). The second position was also captured by computer camera. The captured images on computer camera was imported to image processing program using the transporting function. Two images were called up(i.e., subject's first position and second position) on the screen in the image processing program (Fig. 3). Using an angle measuring function, the angle of the first position and second position was measured. The difference between the initial and second position angles was automatically reported in the screen, when the cursor was moved from the initial position to the second position.

2. Instruments

1) Leighton Flexometer

The Leighton flexometer is basically a gravity-type goniometer. It consists of a weighted pointer mounted in a case. The dial and a pointer operate freely and independently; the movement of each being controlled by gravity. The instrument is designed to record movement while in any position that is twenty degrees or more off the horizontal. The zero mark on the dial and the hairline of the move freely to a position of rest and coincide when the instrument is placed in any position off the horizontal as indicated. Independent locking devices are provided for the pointer and the dial which stop all movement of either at any given position. In using the instrument, the Flexometer



Solid line: first position(initial position)
Dotted line: second position

1. shoulder adduction/abduction
2. shoulder flexion/extension
3. trunk flexion/extension(standing)
4. hip flexion/extension(knee)
5. hip flexion/extension(trunk)
6. upper leg flexion
7. trunk lateral flexion
8. hip adduction
9. trunk flexion/extension(sitting)
10. upper leg adduction

Fig. 4. Range-of-motion movements.

is strapped to the segment being tested. The dial is locked an extreme position(i.e., full flexion of the elbow); the movement is made and the pointer locked at the other extreme position(i.e., full extension of the elbow). The direct reading of the pointer on the dial is the arc through which the movement has taken place. A dampening device has been installed the backs of both dials to reduce oscillation during measurement(Leighton, 1987).

2) Goniometer

Goniometer is used as a measure of joint flexibility. The angle produced between two body segments when maximal motion in a particular plane is measured. It consists two movable arms that pivot about the center of a full-circle protractor. To measure joint angles, the pivot pin is positioned at the joint center and the goniometer arms are aligned with the adjoining body segment(Adams & Keyserling, 1993).

3) Computer-aided method

Computer-aided method was developed in this research for measuring range-of-motion(clothing mobility) using

computer camera and image processing program(Fig. 3).

- Apple Quick Take 100 camera

  This instrument is manufactured from Apple Computer Inc. Quick Tack features automatic exposure, a fixed focus lens(with no zoom capabilities), built in flash, and standard tripod mounting hole. Focus ranges from four feet to infinity(making the camera unsuitable for close-up pictures). For measuring range-of-motion, the pictures of initial and second position of body movement were captured by computer camera.

- Hijaak Draw Version 3.0

  Hijaak Draw is trademarks of inset System Inc. This program contains a drawing and transformation tools along with a set of precision drawing aids. The captured image by the Apple Quick Take 100 camera was imported to Hijaak Draw version 3.0 using the transporting function. Using an angle measuring function, the angle of the first position and second position was measured. The difference between the initial and second position was automatically reported in the screen, when the cursor was moved from the initial position to second position.

3. Test movements

10 test movements(shoulder adduction/abduction, shoulder flexion/extension, trunk flexion/extension on standing position, hip flexion/extension(knee), hip flexion/extension (trunk), upper leg flexion, trunk lateral flexion, hip adduction, trunk flexion/extension on sitting position, upper leg adduction) were selected(Fig. 4).

4. Subjects

Ten male fire fighters in Kansas, USA were participated as subjects. Subject's physical characteristics and body measurements were reported(Table 1, 2).

III. Results & Discussion

For statistical analysis, correlation coefficient (r) was used to analyze the relationship between Leighton flexometer and computer-aided method, computer-aided method and goniometer, and Leighton flexometer and goniometer(Table 3).

According to the results, all three methods were positively correlated. This suggests that the three instruments could be used and should lead to similar results regarding garment effects on range-of-motion. Overall correlation coefficient between the computer-aided method and goniometer was the most highly correlated, Leighton flexometer and the computer-aided method was secondly, Leighton flexometer and goniometer was least correlated.

Table 4 and Fig. 5 demonstrated the angle measurements of range-of-motion among the instruments. The range-of-motion measurement produced by Leighton

Table 3. Correlation Coefficients among Instruments

Range-of-Motion movements	Flexometer/ Computer	Computer/Goniometer	Flexometer/Goniometer
Shoulder adduction/abduction	0.646	0.886	0.543
Shoulder flexion/extension	0.544	0.611	0.672
Trunk flexion/extension on standing	0.916	0.727	0.773
Hip flexion/extension (knee)	0.727	0.734	0.737
Hip flexion/extension (trunk)	0.830	0.866	0.708
Upper leg flexion	0.865	0.837	0.785
Trunk lateral flexion	0.716	0.662	0.634
Hip adduction	0.802	0.903	0.796
Trunk flexion/extension on sitting	0.605	0.518	0.668
Upper leg adduction	0.698	0.773	0.742
Overall mean	0.739	0.748	0.706

flexometer showed the lowest angle measurement among three instruments(i.e., shoulder abduction/adduction, shoulder flexion/extension, trunk flexion/extension, hip flexion/extension and hip adduction). It might be due to the fact that the Leighton flexometer had a circumferential strap to fasten the instrument to the subject's limb securely(Fig. 1). The strap not only fastened the instrument to the subject's body, but also tied the garment to the subject's body. This prevented the garment to slide normally across the skin during the test movement. Therefore, Leighton flexometer was the most restrictive instrument among three instruments. These findings supported Adam's study(1993), presenting that the average reduction in range-of-motion from the semi-nude to oversized garment conditions was 13.1 degrees for the Flexometer, compared to 9.5 degrees for a goniometer.

Table 4. Angle measurements of Range-of-motion movement by instruments (unit: degree)

Range-of-motion movements	Leighton flexometer	goniometer	Computer-aided method
SAA	118.9	136.6	146.9
SFE	168.8	192.5	213.1
TFE on standing	133.8	136.9	142.2
HFE(knee)	63.4	70.6	81.7
HFE(trunk)	78.7	93.9	82.6
ULF	80.8	84.5	88.9
TLF	71.9	65.5	71.9
HA	34.2	62.9	69.4
TFE on sitting	27.2	41.7	36.1
ULA	52.4	43.9	48.9
Total	83.0	92.9	98.2

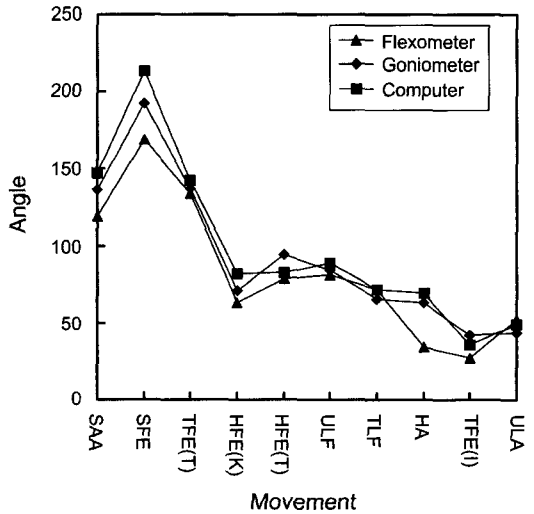


Fig. 5. Angle measurements of range-of-motion movements by instrument

Measurements using goniometer usually produced higher angle measurements than that of Leighton flexometer, but lower angle measurements than that of computer-aided method(Table 4). Goniometer appeared to be less restrictive than Leighton flexometer, but more restrictive than computer-aided method.

The computer-aided method, using digital images captured by a computer camera and analyzing range-of-motion by a image processing program, usually showed the highest value of angle measurement among instruments(Table 4, Fig. 5). It seemed that computer-aided method would not be affected by the measuring equipment. Subjects could move freely without any restriction in front of the computer camera. Computer-aided method was least restrictive method among instruments.

IV. Conclusions

The purpose of this research was to determine the relationship among instruments(a Leighton flexometer, goniometer and computer-aided method) for measuring range-of-motion, to develop more convenient instrument for measuring clothing mobility using computer equipment, and finally to provide basic data for researching functional working clothing. Computer-aided method, using digital images captured by a computer camera and analyzing range-of-motion by a image processing program was developed. Independent variable was three different equipments(a Leighton flexometer, goniometer and computer-aided method). Dependent variable was range-of-motion measurement in the selected joint movements. 10 test movements(shoulder adduction/abduction, shoulder flexion/extension, trunk flexion/extension on standing position, hip flexion/extension(knee), hip flexion/extension(trunk), upper leg flexion, trunk lateral flexion, hip adduction, trunk flexion/extension on sitting position,

upper leg adduction) were selected for measuring range-of-motion.

For statistical analysis, correlation coefficient (r) was calculated to analyze relationship between Leighton flexometer and computer-aided method, computer-aided method and goniometer, and Leighton flexometer and goniometer.

All three methods were positively correlated. This suggested that the three instruments could be used and should lead to similar results regarding garment effects on range-of-motion. Also, there was some advantages using computer-aided method for measuring range-of-motion movements. First, it was least restrictive method among instruments. Results indicated that range-of-motion measurements produced by computer-aided method usually showed highest value of angle measurement among instrument. The subject could move freely in front of computer camera without any restriction. Subject's body motion would not be affected by measuring instrument. Second, the saved images in the computer memory could be kept for a long time, so it could be used repeatedly later.

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