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DEVELOPMENT AND EVALUATION OF PROCEDURES FOR VALID AND RELIABLE ESTIMATION OF THE FLEXIBILITY OF ATHLETES

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ABSTRACT: Following a factor analysis, six measures of flexibility were identified that fulfilled the following criteria: 1) were representative of a wide range of different measures of flexibility; 2) represented movements that were commonly observed in sports; 3) could be measured with precision by sports-scientists working in a standard sports-science laboratory. The six measurements were: 1) spinal-plus-hamstring flexion; 2) hip abduction; 3) hip flexion; 4) ankle dorsi-flexion; 5) hip hyper-extension; 6) shoulder hyper-extension with the arms horizontal. Equipment that allows easy measurement of these variables is described. The reliability of various protocols for the measurement of flexibility is reported and, following more than ten years of experience with the technique, a definitive protocol for each of the six flexibility measurements is described. Descriptive statistics for the six measurements are also reported.

KEY WORDS: Flexibility. Employee performance appraipal. Sports.

INTRODUCTION

Flexibility is an important component of physical fitness. Exercises intended for its development are incorporated into most conditioning programmes; and all warm-up routines include flexibility exercises. Good flexibility is thought to improve athletic performance and to reduce the risk of sports injury[1,4,8], although definitive evidence concerning the latter is lacking[10]. Despite this, procedures for the assessment of flexibility have received relatively little attention and the methods currently available lack the sophistication of techniques for the measurement of power and strength. Many assessment centres that use highly refined measures of strength and aerobic power rely upon a basic sit-and-reach test for an estimation of flexibility. It is unlikely that this one, simple, measure can provide an estimate of the range of motion of all the many joints

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in the human body, especially since many joints have more than one mode of action[3]. Textbooks on the measurement of fitness describe the use of sit-and-reach boxes, flexiometers, tape-measures and a variety of different goniometers for the measurement of flexibility[6]. Flexiometers and goniometers can be used to measure a wide range of different movements and norms for their use are available[2,5,6]. However, it is generally acknowledged that these instruments are difficult to use with precision. The principle problem is in preventing extraneous movement in the subject's body that influence the range of motion of the joint being measured[6,7]. This difficulty results in flexiometer and goniometric assessments being unsuitable for use other than by physical therapists and other specially trained professionals. The present paper describes procedures for the measurement of six aspects of flexibility. The first is the equivalent of the sit-and-reach test: the other five have been identified as being representative of overall flexibility by means of a factor analysis[11].

METHODS

The six measures of flexibility described are:

- Spinal forward flexion
  This measure is equivalent to the sit-and-reach test performed with the subject standing instead of seated on the floor. Our laboratory used this test prior to the sit-and-reach test becoming popular and we believe it has a higher reliability because there is less ambiguity about the placement of the subject's feet.
- Groin flexibility or Hip abduction when the knees are fully flexed.
- Hamstring flexibility or Hip flexion with the knee fully extended.
- Calf flexibility or Ankle dorsi-flexion.
- Quad flexibility or Hip hyper-extension.
- Shoulder flexibility or Shoulder hyper-extension with the arms horizontal.

EQUIPMENT

The six aspects of flexibility were measured using the following equipment which is illustrated in illustrated in Figure 1.

A box 300 mm high, 26 cm wide and 5 cm deep to which is attached a scale of ength 60 cm. This is graduated in cm and has its zero in the centre, at the level of the subject's feet. Above the subject's feet scores range from zero to - 30: below the subject's feet scores are from zero to +30. This instrument was used for test 1. (Figure 1.1)

A specially constructed semi-circular, wooden protractor, 920 cm in diameter and with a central cut-out 300 cm in diameter. This instrument was provided with a wooded base, 6 cm wide, in order to allow it stand up-right. This instrument was used for test 2 and is illustrated in Figure 1.2.

A specially constructed goniometer consisting of a semicircular scale 430 cm in diameter and with a transparent arm 1 m long. The centre of the semicircular scale was provided with a wooden base 6 cm wide which (1) allowed the goniometer to stand upright, and (2) off-set the centre of the scale 9 cm from the surface on which the goniometer was placed. This instrument was used for tests 3, 4 and 5 and is shown in Figure 1.3.

A wooded protractor 1500 cm by 530 cm and containing a semicircular cut-out 440 cm in diameter on one of the longer sides on which zero degrees was marked. In use, this protractor was mounted horizontally on a stand 1.2 m above the ground. The subject sat on an adjustable chair facing away from the protractor with his or her trunk in the cut-out. The subject began the measurement with their arms horizontal, 1 cm from the board, and in-line with the zero mark at the front of the board. This instrument was used for test 6 and is illustrated in Figure 1.4.

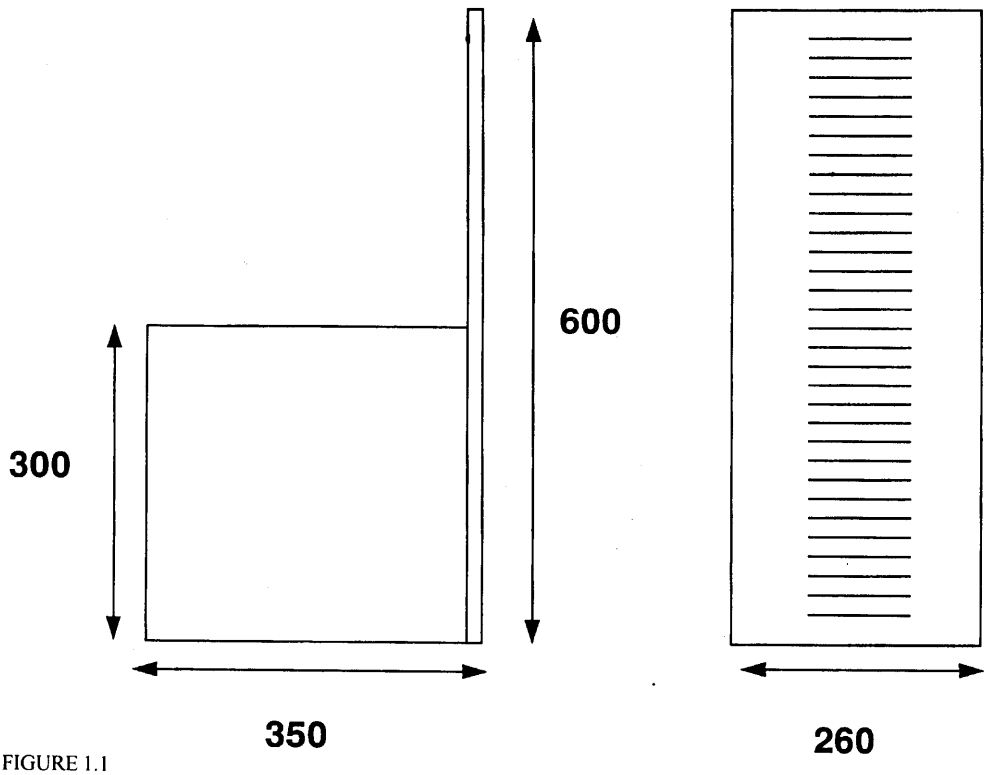

FIGURE 1.1

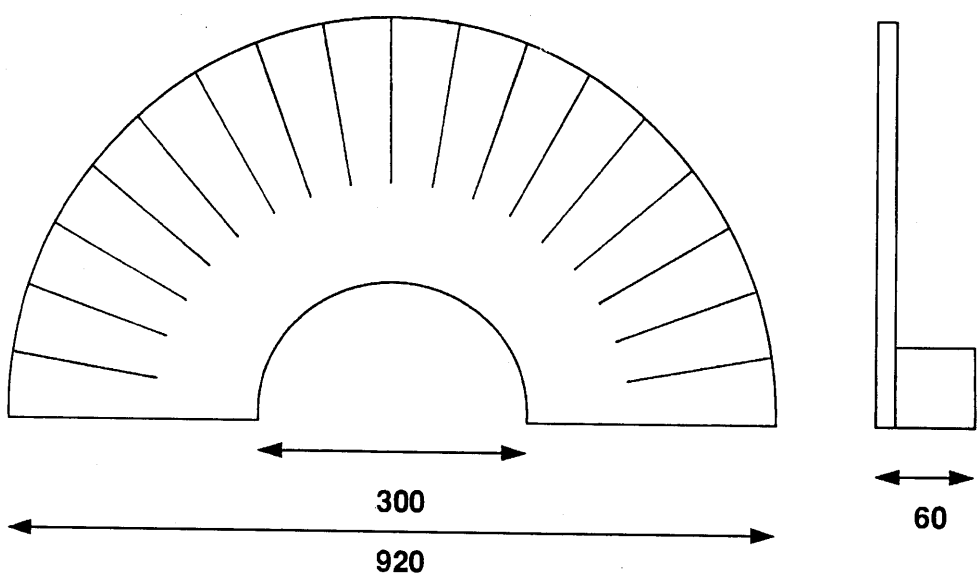

FIGURE 1.2

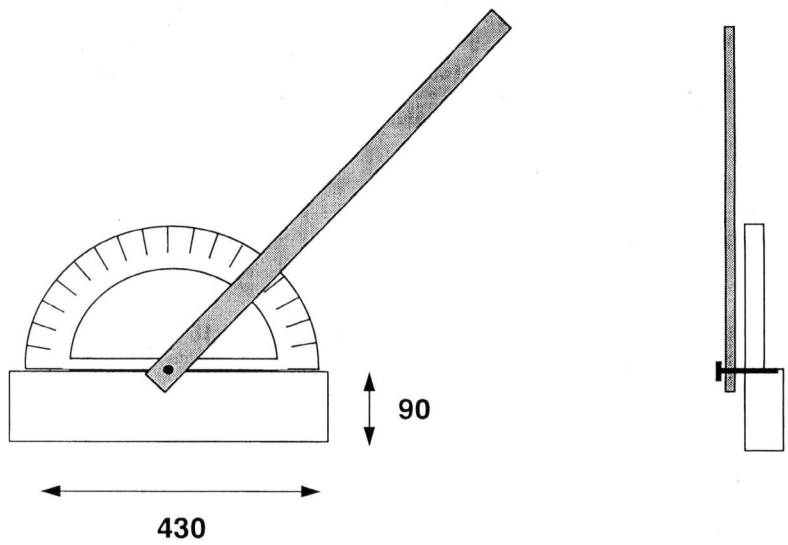

FIGURE 1.3

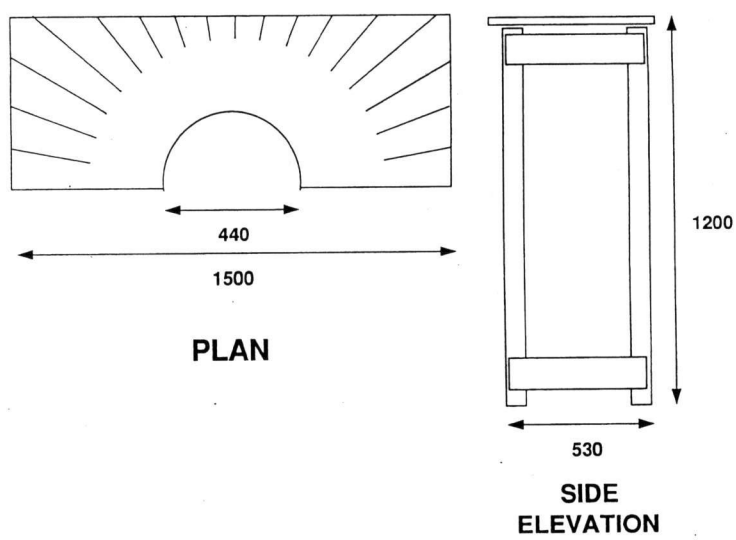

FIGURE 1.4

FIGURE 1 - DIAGRAMS OF THE EQUIPMENT DESCRIBED IN THE PAPER, ALL DIMENSION IN MM. THE APPARATUS SHOWN IN FIGURE 1.1 WAS USED FOR THE SPINAL FORWARD FLEXION TEST, THAT IN FIGURE 1.2 FOR THE GROIN FLEXIBILITY TEST AND THAT IN FIGURE 1.4 FOR THE SHOULDER FLEXIBILITY TEST. THE GONIOMETER SHOWN IN SHOWN IN FIGURE 1.3 WAS USED FOR ALL OTHER MEASUREMENTS.

PROCEDURE

Preliminary investigations into reliability indicated that measurements of flexibility were often extremely inaccurate - errors of ± 20 to 30% were common when the measurements were carried out by a single observer, and could be twice this when more than one observer was involved. Reliability was found to improve to acceptable levels with the following precautions. (Table 1).

TABLE 1 - 95 PERCENT CONFIDENCE LIMITS OF EACH OF SIX FLEXIBILITY MEASUREMENTS (AS A PERCENTAGE OF MEAN SCORES) TAKEN UNDER DIFFERENTR. CONDITIONS

	SPINAL FLEXION (CM) SPINAL FLEXIBILITY	HIP ABDUCTION (DEGREES) GROIN FLEXIBILITY	HIP FLEXION (DEGREES) HAMSTRING FLEXIBILITY	ANKLE DOSI-FLEXION (DEGREES) ANKLE FLEXIBILITY	HIP HYPER-EXTENSION (DEGREES) QUAD FLEXIBILITY	SHOULDER HYPER -EXTENSION (DEGREES) SHOULDER FLEXIBILITY
Measurement taken under ideal conditions and subjects wearing swim-wear or gymnastics leotards	9.1	7.8	8.7	7.8	6.6	8.8
Measurements taken as above but with subjects wearing their normal sports kit	8.4	10.0	13.8	7.7	12.7	13.4
Using straps to hold the subjects in position during the measurements	-	-	10.2	-	10.3	13.7
Using micro-switched to detect extraneous movement of the subject	-	-	-	7.5	-	7.8
Measurements taken following a standardised warm-up	11.8	9.8	10.6	10.4	9.4	10.3
Measurements taken by physical education students	20.4	30.3	16.2	12.4	40.5	35.7
Measurements taken by untrained sports coaches	38.6	72.6	25.3	20.6	94.3	66.3

- The starting position for each measurement of flexibility was precisely defined and standardised. For example: "*subject in the anatomical position and lying supine on a firm surface*".
- The movement to be measured was precisely defined. This usually involved specifying an anatomical land-mark that moved and an axis of rotation that remained stationary, eg "*hip flexion with the knee in full extension, measured by means of the angular movement of the superior condyl of the fibula about the axis of the greater trochanter of the femur*".
- Marking the following anatomical land-marks facilitated accurate measurement of the defined movements: acromion process of the scapula, greater trochanter of the femur, the patella or patella tendon, superior head of the fibula, lateral malleolus.

- The subject was allowed to move freely without resistance from kit or any other constraint.
- All movements in the subject's body, except that being measured during the test, was eliminated. This precaution is crucial if flexibility is to be measured accurately as extraneous movement is probably the major source of inaccuracy. A slight flexion of the subject's knee during the spinal or hamstring flexibility tests can increase the scores by between 10 and 30 per cent. Allowing the subject's spine to rotate and one hip to rise, during the quad flexibility test can double the score obtained. Various ways of eliminating extraneous motion were investigated during the study: a) the use of straps to maintain the subject in the starting position; b) the use of micro-switches to detect motion; c) careful observation of the subject in order to ensure that extraneous movement did not take place.
- The amount of warm-up or prior exercise undertaken by the subject was carefully controlled.
- The kit worn by the subject was selected in order to allow: a) the subject freedom of movement; b) the observer to see the movement executed and the change in position of the anatomical land-marks; c) the tester to observe all other parts of the subject's body in order to be able to detect any extraneous movement.

RESULTS

The first row of Table 1 indicates the reproducibility of the flexibility measurements as carried out by an experienced observer on subjects wearing swim-wear or gymnastics leotards. Under these conditions the 95% confidence limits of all six measurements was a little less that ±10% of the mean score. Row two of the table indicates that when the subjects wore normal games kit the reliability of all the measurements except ankle flexibility declined significantly. The change was particularly large in the case of three tests: hamstring flexibility, quad flexibility and shoulder flexibility. The difference is due to the subject's kit hiding extraneous movement that was thus not detected and which caused a reduction in reliability.

Row 3 of the table shows that the use of straps to reduce extraneous movement of the subject was not particularly successful. In contrast, the use of micro-switches (row 4) was as successful as having the movement controlled by an experienced observer. (Table 2).

TABLE 2 - ZERO ORDER CORRELATION MATRIX FOR THE MEASURES OF FLEXIBILITY AS MEASURED ON 32 ELITE GAELIC FOOTBALLERS. DATA ADAPTED FROM WATSON[9]

	SPINAL FLEXIBILITY	GROIN FLEXIBILITY	HAMSTRING FLEXIBILITY	QUAD FLEXIBILITY	CALF FLEXIBILITY	SHOULDER FLEXIBILITY
	1					
Groin Flexibility	0.4127*	1				
Hamstring Flexibility	0.7490*	0.2924	1			
Calf Flexibility	-0.0852	0.2926	-0.0658	1		
Quad Flexibility	0.4726*	0.3469	0.4077	0.2856	1	
Shoulder Flexibility	0.3129	0.5601*	0.2004	0.3134	0.2752	1

* Correlation coefficient significantly different from zero ($P < 0.05$)

If the subjects were allowed to warm-up before having their flexibility measured their scores increased; but in an unpredictable way, so that the reliability of the measurement was reduced. This result suggests that it is better to take flexibility measurements without a warm-up or previous exercise. The procedure appears to be perfectly safe: it has been used in our laboratory for 12 years without a single mishap due to injury.

The last two rows of Table 1 show how inaccurate flexibility measurements can be if adequate precautions are not taken.

Table 2 is a zero-order correlation matrix of the six variables. The relatively high correlation between spinal flexibility and hamstring flexibility (0.7490) is due to the fact that hamstring length influences the score on the former test. The next highest correlation (0.5601) indicates only 36% of common variance and confirms that these measures of flexibility are largely independent of each

DISCUSSION

The results of this study shows that measurements of flexibility are less reproducible than those of other aspects of fitness such as aerobic and anaerobic power and skinfold thicknesses[8]. Great care is necessary if flexibility is to be measured with a precision that produces results that are not misleading. The six measures of flexibility described in this paper are largely independent of each other and are useful indicators of the flexibility factors isolated in an earlier study[11]. The protocol for their measurement is summarised below.

General precautions

- Flexibility should be measured in a laboratory by an experienced observer who has a sound knowledge of physiological measurement and the control of measurement error. Assessments by unqualified individuals should be discouraged as they have been shown to be misleading.
- The equipment described in this paper should be used to take the measurements.
- The subject should be measured prior to any previous exercise and without a warm-up. This procedure improves reliability and will allow the subject's results to be compared with those published in this paper.
- The subject should be measured wearing tight-fitting, but compliant, racing-type swim-wear or a gymnastics leotard. Excessive amounts of kit make it difficult to detect extraneous movement and lead to a substantial deterioration in reliability.
- Flesh-marks should be placed on the following locations: acromion process of the scapula, greater trochanter of the femur, the patella or patella tendon, superior head of the fibula, lateral malleolus.
- The subject should be instructed not to jerk during the tests and that they are required to hold the final position for 5 seconds.

Spinal forward flexion

- The subject begins this test standing upright on the spinal flexibility box with his or her feet together and their toes touching the scale on the front of the box. The subject's hands should be together with the two index fingers parallel and fully extended. The thumbs should be locked.
- The subject reaches forward and touches the scale on the front of the box, as far down as possible.
- The subject's knees must remain fully extended throughout the test. This precaution is vital as even small degrees of flexion can have a considerable influence on the result of the test.

Groin flexibility or Hip abduction when the subject's knee fully flexed

- The subject sits with his or her back against

a vertical wall. He or she flexes their knees and hips and pulls their heels as close to their body as possible. The ankles are inverted so that the soles of the two feet are in contact.

- The subject grips his or her ankles and gently pushed their knees apart with their elbows.
- The angle between the centre of the patella (mean of left and right) and the vertical is measured as the subject's score.

Hamstring flexibility or Hip flexion with the knee fully extended

- The subject begins the test lying supine on a firm surface, his or her arms by their sides with palms facing downward. The subject should be instructed to lie perfectly symmetrically with both heels, buttocks and shoulders in contact with the surface.
- The subject is instructed to raise one leg and thigh by flexing at the hip. The knee must remain fully flexed during this movement. This precaution is of great importance as even small amounts of knee flexion will increase the score.
- The goniometer is used to measure the ankle made by two lines: a) a line drawn from the greater trochanter to the proximal head of the fibula, and b) the horizontal.

Calf flexibility or Ankle dorsi-flexion

- The subject begins the test standing with his or her feet together and both heels in contact with the floor.
- The subject dorsi-flexes his or her ankles as much as possible, also flexing at the knees in order to maintain balance.
- The goniometer is used to measure the angle made by two lines: a) a line drawn from the proximal head of the fibula to the lateral malleolus, and b) the vertical.

Quad flexibility or Hip hyper-extension

- The subject begins the test lying prone on a firm surface, arms by his or her sides with the palms facing upwards. The subject should be instructed to lie perfectly symmetrically with both feet, knees and anterior iliac spines in contact with the surface.
- The subject raises one thigh by hyper-extending the hip-joint. During this movement the subject's legs and trunk must remain symmetrical. No rotation of the spine is allowed and *both* anterior iliac crests must remain in contact with the surface on which the subject is lying. This precaution is essential and is it important that the observer be in a position to check that the subject's hips remain level.
- The goniometer is used to measure the ankle made by two lines: a) a line drawn from the greater trochanter to the proximal head of the fibula, and b) the horizontal.

Shoulder flexibility or Shoulder hyper-extension with the arms horizontal

The subject sits upright in an chair with his or her spine straight, head looking straight forward, and buttocks, upper back and back of head in contact with a vertical upright. His or her arms are straight out from the shoulders and 1 cm above the measuring board. The subject's palms face downwards.

The subject moves his or her arms backwards as far as possible. While doing this the buttocks, upper back and the back of head must remain in contact with the vertical upright; arms must not be raised or lowered and must remain 1 cm from the measuring board. The subject's arms and shoulders must not rotate and the head must not move forwards or backwards.

The angle that the subject's arms make with the front of the board (mean of right and left) is recorded as the subject's score.

Scores on theses tests for selected groups of subjects are shown in Table 3.

TABLE 3 FLEXIBILITY SCORES OF SELECTED GROUPS OF SUBJECTS (MEAN ± SD)

	SPINAL FLEXION (CM) SPINAL FLEXIBILITY	HIP ABDUCTION (DEGREES) GROIN FLEXIBILITY	HIP FLEXION (DEGREES) HAMSTRING FLEXIBILITY	ANKLE DOSI-FLEXION (DEGREES) ANKLE FLEXIBILITY	HIP HYPER-EXTENSION (DEGREES) QUAD FLEXIBILITY	SHOULDER HYPER-EXTENSION (DEGREES) SHOULDER FLEXIBILITY
Untrained subjects	-7.8 ± 10.4	45.3 ± 7.2	64.7 ± 10.6	28.3 ± 8.3	15.3 ± 8.3	16.7 ± 9.5
Elite swimmers	4.2 ± 7.7	59.2 ± 6.4	75.2 ± 9.6	35.8 ± 5.1	30.2 ± 8.2	42.8 ± 5.3
Elite Gaelic footballers	2.5 ± 5.2	54.4 ± 6.6	72.1 ± 8.1	33.8 ± 4.6	23.3 ± 7.3	27.5 ± 7.6
Sports scholarship holders	12.0 ± 7.2	62.3 ± 6.9	82.3 ± 9.5	38.6 ± 5.6	35.2 ± 10.1	35.1 ± 9.4
Olympic gymnasts	18.1 ± 6.2	68. 8 ± 7.2	108 ± 9.1	42.2 ± 6.6	45.6 ± 7.8	50.3 ± 7.8
Schoolboys aged 15 to 18	-2.4 ± 9.8	57.6 ± 8.0	72.0 ± 10.5	38.4 ± 8.2	23.5 ± 7.7	22.4 ± 8.5

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RESUMO: Para acompanhar a evolução da flexibilidade, foram identificadas seis medidas que preeenchessem totalmente os seguintes critérios: 1) fosse representativa de ampla faixa de diferentes formas de mensurações de flexibilidade; 2) refletissem movimentos comumente observados no esporte; 3) pudesse ser medido com precisão por pesquisadores que trabalhassem em laboratório padronizado da ciência esportiva. As seis medidas foram: 1) flexão de tronco com alongamento dos isquiotibiais; 2) abdução do quadril; 3) flexão do quadril; 4) dorsi-flexão do tornozelo; 5) hiperextensão do quadril; 6) hiperextensão de ombro com os braços na horizontal. Foram descritos os equipamentos que permitiram fácil mensuração dessas variáveis. A confiabilidade de vários protocolos para a mensuração da flexibilidade é relatada e, após mais de dez anos de experiências com a técnica, foi descrito um protocolo definitivo para cada uma das seis medidas descritas. Também foi relatada a estatística descritiva para as seis medidas de flexibilidade.

DESCRITORES: Flexibilidade. Avaliação de desempenho. Esportes.

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