©Journal of Sports Science and Medicine (2021) **20**, 492-499
http://www.jssm.org DOI: https://doi.org/10.52082/jssm.2021.492

Research article

Assessment of the Maximal Range of Motion from Initial Sensation of Stretching to the Limits of Tolerance

Serge P. von Duvillard [1]✉, Luciana P. Carvalho [2], Sara A. Rodrigues [2], Christian E. Cabido [2], Gustavo H. Peixoto [2], Jeffrey W. Bell [3], Mauro H. Chagas [2] and André G. P. de Andrade [2]

[1] Department of Sport Science and Kinesiology, University of Salzburg, Salzburg, Austria; [2] School of Physical Education, Physiotherapy and Occupational Therapy, Universidade Federal de Minas Gerais, Belo Horizonte, Minas Gerais, Brazil; [3] Science Department, Southwest Minnesota State University, Marshall, Minnesota, USA

Abstract

The aim of this study was to determine whether the first sensation of stretching (ROM_{FSS}) may predict the maximum range of motion (ROM_{MAX}) in male (N = 37) and female (N = 32) volunteer subjects, and to assess the reliability of the ROM perceived by subjects in relation to a pre-determined ROM ($ROM_{50\%}$). Subjects attempted three experimental sessions with 48 hours between sessions 1 and 2 and 28 days between sessions 1 and 3. Within each session, five trials were performed with isokinetic equipment to assess posterior thigh muscle flexibility. The results revealed a strong and significant correlation between ROM_{MAX} and ROM_{FSS} for both sexes, females ($r = 0.96$, $p < 0.001$, $R^2 = 0.92$) and males ($r = 0.91$, $p < 0.001$; $R^2 = 0.82$). The accuracy of the model verified by the standard error of estimate (SEE) was high in the equations proposed for both female (SEE = 4.53%) and male (SEE = 5.45%). Our results revealed that ROM_{FSS} may predict the ROM_{MAX} for both male and female subjects. The ROM_{FSS} may contribute to the development of evaluation methods that do not subject the individuals to conditions that may include unnecessary risk of injury and is well suited to monitor the training process of stretching exercises with submaximal loads.

Key words: Prediction equation, range of motion, onset of pain, muscle stretch intensity.

Introduction

Predicting maximal performance from a submaximal effort in resistance training is a useful method to avoid exposure to extreme physical requirements, thereby minimizing the risks of injury (Mayhew et al. 2008). This approach uses muscle endurance performance through a number of repetitions performed to predict maximal strength performance, replacing a 1-repetition maximum protocol (Mayhew et al. 2008; Knutzen et al. 1999). These strength predictions also aid in exercise prescription and manipulation of training load (Mayhew et al. 2008). Unlike muscle strength, prediction equations currently do not exist for flexibility capacity represented by joint maximal range of motion (ROM_{MAX}). The ROM_{MAX} is defined as the maximum range of joint motion tolerated by the participant during a stretching maneuver (Halbertsma et al. 1996; Magnusson et al. 2000; Blazevich et al. 2012).

While ROM_{MAX} is a variable associated with the maximal tolerance of the subject to stretching, another variable related to the individual's tolerance to stretching is the first sign of pain (i.e., first detection of pain), that was first analyzed by Halbertsma and Göeken (1994). In spite of the use of the term “pain”, the authors instructed the volunteers instead to note the first sensation of tension in the musculature, generated during passive stretching. A similar procedure was performed in other studies that also associated the first sensation of tension in the musculature during stretching to the individual's tolerance of stretching (Cabido et al. 2014; Halbertsma et al. 1999; 2001; Ylinen et al. 2009). In these studies, the ROM corresponding to the first muscular sensation of stretching (FSS) was the measure used (ROM_{FSS}). Afferent communication from the muscle-tendon unit (MTU) and joint kinesthetic receptors is responsible for the signaling of ROM_{MAX} and ROM_{FSS} by the individual during a stretching maneuver. The modulation of information by individual anatomical and physiological differences and, consequently, the impacts on ROM variables are currently not addressed in the literature. Some authors have reported that of the various putative neuromuscular factors, higher ROMS are associated with the individual's ability to tolerate higher torque values (Ben and Harvey 2010; Magnusson 1998; Weppler and Magnusson, 2010). According to Blazevich et al. (2012), this capacity and volitional stretch termination may be related to subconscious responses to afferent stretch (I and IIa), pressure (III) and pain (IV), as well as differences in the supraspinal registration of afferent signals. These authors also suggest that future studies are warranted to explain each responses relative influence on ROM.

Considering the multi-factorial influences described above, ROM_{MAX} indicates the maximal tolerable stretching sensation and ROM_{FSS} represents the first sensation of stretching associated with MTU stretch-associated tension. Thus, ROM_{MAX} and ROM_{FSS} could represent the limits of a *continuum* of the individual's tolerance to stretching. Postulating the existence of this *continuum* is based on the results of studies that have analyzed the effects of stretching on these two variables. Furthermore, finding that ROM_{MAX} and ROM_{FSS} both change in the same direction indicates similar factors may be related to their changes after acute (Cabido et al. 2014; Halbertsma et al. 1999; 2001; Ylinen et al. 2009) and chronic muscle stretching (Halbertsma and Göeken 1994). Although the aforementioned studies do not substantiate the level of relationship between ROM_{FSS} and ROM_{MAX}, an analysis based on data presented by Halbertsma and

Received: 16 May 2021 / Accepted: 29 May 2021 / Published (online): 15 June 2021

Göeken (1994) demonstrates a strong and significant correlation between ROM_{FSS} and ROM_{MAX} (r = 0,94; p = 0,001; R^2 = 0,88), supporting the possible existence of this *continuum*. Recently, Chagas et al. (2016) through an exploratory factor analysis reported ROM_{FSS} and ROM_{MAX} were inserted into the same factor. These findings reinforce the expectation that these variables are interrelated and that they may represent a common aspect associated with tolerance to stretching.

In this context, the use of ROM_{FSS} to predict ROM_{MAX} may help in the development of evaluation methods with a lower risk of injury and discomfort. In addition, a greater tolerance to the ROM_{FSS} could improve the monitoring of flexibility training. However, differences between males and females for ROM_{MAX} and the individual's tolerance to stretching could influence the prediction capability via ROM_{FSS} (Hoge et al. 2010; Gajdosik et al. 1990; Gajdosik, 2006; Marshall and Siegler 2014; Wiesenfeld-Hallin 2005). Thus, given the possible differences between males and females, two different sex-specific prediction equations for ROM_{MAX} may need to be developed, as has been proposed in the case of other capacities, such as muscular strength (Mayhew et al. 2008).

Moreover, considering the hypothesis of the *continuum* of stretching tolerance, if an individual can reliably determine a specific point within this *continuum* then this data may reinforce a possible linearity between ROM_{FSS} and ROM_{MAX}. In this way, the ROM registration corresponding to a specific point, (i.e., a tension sensation corresponding to halfway ($ROM_{50\%}$) between the lower (ROM_{FSS}) and upper (ROM_{MAX}) limits of the *continuum)*, may allow for verification of whether the individual is able to reproduce an adequately determined sensation of stretching. Stretching sensation is used as an indicator of the intensity of the elongation stimulus in experimental studies involving flexibility training (Kay et al. 2015; Freitas et al. 2015). Despite this, the reliability of the stretching sensation associated with a submaximal stimulus of the stretching stimulus has not yet clearly been investigated. Another aspect to consider is the comparison of the registered value of $ROM_{50\%}$ and the expected value of this variable obtained by the predicted values of ROM_{MAX} using a measured ROM_{FSS}.

Thus, the objectives of the present study were to: (a) verify whether ROM_{FSS} and ROM_{MAX} are correlated and whether ROM_{FSS} is able to accurately predict ROM_{MAX} in males and females; (b) verify the reliability of the $ROM_{50\%}$ measure; and (c) compare the observed and expected $ROM_{50\%}$ value. We hypothesized that: (a) ROM_{FSS} and ROM_{MAX} will be significantly and strongly correlated, and the first sensation of stretching (ROM_{FSS}) will be a predictor of maximal performance (ROM_{MAX}); (b) $ROM_{50\%}$ will exhibit high reliability values in a test-retest procedure; and (c) there will be no significant difference between the observed and expected mean values of $ROM_{50\%}$.

Methods

Subjects

Based on correlation r values between ROM_{FSS} and ROM_{MAX} from a pilot study, sample size was calculated using GPower 3.1 software (Dusseldorf, Germany). The calculation resulted in 58 individuals for a statistical power above 80% and a priori significance level was set at α = 0.05 (Beck, 2013). The final sample consisted of 69 individuals: 37 males (mean ± SD: age = 23.3 ± 3.8 years, body mass = 75.2 ± 14.2 kg and height = 1.76 ± 0.6 m) and 32 females (mean ± SD: age = 23.0 ± 4.0 years, body mass = 58.4 ± 9.5 kg, height = 1.61 ± 0.5 m). The study was approved by the ethics committee of the University of Minas Gerais, Belo Horizonte, Brazil (Project # CAAE 25468114.7.0000.5149) in accordance with the Declaration of Helsinki, and all volunteers signed an informed consent form prior to any testing. None of the volunteers had undergone flexibility or strength training prior to testing, or had musculoskeletal injury of the lower limbs, spine, or pelvis, in the previous six months.

All subjects met the following inclusion criteria: a) an absence of history of neurological or orthopedic pathologies in the lower limbs within the last six months and no recent or chronic low back pain (Halbertsma et al. 1999); b) an absence of musculoskeletal injury or pain in the lower limbs, spine or pelvis in the last six months (Blackburn et al. 2004); and c) subjects had not participated in activities involving flexibility training during the three months prior to the study and therefore were considered untrained (Halbertsma et al. 1996). The exclusion criteria for this study included (a) the practicing of stretching exercises during the period of data collection; b) missed testing attendance on the scheduled day and time; and c) the ability to achieve full knee extension in the pre-test phase on the provided equipment during ROM_{MAX} measurements.

Experimental Approach

In this study we used a repeated-measures design to assess hamstring flexibility via an isokinetic knee extension test as previously described (Cabido et al. 2014; Peixoto et al. 2015). Participants were seated on the Flexmachine with the distal third of the thigh supported at 45º hip flexion relative to the ground. Positioning prevented complete knee extension and ensured elongation of the muscle-tendon unit was measured and performance was not limited by joint mechanics. Subjects performed the same procedures for each experimental session consisting of five valid repetitions of passive knee extensions, at a speed of 5°.s-1 with an interval of approximately 15 s between each repetition. In each repetition participants were asked to reach maximum knee extension and to press an analog button when experiencing ROM_{FSS} and estimating the mid-point between the first sensation and ROM_{MAX}. Therefore, ROM_{FSS}, $ROM_{50\%}$, and ROM_{MAX} were measured during each maximal attempt.

Participants visited the laboratory on four different days. The first day was a familiarization trial, and the subsequent three days consisted of identical experimental sessions. The time interval between sessions one and two was 48 hours and between sessions one and three was 28 days to verify both the reliability of the measurements and the accuracy of the prediction equation. In sessions one to three ROM_{FSS}, $ROM_{50\%}$, and ROM_{MAX}, corresponding to the lower limit, midpoint, and upper limit of the continuum of stretching tolerance, were measured. For each volunteer, all sessions were conducted at the same time of the day (< 2 hours). Both lower extremities of the volunteers were assessed.

ROM_{FSS} was recorded by asking subjects to indicate when they first felt stretching in the hamstrings by pushing a button. This FSS was recorded as a function of the knee extension angle, generating the ROM_{FSS} variable (Cabido et al. 2014). Together, the ROM_{MAX} and ROM_{FSS} variables determined the continuum of stretching tolerance for each individual, allowing a perceptual scale to be created equally for all participants. Thus, the determination of these variables allowed for the establishment of the minimum and maximum values within the continuum of stretching tolerance. This procedure was based on the study of Gearhart et al. (2001). $ROM_{50\%}$ was defined and recorded at the sensation of stretching corresponding to the midpoint between the lowest (ROM_{FSS}) and highest (ROM_{MAX}) limits of the continuum.

Procedures

Each participant was familiarized with and properly positioned on the isokinetic dynamometer termed the Flexmachine that was built in the Biomechanics Laboratory of the Federal University of Minas Gerais (UFMG, Belo Horizonte, Brazil) (for details see Peixoto et al. 2015). All equipment settings were recorded for future use (Cabido et al. 2014). Familiarization consisted of two stages. Initially, subjects were instructed on how the equipment worked, how the procedures were to be conducted and how the data was to be collected. Then subjects were asked to perform, on average, five trials, during which the ROM_{FSS}, $ROM_{50\%}$, and ROM_{MAX} variables were collected and recorded.

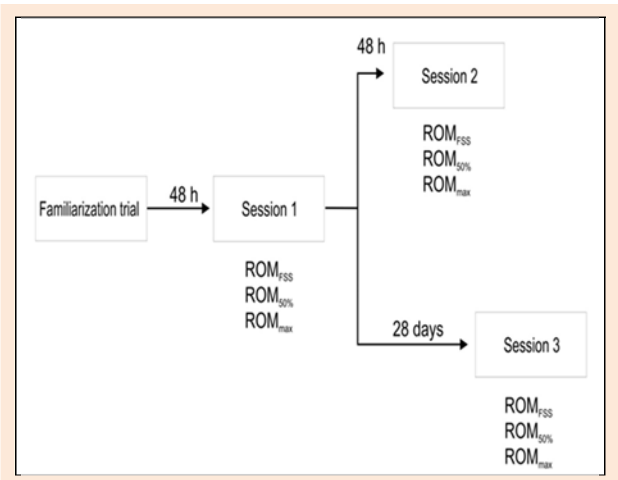

Figure 1. Schematic presentation of the time course associated with the experimental protocol. ROM_{MAX} = joint maximal range of motion; ROM_{FSS} = range of motion corresponding to the first muscular sensation of stretching; $ROM_{50\%}$= the range of motion registration corresponding to a specific point, (i.e., a tension sensation corresponding to halfway ($ROM_{50\%}$) between the lower (ROM_{FSS}) and upper (ROM_{MAX}) limit of the *continuum* of the individual's tolerance to stretching.

Experimental Sessions (S1, S2, and S3)

Subjects performed the same procedures for each experimental session consisting of five valid repetitions of passive knee extensions of each leg, at a speed of 5°.s-1 with an interval of approximately 15s between each repetition. Schematic illustration of the testing protocol is shown in Figure 1.

Statistical Analysis

Subject characteristics are presented as mean and standard deviation of the variables. The strength of relationship between ROM_{FSS} and ROM_{MAX} was determined from a Pearson Product Moment linear correlation coefficient (r), and the ROM_{MAX} prediction by ROM_{FSS} was verified using simple linear regression. The fit quality of the regression model was assessed by the coefficient of determination (R2). The coefficient of determination is interpreted as the proportion of total variance of the dependent variable that is explained by the variance of the independent variable. Moreover, since the value of R2 is defined by a ratio between the variance explained by the model and the total variability that represent the sum of the explained variance and the unexplained variance (error), the larger the value of R2, the smaller the model error (SEE). Together, these two statistics (i.e., R2 and SEE) measure the adequacy of the regression model (Field et al. 2013).

The simple linear regression equation is indicated as follows:

$$y = a + bx \qquad (1)$$

where y is the dependent variable, the predicted value of ROMMAX; x is the independent variable (ROMFSS); and a and b are the estimated coefficients of the regression line using the least squares calculation method. To verify the accuracy of the prediction model, the standard error of estimate (SEE) was computed as the square root of the unpredictable portion of the variance in a set of observations as follows:

$$SEE=\frac{\sqrt{(y-\hat{y})^2}}{n-1} \qquad (2)$$

where, ŷ is the predicted score from the regression line; y is the actual score; and n is the number of subjects. In addition, a repeated measures ANOVA was used to compute the difference between the observed and expected ROMMAX values.

The reliability of $ROM_{50\%}$, in the experimental sessions was determined by the intra-class correlation coefficient (CCI) and the standard error of measurement (SEM). The ICC values were interpreted as weak (<0.4), moderate (0.4-0.59), good (0.6-0.74) and excellent (0.75-1.0) (Cicchetti, 1994). Finally, the comparison between the ROM50% value recorded by the volunteer and the expected value for the variable as defined by (ROM_{MAX} - ROM_{FSS}) / 2 + ROM_{FSS} was performed using a repeated measures ANOVA. Normality and sphericity were verified using Shapiro-Wilks and Mauchly's tests, respectively. When necessary, a post-hoc Tukey HSD test was used to identify the differences reported in the ANOVA. Statistical analyses were conducted using the Statistical Package for the Social Sciences (SPSS version 22.0; Chicago, IL, USA) with a significance level of 5%.

Results

The results from this study are reported in three parts. First, the correlation and variance values between ROM_{FSS} and ROM_{MAX} and the prediction equations with the accuracy values (SEE) are presented. Secondly, the reliability data of $ROM_{50\%}$ (ICC and SEM) from each

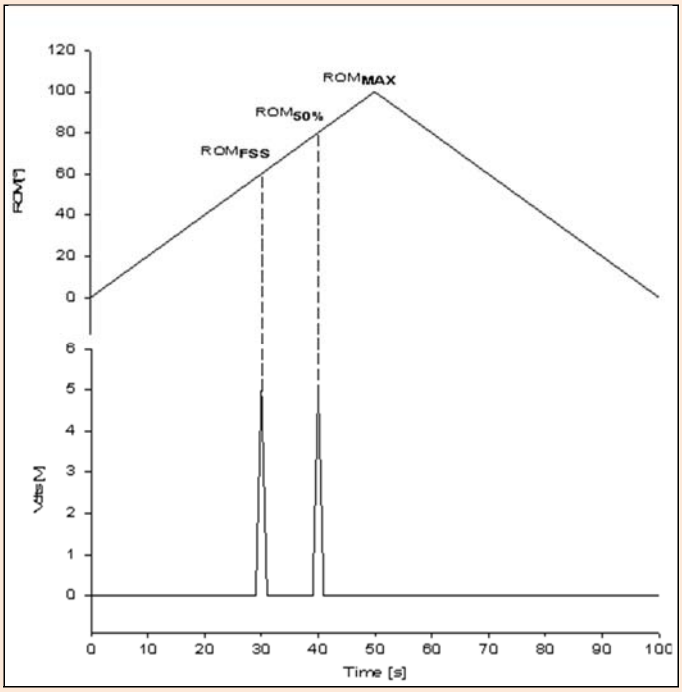

Figure 2. Measurement of the ROM_{FSS}, $ROM_{50\%}$, and ROM_{MAX} variables utilizing Dasylab software.

experimental session are conveyed. The final part presents the repeated measures ANOVA for the comparison of the observed and expected values of $ROM_{50\%}$. In each trial, we recorded the ROM_{FSS}, $ROM_{50\%}$, and ROM_{MAX} variables (Figure 2).

Correlation and Prediction

The correlation values between ROM_{MAX} and ROM_{FSS}, for female and male subjects, and the ROM_{MAX} prediction equations through ROM_{FSS} in all experimental sessions, with the coefficient of determination and standard error of the estimate, are depicted in Table 1.

In Table 1, prediction equations, for females and males, in the three experimental sessions (S1, S2 and S3) accompanied by Pearson Product Moment correlation values (r), coefficient of determination (R^2), standard error of the estimate (SEE) and p values of the means comparison between the observed and expected values of joint maximal range of motion (ROM_{MAX}).

The repeated measures ANOVA results between the observed and expected ROM_{MAX} values are depicted in the Table 1 above (p-value). Interestingly, there were no significant differences between the values observed and predicted in the three experimental sessions in the case of either male or female. Figure 3 illustrates the prediction of ROM_{MAX} by means of ROM_{FSS} in experimental session 1.

Reliability of $ROM_{50\%}$

An intraclass correlation coefficient (ICC) for ROM_{MAX} and ROM_{FSS} was calculated for both male and female from measurements during sessions one and two; these inter-session values were 0.93 and 0.88 for the males, and 0.98 and 0.97 for the females, respectively. In addition, percent standard error of measurement (SEM%) values were reported to reflect the reliability (i.e., 4.44% for ROM_{MAX} and 2.21% for ROM_{FSS} in male; and 2.70% for ROM_{MAX} and 2.70% for ROM_{FSS} in female).

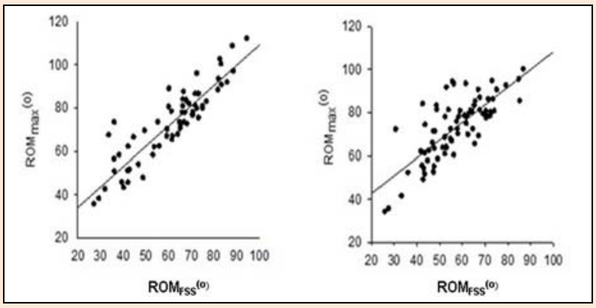

Figure 3. Graphic presentation of prediction equation of ROM_{max} via ROM_{FSS} for males and females. ROM_{FSS} indicates the first sensation of stretching of the posterior thigh musculature as a function of the joint range of motion; ROM_{MAX} denotes the maximal range of motion.

Table 1. The reliability statistics for $CCI_{2,k}$ and SEM of $ROM_{50\%}$, for the three collection sessions.

Gender	Session	Predicted values for ROMmax				P value
		ROMmax predicted	r	R^2 (%)	SEE (°)	Y–Y'
Women	S1	15.5 + (0.94 x ROMFSS)	0.96	92.16	7.62	0.97
	S2	15.1 + (0.88 x ROMFSS)	0.85	72.25	7.54	0.94
	S3	15.3 + (0.86 x ROMFSS)	0.83	68.89	9.12	0.93
Men	S1	26.4 + (0.82 x ROMFSS)	0.89	79.21	9.32	0.95
	S2	22.4 + (0.80 x ROMFSS)	0.88	77.44	9.75	0.95
	S3	24.2 + (0.77 x ROMFSS)	0.82	67.24	10.72	0.93

r = Pearson correlation value; R^2 = coefficient of determination; SEE = Standard Error of Estimate; S1, S2 and S3 = experimental sessions; y = $ROMmax_{observed}$; y' = $ROMmax_{predicted}$; p value = p value for the means comparisons between the observed and expected values of ROM_{max}.

Table 2 depicts intraclass correlation coefficient (ICC) and standard error of measurement (SEM) values for the range of motion corresponding to halfway ($ROM_{50\%}$) between the lower (ROM_{FSS}) and upper (ROM_{MAX}) limits of the *continuum* of the individual's tolerance to stretching, in each of the three experimental sessions (S1, S2 and S3). $ROM_{50\%}$ reliability was strong for the three experimental sessions' ICC values in both males and females. In addition, SEM values found for $ROM_{50\%}$ varied between 3.15º and 3.62º for female subjects and between 3.34º and 3.69º for male subjects.

Table 2. Intraclass correlation coefficient (ICC) and standard error of measurement (SEM) values of the range of motion corresponding to halfway ($ROM_{50\%}$) between the lower (ROM_{FSS}) and upper (ROM_{MAX}) limits of the *continuum* of the individual's tolerance to stretching, for the three experimental sessions (S1, S2 and S3).

Gender	Session	*Relative* ICC	*Relative* *p* value	*Absolute* SEM (º)
Women	S1	0.96	0.001	3.15
	S2	0.95	0.001	3.21
	S3	0.97	0.001	3.62
Men	S1	0.94	0.001	3.34
	S2	0.93	0.001	3.58
	S3	0.94	0.001	3.69

S1, S2 and 3 = experimental sessions 1, 2 and 3; ICC = intraclass correlation coefficient; SEM = Standard error of measurement.

Comparison of the observed and predicted values

The results of the repeated measures ANOVA did not indicate significant differences between the observed $ROM_{50\%}$ value and predicted values for the three experimental sessions, for either males or females ($p = 0.65$; $\eta^2 = 0.15$).

Discussion

The first hypothesis of the present study was that ROM_{FSS} and ROM_{MAX} would be strongly correlated, and that the first sensation of stretching (ROM_{FSS}) would predict maximal performance (ROM_{MAX}) in male and female subjects. The results revealed a strong and significant Pearson Product Moment correlation between ROM_{FSS} and ROM_{MAX}, with a statistic that was higher than 0.80 in all experimental sessions (Table 1). Our results support the data from a previous study ($r = 0.94$; $p = 0.001$) (Halbertsma and Göeken 1994). In addition, the strong correlation between ROM_{FSS} and ROM_{MAX} determined in the present study corroborates the results of Chagas et al. (2016). These authors performed an exploratory factor analysis (EFA) involving variables often used to evaluate the response of the MTU to stretching exercises and found that the ROM_{FSS} and ROM_{MAX} represent a common construct (factor). Thus, considering EFA theory, factors are composed of variables measuring common aspects. The strong correlation found between ROM_{FSS} and ROM_{MAX} in this study allowed linear prediction modelling in this analysis and verification for the ability of ROM_{FSS} to predict ROM_{MAX} with accuracy in male and female subjects. The results of the coefficient of determination (R^2) of the prediction model were between 67.2% and 92.0% (average of 76.4%), for both males and females (Table 2). It is reasonable to conclude that on average, 76.4% of the variability of ROM_{MAX} are explained by the variability of ROM_{FSS}. For a model to be considered a good predictor, it must have R^2 values above 70% (Hair et al. 1999). In the present study, the mean accuracy of the model given by the SEE for males and females was 9.01º (range 6.54º - 10.72º) (Table 2). The SEE measures the mean deviation (error) between the observed and predicted values of ROM_{MAX} and is interpreted as the standard deviation of residuals, since these residuals are normally distributed and what is sought is the achievement of the lowest possible value of SEE (Field et al. 2013). In our study, the mean value of SEE was 9.01º that together with the non-verification of a significant difference between the observed and predicted ROM_{MAX} values ($p > 0.05$) for the three experimental sessions, allows us to reasonably infer that the prediction model rendered high accuracy.

These results together reinforce the idea that ROM_{FSS} and ROM_{MAX} may represent points at the ends of a *continuum* of individual tolerance for stretching exercises ranging from the initial through final individual tolerance, respectively (Chagas et al. 2016). However, an explanation that involves the structures and mechanisms associated with the modulation of individual tolerance to stretching (i.e., the beginning and end of the *continuum*) is not yet fully accessible. The tension perceived by an individual during stretching is due to mechanical stimulation of the existing receptors in the musculotendinous unit, especially the free nerve endings (afferents of group III and IV) (Stacey 1969). Different studies have reported that these free nerve endings are stimulated during stretching, in particular, triggering depolarization of type III afferent fibers (Hayes et al. 2005; Mense and Meyer 1985; Paintal 1960). Findings from the study of Cleland et al. (1990) have revealed that the response frequency of type III afferent fiber (i.e., the change in the number of action potentials) increases with the increase in passive force that results from stretching. Furthermore, the stimulus originated by the afferent pathways penetrates the posterior horn of the medulla reaching the gelatinous substance. According to the gate theory of Melzack and Wall (1965), this would modulate the afferent signal that is sent to the higher centers. This modulated signal is perceived by the superior centers as a process, and not as a single event that is interpreted on the basis of the attention, emotion and memories of previous experiences (Melzack and Wall 1965). As such, this mechanism indicates the possibility of modulating stretching sensation through these afferent pathways. In addition, this mechanism reinforces the perspective of a *continuum* of the individual's tolerance to stretching, since lower levels of activation of the afferent pathways during stretching would be associated with lesser sensation of stretching (i.e., ROM_{FSS}, while ROM_{MAX} would be related to a greater level of activation of these afferent pathways). Thus, increased activation of these mechanoreceptors results in a highly uncomfortable sensation that could limit the achievement of a greater range of motion (e.g., ROM_{MAX}). In addition, results from previous studies that investigated ROM_{FSS} and ROM_{MAX}, also corroborate this perspective of a *continuum* of tolerance. Cabido et al. (2014) and Ylinen et al. (2009) both found that an increase in ROM_{MAX} was accompanied by a corresponding increase in ROM_{FSS}.

The second hypothesis, that $ROM_{50\%}$ would show high reliability values in a test and re-test procedure, was confirmed by ICC and SEM values (Table 2). The ICC determines the capacity to differentiate between subjects, and is calculated by dividing the variance between subjects by the total variability (i.e., variance between subjects plus error) (Weir 2005). The SEM quantifies the error in the same unit of measure as the original variable, and is not influenced by the variability between individuals (Weir 2005). Therefore, small ICC values may indicate that the sample is homogeneous, via a consideration of the study variable and not that the reproducibility is small (Weir 2005). The SEM value reflects the degree of fluctuation of the scores of an individual in a test or condition, indicating the expected natural variability (i.e., random error) for the response of a given variable (Weir 2005). Higher SEM values indicate higher ranges of expected scores for a certain variable making it difficult to perceive significant changes in the scores of an individual following a systematic intervention (e.g., training). ICC results (~ 0.94) and SEM (~3º) for the three experimental sessions that corroborate the second hypothesis (i.e., that $ROM_{50\%}$ indicated a high reliability).

Finally, the third hypothesis of this study considered was that there would be no significant difference between the observed and expected $ROM_{50\%}$ mean values. This was confirmed by repeated measures ANOVA ($F_{(2,32)} = 0.44$, $p = 0.65$; $\eta^2 = 0.147$). These findings indicate that the individuals who participated in the study were accurate in determining the sensation of tolerance to stretching, since the value registered by these individuals was not different from the expected value.

The concept of a *continuum* of the individual's tolerance to stretching is strengthened by the reliability of $ROM_{50\%}$, the absence of statistical difference between the observed and expected mean values for $ROM_{50\%}$, and data from ROM_{FSS} and ROM_{MAX}. These results allow us to assert some assumptions. The first assumption is that the *continuum* of the individual's tolerance to stretching can be considered a perceptual range. Furthermore, this range of perception can be established equally for all individuals by determining a lower (ROM_{FSS}) and higher (ROM_{MAX}) limit of the *continuum* of tolerance to stretching. Thus, even if there is inter-individual variation in the perception range, all individuals should be able to undergo the same process of anchoring the range limits. Since the definition for this range limits is reliable and consistent over time, an individual should also be able to reliably and consistently indicate a point within the range of perception that would represent a particular "intensity" of individual perception. This assumption was tested in the present study through having the subject indicate an "intensity" corresponding to the half of the lowest (ROM_{FSS}) and highest (ROM_{MAX}) limits of the perception range ($ROM_{50\%}$) during the stretching maneuver. The individual's capacity to accurately and reliably determine this point provides support for the assumption of the linearity of the perception response to stretching stimulus. Interestingly, results from the present study confirmed this assumption. In this way, the present study demonstrates need for the development of a standardized scaling procedure of individually perceived "intensity" during stretching. Future studies are warrantied, however, to verify the impact of using this standardized scaling procedure on the response of the muscle-tendon unit submitted to a training process in both more controlled conditions (e.g., in the laboratory), and in those with a greater ecological validity.

Any extrapolation of the results found in the present study may need to consider the sample of the population studied (i.e., young males and females). Furthermore, extrapolation can only be made for individuals without musculoskeletal injury in the joint of interest. In the scientific literature, the elderly and individuals with musculoskeletal injuries have a lower maximum passive torque, indicating a lower tolerance to stretching in these populations (Magnusson 1998; Bressel and McNair 2001). Consequently, it is possible that the difference in tolerance changes the relationship between ROM_{FSS} and ROM_{MAX}. Thus, group differences for tolerance still needs to be investigated in future studies to determine valid prediction equations for specific populations. Finally, additional research is necessary to verify if the results found in this study are reproducible in other muscle groups.

Conclusion

The present study reports results that support the perspective of a *continuum* of tolerance to stretching and a proposal that ROM_{MAX} may be predicted by the first sensation of stretching (ROM_{FSS}). Such findings are of great importance in the context of sports and rehabilitation, since they will allow sports scientists, coaches, and physiotherapists to predict an individual's ROM_{MAX}, without performing a maximal physical test, thereby minimizing the risk of injury. However, at this time, this recommendation is limited to young male and female subjects, as well as to the muscle group investigated in this study. Thus, an important aspect to be considered is that the relationship was found using a method that allowed for the control of several factors that could interfere in the ROM_{FSS} and ROM_{MAX} including the standardization of the individual's positioning, the speed of the stretch, the muscle group, and the way to operationalize the variables. For greater external validity, future studies should investigate measures similar to those performed in a clinical situation. In addition, future studies should investigate whether the linearity found in the extremes of the *continuum* of stretching tolerance, given by ROM_{FSS} and ROM_{MAX}, would also be true in the case of the submaximal values that lie within that *continuum*.

Acknowledgements

This study was supported by the Fundação de Amparo à Pesquisa do Estado de Minas Gerais (FAPEMIG), Pró-Reitoria de Pesquisa da Universidade Federal de Minas Gerais (PRPG-UFMG), and Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (CAPES) in Brazil. The experiments comply with the current laws of the country in which they were performed. The authors have no conflict of interest to declare. The datasets generated during and/or analyzed during the current study are not publicly available, but are available from the corresponding author who was an organizer of the study.

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Key points

- An individual's tolerance to stretching can be considered a continuum marked by the first sensation of stretching and the maximum range of motion as the continuum's end-points.
- The first sensation of stretching and the point representing halfway between the first sensation and maximal range of motion are reliable measures in young men and women.
- The first sensation of stretching may be a safe and useful predictor of maximal range of motion.

AUTHOR BIOGRAPHY

Serge P. von DUVILLARD
Employment
Professor at the University of Salzburg in the Department of Sport and Exercise Science in Austria
Degree
Ph.D, FACSM, FECSS
Research interests
Exercise science and human performance, specifically cardiopulmonary physiology, human biochemistry, and metabolic responses to human performance.
E-mail: spvonduvillard@aol.com

Luciana Pesce de CARVALHO
Employment
Physiotherapist at the Brazilian School of Osteopathy (EBOM, FCMMG).
Degree
MS
Research interests
Orthopedics, sports and aquatic physiotherapy
E-mail: lupesce82@hotmail.com

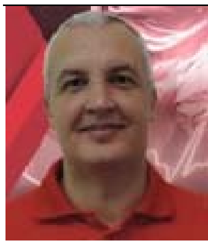
Sara Andrade RODRIGUES
Employment
Sports scientist and physiotherapist at the Biomechanics Laboratory at Federal University of Minas Gerais and an adjunct professor at the Federal Institute of Southeast of Minas Gerais.
Degree
PhD
Research interests
Muscle biomechanics, with emphasis on flexibility training.
E-mail: sarfisioterpia@gmail.com

Christian Emmanuel Torres CABIDO
Employment
Professor in the Department of Physical Education and leading the research group in physical exercise, health, and human performance at the Federal University of Maranhão.
Degree
PhD
Research interests
Physical exercise, health, and human performance
E-mail: christianemmanuel@gmail.com

Gustavo Henrique PEIXOTO
Employment
Adjunct Professor of sport science at the Federal University of Minas Gerais (UFMG).
Degree
PhD
Research interests
Biomechanics of Muscle-tendon unit and sports training, with emphasis on muscle adaptation to strength and flexibility training.
E-mail: gupeixoto@yahoo.com.br

Jeffrey W. BELL
Employment
Professor of exercise science in the Science Department at Southwest Minnesota State University, In Marshall, United States.
Degree
PhD
Research interests
Sport performance, exercise physiology, atherosclerosis, and spinal cord injured athletes.
E-mail: Jeffrey.W.Bell@smsu.edu

Mauro Heleno CHAGAS
Employment
Assoc. Prof. in the Department of Sports at the Federal University of Minas Gerais in Brazil.
Degree
PhD
Research interests
Neuromechanics of human movement with the focus on the mechanical and sensory responses of the muscle-tendon units in relation to resistance and stretching training.
E-mail: mauroufmg@hotmail.com



Andre Gustavo Pereira de ANDRADE
Employment
Professor in the Department of Sports at the Federal University of Minas Gerais, Brazil.
Degree
PhD
Research interests
Relationship of strength asymmetry with performance and injury, movement pattern analysis through functional data analysis.
E-mail: andreguto@yahoo.com.br

✉ **Serge P. von Duvillard, Ph.D., FACSM, FECSS**
Department of Sport Science & Kinesiology, University of Salzburg, Rifer Schlossallee 49, A-5400 Hallein/Rif, AUSTRIA