The acute effect in performing common range of motion tests in healthy young adults: a prospective study

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In the application of range of motion (ROM) tests there is little agreement on the number of repetitions to be measured and the number of preceding warm-up protocols. In stretch training a plateau in ROM gains can be seen after four to five repetitions. With increasing number of repetitions, the gain in ROM is reduced. This study examines the question of whether such an effect occurs in common ROM tests. Twenty-two healthy sport students (10 m/12 f.) with an average age of 25.3 ± 1.94 years (average height 174.1 ± 9.8 cm; weight 66.6 ± 11.3 kg and BMI 21.9 ± 2.0 kg/cm²) volunteered in this study. Each subject performed five ROM tests in a randomized order—measured either via a tape measure or a digital inclinometer: Tape measure was used to evaluate the Fingertip-to-Floor test (FtF) and the Lateral Inclination test (LI). Retroflexion of the trunk modified after Janda (RF), Thomas test (TT) and a Shoulder test modified after Janda (ST) were evaluated with a digital inclinometer. In order to show general acute effects within 20 repetitions we performed ANOVA/Friedman-test with multiple comparisons. A non-linear regression was then performed to identify a plateau formation. Significance level was set at 5%. In seven out of eight ROM tests (five tests in total with three tests measured both left and right sides) significant flexibility gains were observed (FtF: \( p < 0.001 \); LI-left/right: \( p < 0.001/0.001 \); RF: \( p = 0.009 \); ST-left/right: \( p < 0.001/p = 0.003 \); TT-left: \( p < 0.001 \)). A non-linear regression with random effects was successfully applied on FtF, RF, LI-left/right, ST-left and TT-left and thus, indicate a gradual decline in the amount of gained ROM. An acute effect was observed in most ROM tests, which is characterized by a gradual decline of ROM gain. For those tests, we can state that the acute effect described in the stretching literature also applies to the performance of typical ROM tests. Since a non-linear behavior was shown, it is the decision of the practitioner to weigh up between measurement accuracy and expenditure. Researchers and practitioners should consider this when applying ROM assessments to healthy young adults.

Abbreviations

| Abbreviation | Description |
|--------------|-------------|
| ROM          | Range of motion |
| FtF          | Fingertip-to-floor test |
| LI           | Lateral inclination test |
| RF           | Retroflexion of the trunk modified after Janda |
| TT           | Modified Thomas test |
| ST           | Shoulder test modified after Janda |

In the application of range of motion (ROM) tests there is little agreement on the number of repetitions to be measured and the number of preceding warm-up protocols. In general, ROM tests are tools to measure joint mobility on the basis of routine (scientific) procedures1–4. The aim of any ROM test is to determine the maximum
joint mobility. Hence, in every execution of the test, a stretching stimulus is applied on the connected muscle–tendon units. It has been shown, that in stretch training, such an acute effect occurs after only a few repetitions and manifests itself among other things in increased mobility, stretch tolerance and reduced passive torque4,5. It can be expected that this acute effect also occurs during the ROM test. Therefore, differences in the measurement protocol with regard to the measured repetitions and previous warm-up exercises, could lead to different results. However, the current evidence does not allow a determination of precise measurement protocols.

With a reproducible test procedure, the ROM value is a parameter to show changes in flexibility in an intervention. Depending on the joints to be measured, measuring tapes, goniometers or inclinometers are usually applied10–12. In general, ROM assessments depict either the active ROM or the passive ROM. To perform active ROM, the person to be tested moves the assessed joint without assistance using the agonistic musculature. In passive ROM, the therapist, the investigator, or another external force, moves the body part of the person to be tested through the ROM1. However, changes in passive torque, stretch tolerance and isometric muscle force influence the ROM value.

In static and dynamic stretching, an acute effect occurs within the first five stretches for ROM, stretch tolerance, passive torque and energy, which then return to baseline after 1 h6,9. The acute effect of stretching on ROM shows the greatest improvement in the first repetitions, whereas the ROM gain is reduced with increasing repetitions6,7. Consequently, four to five repetitions are recommended for the practical implementation within a stretch training session since subsequent gains are only minimal6,7. Accordingly, a logarithmic behaviour can be attributed to the acute effect of stretching on ROM. This is valid for stretching training, but how does it behave when the ROM is to be determined in an assessment setting?

The current literature provides no answers on whether such an effect occurs in the performance of common ROM tests. Scientific practice uses mixed approaches for the problem of acute effects. For example, in interventions and normative data surveys, one to three repetitions were carried out with or without two trials' warm-ups, mostly without any information on rest times3–17 or with no information about the number of repetitions8,19. In most reliability studies, either one repetition was primarily carried out10,20,21 or a warm-up on a bicycle ergometer employed, followed by one to two trials of warm-up prior to the actual measurement being conducted22,23. In a reliability study investigating trunk mobility, each subject was instructed to perform five repetitions of each tested motion in advance of the measurement being taken24.

In conclusion, there is no homogeneity regarding warm-up, the number of repetitions and averaging in the context of interventions, normative data surveys and reliability studies. Particularly, in light of a possible acute effect of stretching on ROM, a standardized procedure is necessary, since in common stretching the effect is very large, especially in the first five repetitions4,6,7. Due to the inconsistent implementation, in both the practical application and in reliability studies, the presence of an acute effect harms the comparability of ROM test results. Also, if it can be assured, that subjects are in a warmed up state, possible stiffening factors (e.g. sports prior to measurement) can be controlled for.

Thus, the aim of this study was to investigate the repetition-dependent acute effect of stretching on the ROM in the application of ROM tests and whether an equal behaviour can be derived. One further goal was to test whether there is a plateau formation after several repetitions. Therefore, multi-joint movements were chosen because they are restricted by the muscle–tendon unit. Single-joint movement are on the other hand limited by bones (e.g. elbow extension), mass (e.g. knee flexion) or ligaments (e.g. knee extension)25. Five frequently used and evaluated multi-joint ROM tests were selected, which mainly evaluate the mobility of the trunk: Fingertip-to-Floor test (right and left side)2, Lateral Inclination test (left and right side)1,26, Shoulder and Thomas test after Janda (left and right side)1,28 and the modified Thomas test (left and right side)1,10,29. On this basis, recommendations can be derived for the practical application of quality criteria.

Material and methods

Subjects. Twenty-two healthy sports students (10 m/12 f.; 25.3 ± 1.94 years; 174.1 ± 9.8 cm; 66.6 ± 11.3 kg; 21.9 ± 2.0 kg/m²) volunteered in this prospective study. Exclusion criteria were relevant operations or surgical stiffening of the musculoskeletal system, a relevant artificial joint replacement, severe diseases such as ankylosing spondylitis, chronic destructive joint diseases, multiple sclerosis, myodystrophic or neurodegenerative diseases, congenital malpositions of the musculoskeletal system or an acute herniated disc. In addition, the intake of muscle relaxants or other drugs that influence the elasticity of the musculature and pregnancy were considered as contra indicators. Two sports students with experience in exercise physiology carried out the measurements; both raters were instructed on the methods and practised until the execution was satisfactory.

All participants provided written informed consent to take part in the study in advance. This study was approved by the ethics research committee of the Goethe-University (2018–46) in Frankfurt am Main, Germany and was conducted in accordance with the 1964 Helsinki Declaration and its later amendments.

Measurement systems and ROM tests. The ROM measurements used in this study, which are described below, were evaluated with either a tape measure (Fingertip-to-Floor and Lateral Inclination test)2,6,30–33 or a digital inclinometer (Retroflexion, Shoulder and Thomas test)10,27,29,34–41 (Fig. 1). The digital inclinometer (Model: Acumar Digital Inclinometer Model ACU002 / Lafayette Instrument Company / Lafayette / USA) has a measurement accuracy comparable to a goniometer35. As the digital inclinometer shows only integers, the absolute measurement error was set to 0.3°. A detailed description of the measurement tools and the ROM tests can be found in Holzgreve et al.15.

Fingertip-to-floor test (FtF). The FtF test is used to assess the active ROM of the back, both hips, the ischiocrural musculature and the neuromeningeal structures1 (Fig. 1a). A tape measure is used to assess the distance
between the most distal point of the fingers and the floor. Accordingly, a smaller measure corresponds to a
greater flexion performance. The reliability of this test lies between \( r = 0.76 \) and \( r = 0.99^{20,30-32} \) and shows a good
sensitivity for changes\(^26\).

**Lateral inclination (LI).** This test is performed in a standardized stand position by flexing the upper body in the
frontal plane (Fig. 1.b). Sagittal fluctuations in the Lateral Inclination are eliminated by leaning the back against a
wall. The trunk lateral flexion active ROM is evaluated with a tape measure measuring the distance between the
fingertip and the floor\(^1,27\) and has an intrarater reliability of 0.95\(^42\).

**Retroflexion of the trunk after Janda in a modified version (RF).** In order to evaluate the extension of the lumbar
and thoracic spine, the modified retroflexion test according to Janda (RF) was performed\(^28\) (Fig. 1c). The participants
lay on a treatment couch with a tensioning strap located at the level of the posterior superior iliac spina,
counteracting pelvic rotation in the sagittal plane. With the hands placed next to the shoulders the participants
push and extend their elbows as far as possible. The position of the thoracic spine in the sagittal plane is deter-
mined by placing the digital inclinometer on the sternum. This test evaluates the spinal active ROM\(^1\).

**Shoulder test modified after Janda (ST).** This shoulder mobility test is a modification of the examination after
Janda\(^28\) (Fig. 1d). The ST is a passive ROM test\(^1\) which evaluates the mobility of the shoulder joint, especially of
the pectoralis major muscle. For this purpose, the subjects were positioned on the bench in a supine position.
The arm is extended in 90° abduction. In contrast to Janda, the elbow is stretched. The digital inclinometer is
then placed proximal to the processus styloideus radii on the radius.

**Modified Thomas test (TT).** The pelvic inclination must be controlled to obtain valid results\(^29\) (Fig. 1e). In order
to standardize the pelvic inclination, the digital inclinometer is placed downwards of the anterior superior iliac
spine. In this position, the alignment of the pelvis is set to 0°. The extension inclination is then measured by
placing the inclinometer on the thigh above the patella. The modified Thomas test is a widely used passive ROM
test to assess the presence of hip flexion contracture and to measure hip extensibility\(^2-29\). For both the digital
inclinometer and goniometer, high intrarater reliabilities have been reported (\( r = 0.91-0.93; \text{ICC} = 0.89-0.92 \))\(^30\).
The intrarater parallel-forms reliability is also very high with correlations of \( r = 0.91-0.93; \text{ICC} = 0.89-0.92 \)\(^30\).

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**Figure 1.** The ROM tests examined in this study: (a) Fingertip-to-Floor test; (b) Lateral Inclination test; (c)
Retroflexion of the trunk after Janda in a modified version; (d) Shoulder test modified after Janda; (e) Modified
Thomas test.
Procedure. There was no standardized warm-up, because every repetition represents a specific warm-up. All subjects performed all testing in one day. There was no familiarization prior to the testing. Each subject performed 20 repetitions in each ROM test listed above. The test order was randomized. Each test repetition had to be held on the active or passive maximum ROM (according to the test) for about three seconds. The investigator counted down from three, when the maximum ROM position was reached. At zero, the examiner recorded the ROM according to each test protocol. There was a break of 3 s between each repetition in each testing session. All measurements were carried out by two raters.

Statistical analysis. Statistical analysis was performed using BiAS version 11.08 (Epsilon-Verlag, Darmstadt, Germany) and R (R Core Team 2019)43 and figures were produced using the package ggplot244. Since no such study is known to date from which expected results can be derived and, in particular, no information on the dispersion of the data is available, no formal power analysis is carried out. The study described here is therefore to be regarded as a pilot study. To determine if an acute effect occurs at the individual level, a regression was performed on every individual’s performance. Subsequently, the number of subjects with a slope sign corresponding to an ROM gain were counted for each ROM test. According to normal distribution of the data, either univariate ANOVA with repeated measurements45 or the Friedman-test46 with multiple comparisons were conducted. These tests were performed in order to identify an overall effect and changes within 20 repetitions. Bonferroni correction was used to counteract the problem of multiple comparisons. The mean of the standard error of measurement in contralateral sides differ in ST (1.65/1.989) and TT (1.185/1.564), whereas LI shows almost identical mean values of the standard error of measurement in contralateral sides (1.005/1.005) (Table 1). Furthermore, multiple comparisons revealed the first significant ROM gain in FtF, LI-left/right, RF and ST-left after five to eight repetitions, whereas in ST-right the first significant gain occurred after 19 repetitions. However, TT-left and TT-right showed no significant changes in multiple comparisons. All repetitions were held for 3 s.

Table 1. P-values of Friedman test and ANOVA for each ROM test. Relative amount of individuals with an ROM gain, mean of the standard measurement error and number of repetitions needed to achieve 50% and 75% of the total ROM increase for each ROM test, respectively. ANOVA = 1; Friedman test = 2.

| Test                  | FtF       | Lateral Inclination     | Shoulder test   | Mod. Thomas test |
|-----------------------|-----------|-------------------------|-----------------|------------------|
|                       | Left      | Right                  | Left            | Right            |
| Friedman/ANOVA        | p < 0.001 | p < 0.001               | p < 0.001       | p < 0.001        |
| Individuals w/ROM gain| 22/22     | 18/22                   | 20/22           | 16/22            |
| Mean of standard error of measurement | 1.555     | 0.664                   | 0.665           | 0.818            |
| 50% of movement       | 5         | 5                      | 5               | 2                |
| 75% of movement       | 10        | 9                      | 9               | 3                |
|                       |           |                         |                 |                  |

Significance was set at 5%.

Ethics approval. All participants provided written informed consent to take part in the study in advance. This study was approved by the ethics research committee of the Goethe-University (2018–46) in Frankfurt am Main, Germany.

Results

Except of TT-right (p = 0.93), all ROM tests revealed significant flexibility gains within 20 repetitions, indicating changes of ROM due to repetitive stretching (FtF: p < 0.001; LI-left/right: p < 0.001/p < 0.001; RF: p = 0.009; ST-left/right: p < 0.001/p = 0.003; TT-left: p < 0.001) (Table 1). Furthermore, multiple comparisons revealed the first significant ROM gain in FtF, LI-left/right, RF and ST-left after five to eight repetitions, whereas in ST-right the first significant gain occurred after 19 repetitions. However, TT-left and TT-right showed no significant changes in multiple comparisons. All repetitions were held for 3 s.

In the individual analysis, only FtF showed a uniform effect, indicating a ROM gain for every volunteer. Furthermore, in LI-left/right and ST-left/right more than 80% of the subjects experienced a ROM gain (Table 1). In contrast, in RF and TT-left/right less than 75% of the subjects recorded a ROM gain (Table 1).

Furthermore, mean values of the standard error of measurement in contralateral sides differ in ST (1.65/1.989) and TT (1.185/1.564), whereas LI shows almost identical mean values of the standard error of measurement (0.664/0.665) (Table 1).

The non-linear regression for FtF, RF, LI-left/right, ST-left and TT-left showed a repetition dependent gradual decline in the ROM gained (Fig. 2). Hence, a plateau formation could be derived from the non-linear regression. As the non-linear model was not adequate for ST-right and TT-right a linear regression with random effects was performed to quantify the trend (Fig. 2). Whereas in ST-right a slope of at least 0.127 of ‘a’ could be derived, there was no significant difference between ‘a’ and zero for TT-right.
The parameter estimates LI-left and -right were significantly different for the parameter ‘a’ (p < 0.0001). Having successfully applied a non-linear regression on six out of the eight ROM tests, it is possible to postulate predictions on the number of repetitions needed to achieve a certain amount of maximal ROM gain (Table 2).

Discussion
Except of TT-right all ROM tests demonstrated a repetition-dependent change in ROM. In addition, six out of the eight ROM tests (FtF, RF, LI-left/right, ST-left and TT-left) showed a gradual decline in the amount of ROM gained, indicating a plateau formation (Fig. 2). The results confirm the hypothesis that ROM tests provide a stretch stimulus analogous to stretching exercises. They are consistent with repetition-dependent acute effects of stretch training conventionally demonstrated, and we propose that this effect is also present in typical ROM tests. Based on the

![Figure 2. Non-linear regression for FtF, RF, LI, ST left and TT left. Linear regression for ST right and TT right. Parameters of the function are shown below.](image)

**Table 2.** Relative ROM gain dependent on the number of repetitions for each ROM test.

| % total ROM increase | Fingertip-to-floor test | Lateral inclination | Shoulder test | Mod. Thomas test |
|---------------------|-------------------------|--------------------|---------------|-----------------|
|                     | Left | Right | Retroflexion | Left | Right | Left | Right |
| 25                  | 3 | 2 | 1 | 3 | - | 3 | - |
| 50                  | 5 | 5 | 2 | 6 | - | 6 | - |
| 60                  | 7 | 6 | 2 | 8 | - | 7 | - |
| 70                  | 9 | 8 | 2 | 10 | - | 9 | - |
| 80                  | 12 | 10 | 3 | 13 | - | 12 | - |
| 90                  | 17 | 14 | 4 | 18 | - | 17 | - |
| 95                  | 22 | 19 | 5 | 24 | - | 23 | - |
| 99                  | 32 | 28 | 8 | 36 | - | 34 | - |
Conducted regression, a plateau could be derived for each ROM test, which depicts an area where ROM gain is very small and negligible with each further repetition. The increase in mobility lies between 1 and 6 degrees and 2 and 6 cm, respectively (Fig. 2). Thus, it can be stated that a different number of repetitions performed in mobility assessment settings lead to different angle values for the ROM (Fig. 2).

For the practical application of these six ROM tests, the regression provided information on the number of repetitions above which the test offers reliable values for the evaluated ROM (Table 2). This is especially the case when different or unknown warm-up states are employed; the execution of several repetitions according to the regression can allow for a better standardization. The number of repetitions required for a certain increase in ROM is very similar amongst ROM tests which supports the stability of the applied methods.

With respect to the practical application, we recommend to assess in the area of the plateau of each test. Yet a concrete naming of a plateau should be avoided since, even in higher stretch repetitions, small gains were recognizable. However, increasing the ROM from 50% of maximal to 60% of maximal required only one or two repetitions (e.g. FtF/LI in Table 2). When approaching the plateau, more repetitions were needed to gain the same amount of ROM, for instance, to increase from 80 to 90% up to five additional repetitions were necessary (Table 2). The respective plateau formation can be derived descriptively from Fig. 2. Only the RF differed significantly from the other results. The goodness of fit of RF (adjusted R squared: 0.606; root mean square error: 0.746) was clearly worse than those of the other tests; this may be due to the fact that performing the RF requires maximum elbow extension, therefore, fatigue effects cannot be excluded when performing 20 maximum repetitions.

Although the type of stretching used in all ROM tests was static, the duration differed greatly from the duration used in static stretching. While in common ROM tests the subjects keep their positions for seconds, recommendations for static stretching range from five seconds to 15 min or even more. Here, one sees differences favoring the tape measure over the digital inclinometer regarding individual performances. Angle values obtained from protocols that differ in the application of the number of repetitions, preliminary sample measurements, different warm-up states, special warm-ups or faulty measurements with subsequent second repetitions falsify the results. Since the influence of additional repetitions on the ROM in the context of ROM tests has scarcely been investigated so far, reference must be made at this point to further, future investigations. The mean standard error of measurement of the basis for a mobility measurement on the plateau. This could serve as a basis for the comparability of ROM tests.

No exponential regression could be performed in ST-right and TT-right, whereas it could be applied for the contralateral side. Considering the mean values of the standard error of measurement for each ROM test, Table 1 shows discrepancies among contralateral sides in ST and TT. The mean standard error of measurement of the right side was considerably greater; this may explain the inconsistent data for the right side in ST and TT. In both tests, which measure the mobility of extremities, the right side showed little or no difference. The discrepancy may be due to the one-sided distribution of handedness and footedness. Biomechanical differences have been shown between left- and right-handed baseball pitchers and also for the elbow flexion, horizontal glenohumeral abduction and wrist coronal plane motion. Furthermore, discrepancies in the test protocol existed in TT and ST compared to FtF, LI and RF. In TT there was no offset visible between the measurements during the test execution. The subjects remained in a permanent strain with sub-maximal intensity. The duration of stimulus exposure was, therefore, significantly longer than in the active ROM tests, in which the stimulus was maintained for about 3 s. In addition, in ST the arm to be measured was moved through and repositioned after each measurement repetition. However, these discrepancies do not explain different contralateral results, but may lead to different interest outcomes. There are further differences between the ROM tests in the different strain methods implicitly used in the test execution that may lead to different outcomes. If the ROM tests are categorized according to the properties and effects of stretching, then differences between the tests become apparent (Table 3).

Differences in either active or passive stretching are particularly remarkable. While FtF, LI and RF tested at maximum torque, ST and TT tested at sub-maximal torque. The source of torque in ST and TT derived solely from gravity and depended on the weight, length and weight distribution of the lever-arm. As the effects between maximal and sub-maximal stretching on the ROM differed, this, may explain the discrepancies.

As our subjects were young healthy adults, further studies are needed to exploit whether this effect does also occur in impaired populations or in the elderly.
Table 3. Stretching properties (stretching type, torque type, source of torque, intensity and physiological cause for increased ROM) for each ROM test.

| Stretching type | Torque type | Source of torque | Intensity | Physiological cause for increased ROM |
|-----------------|-------------|------------------|-----------|--------------------------------------|
| Static          | Active      | Antagonist and gravity | Maximal  | Muscle/tendon stiffness ↓ stretch tolerance ↓ |
| Static          | Active      | Antagonist and gravity | Maximal  | Muscle/tendon stiffness ↓ stretch tolerance ↓ |
| Static          | Active      | Antagonist and elbow extension | Sub-maximal | Muscle/tendon stiffness ↓ |
| Static          | Passive     | Gravity           | Sub-maximal | Muscle/tendon stiffness ↓ |

Conclusion
An acute effect was observed in most ROM tests, which is characterized by a gradual decline in the amount of ROM gain. Thus, the same number of repetitions is required for the increase in ROM of 0–50% as for the increase of 50–75% of the total ROM increase. The behaviour of this acute effect could be determined using a non-linear regression for most of the ROM tests. For these tests, we can state that the acute effect described in the stretching literature of ROM also applies to the performance of typical ROM tests. Researchers and practitioners should consider this when applying ROM assessments to young healthy adults.

Data availability
There are no further data or materials than shown in this manuscript.

Received: 16 January 2020; Accepted: 17 November 2020
Published online: 10 December 2020

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Acknowledgements
All authors confirm that all methods were carried out in accordance with relevant guidelines and regulations.

Author contributions
F.H. and C.M. developed the theory and performed the computations. F.H.; L.M. and D.O. devised the project, the main conceptual ideas and proof outline. C.M. worked out almost all of the technical details. N.F. verified the analytical Methods. F.H.; L.W.; L.P.; E.K.; A.S.; J.I.; M.M.K.; L.M. and D.O. carried out the experiment. F.H. wrote the manuscript with support from C.M.; N.F.; L.M.; A.v.M. and D.A.G. D.A.G. and D.O. helped supervise the Project. C.M. and N.F. developed the theoretical formalism, performed the analytic calculations and performed the numerical simulations. All authors discussed the results and contributed to the final manuscript.

Funding
Open Access funding enabled and organized by Projekt DEAL.
Competing interests
The authors declare no competing interests.

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