Isometric Rate of Force Development, Maximum Voluntary Contraction, and Balance in Women With and Without Joint Hypermobility

CHRISTINE MEBES,1 ASTRID AMSTUTZ,1 GERE LUDER,1 HANS-RUEDI ZISWILER,1 MATTHIAS STETTLER,2 PETER M. VILLIGER,1 AND LORENZ RADLINGER2

Objective. To determine differences between hypermobile subjects and controls in terms of maximum strength, rate of force development, and balance.

Methods. We recruited 13 subjects with hypermobility and 18 controls. Rate of force development and maximal voluntary contraction (MVC) during single leg knee extension of the right knee were measured isometrically for each subject. Balance was tested twice on a force plate with 15-second single-leg stands on the right leg. Rate of force development (N/second) and MVC (N) were extracted from the force-time curve as maximal rate of force development (\( \Delta \text{force}/\Delta \text{time} \)) and the absolute maximal value, respectively.

Results. The hypermobile subjects showed a significantly higher value for rate of force development (15.2% higher; \( P = 0.038, P = 0.038, \epsilon = 0.693 \)) and rate of force development related to body weight (16.4% higher; \( P = 0.018, P = 0.018, \epsilon = 0.601, \epsilon = 0.601 \)) than the controls. The groups did not differ significantly in MVC (\( P = 0.767, P = 0.767, \epsilon = 0.136, \epsilon = 0.136 \)), and MVC related to body weight varied randomly between the groups (\( P = 0.921, P = 0.921, \epsilon = 0.065, \epsilon = 0.065 \)). In balance testing, the mediolateral sway of the hypermobile subjects showed significantly higher values (11.6% higher; \( P = 0.034, P = 0.034, \epsilon = 0.050, \epsilon = 0.050 \)) than that of controls, but there was no significant difference (4.9% difference; \( P = 0.953, P = 0.953, \epsilon = 0.000, \epsilon = 0.000 \)) in anteroposterior sway between the 2 groups.

Conclusion. Hypermobile women without acute symptoms or limitations in activities of daily life have a higher rate of force development in the knee extensors and a higher mediolateral sway than controls with normal joint mobility.

Introduction

Even though joint hypermobility and the benign generalized joint hypermobility (BGJH) syndrome are frequent and important phenomena in rheumatology, they have not received adequate attention and are still not sufficiently understood. Perceived joint instability and a higher risk for joint distortions and dislocations, especially in the lower extremities, are the major problems in affected persons (1).

Joint stabilization is based on both passive and active components. Passive mechanisms, including joint morphology and elastic properties of soft tissue structures (stiffness), have been investigated in several studies that showed differences in collagen type distribution and reduced tissue stiffness in patients with BGJH syndrome compared with controls with normal mobility (2,3). Active components are mainly based on neuromuscular properties and muscular strength. However, there is only a limited amount of literature on the subject, and the mechanisms of neuromuscular active joint stabilization are not well understood.

Less precise knee proprioception (4) and reduced balance (5) have been described for subjects with hypermobility syndrome. Changes in muscle reflexes have been mentioned as a possible explanation, indicating subtle neurophysiologic abnormalities (6), but it has been shown by Ferrell et al that adequate treatment improves proprioception as well as balance (5). Moreover, not only does strength and balance training improve strength and balance, but it also reduces pain and thus has a positive effect on quality of life (5). However, in their study, Ferrell and colleagues remained unclear about the exact training protocol concerning velocity and type of muscle contraction.

1Christine Mebes, PT, Astrid Amstutz, PT, Gere Luder, PT, Hans-Ruedi Ziswiler, MD, Peter M. Villiger, MD: University Hospital Bern, Bern, Switzerland; 2Matthias Stettler, PT, Lorenz Radlinger, PhD: Bern University of Applied Sciences, Bern, Switzerland.

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Address correspondence to Christine Mebes, PT, Department of Rheumatology, Clinical Immunology, and Allergology, University Hospital Bern, BHH B116, CH-3010 Bern, Switzerland. E-mail: christine.mebes@insel.ch.

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as well as training methods. With exercise physiology, it is important to keep in mind that muscle strength, as a sensorimotor skill, has to be differentiated into categories such as maximum strength, strength endurance, and rate of force development. Maximum strength is defined as the highest voluntary force possible under dynamic concentric, dynamic eccentric, or isometric muscle action conditions, and is limited by muscle fiber recruitment and frequency of action potentials. Strength endurance is the resistance against fatigue under anaerobic strength conditions and is based on anaerobic capacity. The rate of force development describes the ability for fast force generation (7).

Major daily life activities such as gait and stair climbing are based on specific strength requirements, especially the rate of force development. Although these activities seem to be quite slow and undemanding, the analysis of ground reaction forces measured with force plates shows high and fast force developments. During normal gait, for instance, weight acceptance is typically reached in ∼150–300 msec and, in this period, the peak force reaches 1.2 times the body weight on a single leg (8). During stair climbing, even shorter times occur. Mean values of 146 msec and 168 msec were reported for descending and ascending stairs, respectively, with peak forces of 1.6 times the body weight in descent and 1.2 times the body weight in ascent (9). In sports like running, volleyball, or basketball, even shorter impact times and higher impact loads were described (10). Finally, the muscular reaction has to occur within 120 msec to prevent ankle distortions. Without an adequate rate of force development in the corresponding muscles, such a reaction is not possible and an injury will result (11).

These short time intervals for muscular contraction indicate that rate of force development is an important factor for joint stabilization. Subjects with BGJH syndrome often mention problems with stabilization in daily life or sports (2); therefore, the role of rate of force development may be even more important for them than for healthy individuals.

The lack of knowledge concerning the necessity of strength abilities, especially rate of force development but also balance, in hypermobile subjects led to the research question of the present study: is there a difference between hypermobile subjects and controls in maximum strength, rate of force development, and balance?

Patients and Methods

Patients. Women with hypermobility (n = 13) and a control group of women with normal mobility (n = 18) were recruited ad hoc from the staff of the University Hospital Bern, the student body of the Bern University of Applied Sciences, and from additional sources. Potential participants were recruited by posting fact sheets with information on hypermobility and the Beighton score in the above institutions. Interested women were screened over the phone with a pretest that checked their joint mobility, and only subjects presumed to meet the criteria for either the hypermobile or the control group were selected.

In the hypermobility group, the mean ± SD age was 28.1 ± 6.4 years, the mean ± SD height was 1.69 ± 0.06 meters, the mean ± SD body weight was 60.3 ± 8.2 kg, and the mean ± SD body mass index (BMI) was 21.0 ± 2.2 kg/m². In the control group, the mean ± SD age was 27.2 ± 4.6 years, the mean ± SD height was 1.68 ± 0.06 meters, the mean ± SD body weight was 60.0 ± 5.7 kg, and the mean ± SD BMI was 21.3 ± 1.7 kg/m². There were no significant group differences in baseline data concerning age, height, weight, and BMI (P > 0.05). The hypermobile group had a significantly higher Beighton score (12) than the controls (mean ± SD 7.6 ± 1.1 versus 0.5 ± 0.5; P < 0.001). This is consistent with the following major inclusion criteria: women ages 18–40 years, BMI range 18–30 kg/m², without pain or other clinically relevant problems. Because it is well known that pain considerably affects strength testing, subjects with pain or clinically relevant problems were excluded in order to guarantee a regular strength test performance in this first of a series of investigations.

The hypermobile group was additionally defined by a Beighton’s scoring system ≥6. Beighton’s scoring system (12) is based on the following movements: 1) passive dorsal flexion of the little finger beyond 90°; 2) passive opposition of the thumbs to the flexor aspect of the forearm; 3) hyperextension of the elbows beyond 10°; 4) hyperextension of the knees beyond 10°; and 5) forward flexion of the trunk, with the knees straight, so that the palms of the hands rest easily on the floor. Tests 1–4 are bilateral, giving a total score between 0 and 9 points. Due to the planned strength testing of the lower right extremity only, hypermobile subjects in the current study had to fulfill mandatory criteria 4 and 5 on the right side.

Exclusion criteria were surgeries or traumas of the lower leg or lumbar spine or pregnancy within the past 2 years. Subjects with a known diagnosis of Marfan’s syndrome, Ehlers-Danlos syndrome I and II, or osteogenesis imperfecta were also excluded.

Study design. This was a prospective experimental cross-section pilot study. Each study participant was examined on only 1 occasion. Investigation of inclusion criteria, including Beighton score, was done by an independent physiotherapist. All other measurements were performed by blinded assessors. The study was approved by the Canton of Berne’s Ethics Committee and all subjects gave written informed consent.

Strength testing. Rate of force development and maximal voluntary contraction during single leg knee extension of the right knee were measured isometrically for each subject on a knee extension device while sitting. The hip and knee joints were fixed at a 90° angle. At the lower end of the tibia a sling was attached, linked to a unidimensional strain gauge, which was calibrated in newtons (N). For rate of force development and maximum voluntary contraction (MVC), each study participant was instructed to perform a maximal fast force rise and to maintain maximal contraction for 3 seconds. The test was exercised in detail after verbal instructions and with the tester’s concurrent feedback about the subject’s performance and movement quality, and participants watched visible force
time curves on a computer monitor. After these preliminary test exercises and a 2-minute break, MVC and rate of force development were measured 3 times without visual feedback, with 15 seconds of rest between trials.

Force data were collected by a force transducer (KM 1500S; Megatron, Munich, Germany), amplified by a measuring amplifier (UMVE; uk-labs, Kempen, Germany), and converted by a 12-bit analog-to-digital converter (Meilhaus ME-2600i; SisNova Engineering, Zug, Switzerland). Force was sampled at a rate of 1 kHz and the signal was filtered by a band pass of 10–500 Hz (Butterworth, 24 dB/oct). Force-time measurements were recorded with the Analog/Digital Signal Analysis software (ADS, uk-labs).

**Balance testing.** Balance was tested twice on a force plate (Kistler, Winterthur, Switzerland) with 15-second single-leg stands on the right leg, with eyes open. Data recording of anteroposterior and mediolateral sway followed the above procedure, were calculated by root mean square algorithm, and averaged over 15 seconds.

**Signal analysis and statistics.** Rate of force development (N/second) and MVC (N) were extracted from the force-time curve as maximal rate of force development (\( = \text{limit} \Delta \text{force}/\Delta \text{time} \)) and the absolute maximal value, respectively. The averages for the 3 trials were calculated and, in a second step, were related to individual body weight (kg bw). Anteroposterior sway (mm) and mediolateral sway (mm) were determined for balance and averaged for the 2 trials. Test–retest reliability of measurements was first individually calculated by SD, representing absolute values, and by mean to SD ratio, representing a relative value. Individual absolute and relative values were then averaged over all subjects. Additionally, the Spearman’s rank correlation coefficient and significance between trials were estimated.

In test–retest reliability, the anteroposterior sway varied by 1.2 mm (18.1%, \( P = 0.244, P = 0.111 \)) and the mediolateral sway varied by 0.5 mm (11.6%, \( P = 0.402, P = 0.006 \)). The rate of force development varied by 476.6 N/second (15.4%, 0.529 \( \leq \rho \leq 0.688, P < 0.001 \)) and the MVC varied by 14.1 N (3.9%, 0.858 \( \leq \rho \leq 0.935, P < 0.001 \)). Therefore, the 3 trials of strength testing and the 2 trials of balance testing were averaged to improve reliability. Descriptive statistical data of MVC and rate of force development during knee extension are presented as means and 95% confidence intervals. The significance of the differences between the 2 independent groups in terms of baseline, strength, and balance data was calculated with the nonparametric Mann-Whitney U test using SPSS software, version 15.0 (SPSS, Chicago, IL). All statistical tests were 2-tailed, and \( P \) values less than or equal to 0.05 were considered significant. Statistical power (\( P = 1-\beta \) error probability) and effect size (\( \epsilon \)) of strength and balance data were calculated post hoc with GPower, version 3.0.4 (13).

**Results**

The hypermobile group showed a significantly higher value (15.2% higher) for rate of force development (mean \( \pm \text{SD} \) 3,270 \( \pm \) 781 N/second) than the control group (mean \( \pm \text{SD} \) 2,779 \( \pm \) 627 N/second) \( (P = 0.038, P = 0.453, \epsilon = 0.693) \). In rate of force development related to body weight, the hypermobile group (mean \( \pm \text{SD} \) 53.9 \( \pm \) 8.7 N/second/kg bw) also had significantly higher values (16.4% higher) than the control group (mean \( \pm \text{SD} \) 46.3 \( \pm \) 9.5 N/second/kg bw; \( P = 0.018, P = 0.601, \epsilon = 0.834 \)) (Figure 1).

In MVC, the hypermobile group (mean \( \pm \text{SD} \) 357 \( \pm \) 57 N) did not differ significantly from the control group (mean \( \pm \text{SD} \) 365 \( \pm \) 61 N) \( (P = 0.767, P = 0.136, \epsilon = 0.065) \). Similarly, MVC related to body weight varied randomly between the control group (mean \( \pm \text{SD} \) 6.0 \( \pm \) 0.75 N/kg bw) and the hypermobile group (mean \( \pm \text{SD} \) 6.0 \( \pm \) 0.58 N/kg bw; \( P = 0.921, P = 0.050, \epsilon = 0.000 \)) (Figure 2).

In balance testing, the mediolateral sway of the hypermobile group (mean \( \pm \text{SD} \) 4.8 \( \pm \) 0.6 mm) showed significantly higher values (11.6% higher) than that of controls (mean \( \pm \text{SD} \) 4.3 \( \pm \) 0.9 mm) \( (P = 0.034, P = 0.050, \epsilon = 0.000) \), but there was no significant difference (4.9% difference) in anteroposterior sway between hypermobile subjects (mean \( \pm \text{SD} \) 6.1 \( \pm \) 1.2 mm) and controls (mean \( \pm \text{SD} \) 6.4 \( \pm \) 2.0 mm) \( (P = 0.953, P = 0.050, \epsilon = 0.000) \).

**Discussion**

The main result of this pilot study is the significantly higher rate of force development of the hypermobile group compared with the control group. A possible explanation is that, for daily life activities using the lower extremities like gait and stair climbing, fast muscle reactions are common and often used, generally in both groups (8,9). As
earlier studies have shown, rate of force development is thought to be important for fast joint stabilization. Therefore, subjects with hypermobility need more joint stability by means of active and neuromuscular mechanisms, especially rate of force development, because they have less stability due to the laxity of their passive structures (2). Subjects in the present study, although formally fulfilling the criteria for hypermobility, did not experience severe symptoms or problems in daily life activities or sports. Perhaps this was due to their increased rate of force development.

In contrast, no significant differences in MVC were found between the 2 groups. Maximum strength may not be very important for joint stabilization and, therefore, maximum strength of the lower extremities may be an unusual requirement for the daily life of healthy individuals. Perhaps this was due to their increased rate of force development.

In agreement with the results of Ferrell and colleagues (5), balance testing showed that the mediolateral sway in the hypermobile group was higher compared with that in the control group, which was not true for the anteroposterior sway. A possible explanation could be that hypermobile subjects can stabilize their knees in the anteroposterior direction with their leg muscles, especially using their higher rate of force development of knee extensors. In the mediolateral direction, active stabilization is not possible to the same extent; thus, passive stabilization, which hypermobile subjects have more problems with, would be more important.

One conclusion of these results is that isometric MVC is perhaps not an ideal parameter to represent daily life activities. MVC testing does not always correspond to daily life activities and, in this case, does not distinguish subjects in the hypermobile group from subjects with normal mobility. It was shown that the diminished ability to rapidly generate knee extension torque contributes more to decreased walking speed than reduced maximal strength, but this is only true for patients after stroke (14) and patients with spastic paresis (15). Consequently, it is recommended to measure rate of force development rather than MVC because rate of force development is the more sensitive and adequate parameter.

A limitation of the present study is that, despite the high effect sizes, the statistical power of the rate of force development tests is barely sufficient due to the sample size. Thus, a larger sample size (n ≥16 for a hypermobile group and n ≥22 for a control group) would be needed for further studies in order to achieve statistical power >0.8.

For the future, it should be kept in mind that the subjects of the present study did not have any acute symptoms or serious problems in daily life activities. Consequently, it might be interesting to investigate whether hypermobile subjects with recurrent microtraumas or severe pain of the knee or ankle also show a higher rate of force development than controls.

In summary, this investigation showed that hypermobile women without acute symptoms or limitations in activities of daily life have a higher rate of force development in the knee extensors than controls with normal joint mobility. This difference may be explained with those daily life activities that demand good rate of force development for joint stabilization. Consequently, measuring rate of force development may be a more adequate parameter than maximum strength to identify the functional abilities of patients with hypermobility in gait and stair climbing.

**AUTHOR CONTRIBUTIONS**

Ms Mebes had full access to all of the data in the study and takes responsibility for the integrity of the data and the accuracy of the data analysis.

**Study design.** Mebes, Amstutz, Luder, Ziswiler, Villiger, Radlinger.

**Acquisition of data.** Mebes, Amstutz, Luder, Radlinger.

**Analysis and interpretation of data.** Mebes, Amstutz, Luder, Villiger, Radlinger.

**Manuscript preparation.** Mebes, Amstutz, Luder, Ziswiler, Stettler, Villiger, Radlinger.

**Statistical analysis.** Luder, Radlinger.

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