ABSTRACT: Impaired position sense and impaired joint reaction angle of the lower limbs after muscle-damaging activities is a serious functional limitation that may lead to an increased risk of injury, particularly in older populations. The purpose of the present study was to examine whether position sense and joint reaction angle to release can be affected by eccentric exercise–induced muscle damage. Twelve women underwent an isokinetic exercise session of the lower limb. Isometric peak torque, delayed-onset muscle soreness, serum creatine kinase, position sense, and knee joint reaction angle to release were examined before, immediately after, and 24, 48, and 72 h post-exercise. Due to the effect of eccentric exercise, subjects persistently placed their lower limb at a more extended position, representing a shorter knee extensor muscle. Eccentric exercise increased the knee reaction angle of the lower limb after release from 0° and 15° but not from 30° and 45°. Position sense and joint reaction to release were similarly affected by eccentric exercise and independently of visual feedback. Position sense was impaired only immediately post-exercise (probably due to muscle fatigue), whereas impairment of the reaction angle to release persisted up to 3 days post-exercise (probably due to muscle damage). Attenuation of position sense and joint reaction angle of the lower limbs after damaging activities is a serious functional limitation that may lead to an increase risk of injury, particularly in older populations.

THE EFFECT OF ECCENTRIC EXERCISE ON POSITION SENSE AND JOINT REACTION ANGLE OF THE LOWER LIMBS

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Although skeletal muscle is extremely elastic, muscle damage may occur in response to eccentric exercise18 and is characterized by sustained loss of muscle force and range of motion,22,29,32 histologic disturbance of muscle and connective tissue, large increases of muscle proteins and oxidative stress in the blood, and development of delayed-onset muscle soreness (DOMS) and swelling.1,5,7,8,33 These changes typically begin approximately 6 h after unaccustomed exercise, peak at 24–72 h, and subside 3–7 days after exercise.1,42 Adequate position sense is required for capable and safe human movement. Disturbed position sense (particularly of the lower limbs) may lead to perturbations in daily activities (such as walking) and ultimately to injuries. Position sense is normally expected to be disturbed after muscle-damaging exercise. Eccentric exercise of the upper limbs disturbs position sense in the exercised arm.3,26,37,39,41 Studies that have examined the effect of eccentric exercise on position sense used muscles of the upper limb.3,26,37,39,41 However, it is a common experience that we feel unsteady on our legs and have difficulty in performing common movements after some activities such as downhill walking. This may relate to diminished position sense of the lower limbs and may increase the risk for injuries. To our knowledge, no study has investigated the effect of eccentric exercise on position sense of the lower limb.

Abbreviations: ANOVA, analysis of variance; CK, creatine kinase; DOMS, delayed-onset muscle soreness

Key words: creatine kinase; delayed-onset muscle soreness; isokinetic peak torque; joint reaction angle; position sense

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Muscle reaction time is defined as the time from a stimulus to the beginning of a muscle response, and has been used frequently in the evaluation of motor performance.\textsuperscript{9,13,24} It is frequently measured by asking a subject to move the limb from a resting position to a reference position as rapidly as possible in response to a visual or auditory stimulus.\textsuperscript{14,19,20,26} Two studies investigated the effect of eccentric exercise on muscle reaction time of the upper limbs after a light stimulus and produced contrasting results.\textsuperscript{8–10,26} The stimulus in these studies originated from an external source (vision) rather than the muscle. For the present investigation, a new test was developed that measures the reaction angle of the lower limb in response to a stimulus (free fall) originating from the muscle itself.

To our knowledge, there are no data regarding the effect of eccentric exercise on position sense and muscle reaction time of the lower limbs. As the lower limbs play a major role in body movements during exercise and everyday activities, the primary purpose of the present study was to examine whether position sense and joint reaction angle to release can be affected by eccentric exercise–induced muscle damage. Additionally, we present a new test for measuring joint reaction angle to release, performed in a common isokinetic dynamometer.

**MATERIALS AND METHODS**

**Subjects.** Twelve healthy untrained women (age 20 ± 1 years, height 168 ± 1 cm, mass 57 ± 2 kg) took part in the study. Subjects had no experience with eccentric exercise training for at least 6 months prior to the study and were not taking anti-inflammatory drugs. They were instructed to abstain from strenuous exercise for 3 days prior to and during data collection. All volunteers were eumenorrheic (reporting their menstrual cycle as lasting 24–30 days). The eccentric exercise trial fell within the luteal phase, during which estrogen concentrations are more stable and higher than during the follicular phase. Subjects read and signed an informed consent form. The study was approved by our institutional review board.

**Research Design and Measurements.** An isokinetic eccentric exercise protocol was undertaken by all participants in their dominant leg while the other leg served as control. DOMS, isometric peak torque, position sense, and knee joint reaction angle to release were examined before, immediately after, and 24, 48, and 72 h post-exercise. Serum creatine kinase (CK) activity was determined at the same time-points, except for immediately after exercise. Each subject was familiarized with the experimental procedures by performing all assessments prior to formal measurements.

**Isokinetic Exercise Protocol.** An isokinetic dynamometer (Cybex Norm, Ronkonkoma, New York) was calibrated weekly according to the manufacturer’s instructions. Subjects were seated (120° hip angle) with the lateral femoral condyle aligned with the axis of rotation of the dynamometer, and were coupled to the dynamometer by an ankle cuff attached proximal to the lateral malleolus. The position of each subject was recorded and used in follow-up measurements. Each subject’s functional range of motion was set electronically between full extension (0°) and 120° of knee flexion to prevent hyperextension and hyperflexion. Gravitational corrections were made to account for the effect of limb weight on torque measurements. Feedback of the intensity and duration of eccentric exercise was provided automatically by the dynamometer.

Prior to each exercise session, subjects performed a warm-up consisting of 8-min cycling on a cycle ergometer (Monark, Vansbro, Sweden) at 70 rpm and 50 W, followed by 5 min of ordinary stretching exercises of the major muscle groups of the lower limbs. Exercise sessions consisted of eccentric contractions of the knee extensors of the dominant lower limb at an angular velocity of 60°.s\textsuperscript{−1} (knee range, 0° to 90°), while the other leg served as control limb. In each exercise session, subjects had to accomplish 5 sets of 15 eccentric maximal voluntary contractions in the seated position as previously described.\textsuperscript{2,15,35} A 2-min rest interval was incorporated between sets.

**Muscle Damage Indices.** Each subject determined soreness of the exercised lower limb by self-palpation of the muscle belly and the distal region of the vastus medialis, vastus lateralis, and rectus femoris in a seated position with the muscles relaxed. Perceived soreness was then rated on a scale ranging from 1 (normal) to 10 (very sore) as previously suggested.\textsuperscript{7,21}

The isokinetic dynamometer was used for the measurement of isometric peak torque of quadriceps femoris at 90° knee flexion.\textsuperscript{22,23,30–32} The best of three maximal voluntary contractions was recorded. There was a 1-minute rest between isometric efforts. Prior to the maximal voluntary contractions, all subjects were familiarized with the experimental procedure.
Blood samples were drawn from an antecubital vein into plain evacuated test tubes. The blood was allowed to clot at room temperature for 30 min and centrifuged at $1500 \times g$ for 10 min. The serum layer was removed and frozen at $-30^\circ C$ until analyzed. Serum CK was determined spectrophotometrically (Spectronic 401; Milton Roy, Rochester, New York) in duplicate using a commercially available kit (Spin-react, Sant Esteve, Spain). The reference range of serum CK activity for females according to this method is up to 170 U.L$^{-1}$ at $37^\circ C$.

**Position Sense at the Knee.** Subjects sat upright on the isokinetic dynamometer (with the trunk tilted back at a $120^\circ$ hip angle) while the evaluation was performed with or without visual feedback (i.e., blindfolded) in random order. During the evaluation with visual feedback, the limb was in the visual field of the subjects. All assessments were performed on both lower limbs (the non-dominant limb was the control limb) in random order. The angles were automatically recorded by the dynamometer. During determination of the perception of knee joint angle, the limb was moved from full extension ($0^\circ$) to $90^\circ$ knee flexion in order to familiarize subjects with the range of motion. Then the investigator positioned the limb at the reference angle ($45^\circ$), maintained it for 10 s, and returned the lower limb to the initial position ($90^\circ$). Afterwards, subjects were asked to remember where the reference position was ($45^\circ$) and reproduce it from memory. Subjects actively moved their limb to the target angle and, when they were satisfied with the angle they had selected, they would hold it for about 2 s. The direction and degrees deviating from the reference angle were recorded. Four efforts were performed and the two best were recorded. The test–retest reliability in the joint reaction angle to release with or without visual feedback (measured in 4 individuals on 5 consecutive days) was 0.95 and 0.96, respectively.

**Knee Joint Reaction Angle to Release.** The isokinetic dynamometer was also used for the new test developed for the evaluation of reaction angle of the lower limb. The subjects sat upright ($120^\circ$ hip angle) while the evaluation was performed with or without visual feedback. All assessments were performed on both lower limbs, with the non-dominant limb serving as the control limb. The angles were automatically recorded by the dynamometer. The lower limb was passively positioned by the investigator at one of the four different angles ($0^\circ$, $15^\circ$, $30^\circ$, and $45^\circ$) in random order. When muscles of the lower limb relaxed at the predetermined angle, the investigator without warning let the limb fall. The muscle belly was palpated by the investigator to ensure muscle relaxation. The instruction given to the subjects was to stop the fall of the limb as soon as it was perceived as being released. The angle through which the leg moved before the subjects managed to stop the motion was recorded and considered the knee joint reaction angle to release. Four trials were performed and the two best were recorded. The test–retest reliability in the joint reaction angle to release with or without visual feedback (measured in 4 individuals on 5 consecutive days) was 0.98 in both cases.

**Statistical Analysis.** The distribution of all dependent variables was examined by the Kolmogorov–Smirnov test and was found not to differ significantly from normal, except for serum CK values. We used two-way analysis of variance (ANOVA; state × time) with repeated measurements on time to analyze DOMS and isometric peak torque. Serum CK activity was analyzed non-parametrically by Friedman’s test. Position sense and knee joint reaction angle to release were analyzed by three-way ANOVA (state × visual feedback × time) with repeated measurements on time. If a significant interaction was obtained, pairwise comparisons were performed through contrasts analysis. The test–retest reliability of the position sense and reaction angle test were determined by performing the intraclass reliability test. Data are presented as mean ± SEM. The level of significance was set at $\alpha = 0.05$. SPSS version 13.0 was used for all analyses (SPSS, Inc., Chicago, Illinois).

**RESULTS**

**Muscle Damage Indices.** All muscle damage indices are presented in Figure 1. Isometric peak torque
decreased immediately, and at 24 h and 48 h following eccentric exercise in the test limb (\(P < 0.05\)), whereas no changes were noted at any time-point in the control limb. Compared to baseline data, DOMS and serum CK activity increased (\(P < 0.05\)) at all time-points after exercise.

**Position Sense at the Knee Joint Angle at Absolute Values.** Eccentric exercise disturbed position sense at the knee joint angle, as measured through degrees (in absolute values) deviating from the reference angle only immediately after exercise (\(P < 0.05\)), regardless of whether the trial was performed with visual feedback (Fig. 2). In all trials, subjects placed their limbs in a more extended position (i.e., produced negative degree values). Independent of exercise, there were no significant differences in position sense with or without visual feedback.

**Knee Joint Reaction Angle to Release.** Eccentric exercise increased the knee joint reaction angle to release from 0° and 15° (main effect of exercise, \(P < 0.05\)), independent of visual feedback, at most of the post-exercise time-points (Fig. 4). In contrast, the knee joint reaction angle to release from 30° and at 45° remained unaffected by eccentric exercise, independent of visual feedback (Fig. 5).

**DISCUSSION**

The main purpose of the present study was to determine whether an eccentric exercise session designed to cause muscle damage could affect position sense and reaction angle to release of the knee joint of the lower limb. To this end, a new test performed on a common isokinetic dynamometer measuring knee joint muscle reaction angle to release was developed.
We found that eccentric exercise induced muscle damage and impaired position sense immediately after exercise; indeed the limb was constantly extended relative to the reference angle at 45°. Additionally, eccentric exercise increased the knee reaction angle of the lower limb (measured by the new test) after release from 0° and 15° up to 72 h, but not from 30° and 45°.

The special feature of our new test is that it measures the reaction angle of the knee joint by receiving the signal of release from the very muscles of the knee joint. That is, the knee joint receives information for alteration in its position from proprioceptors. In contrast, in other frequently used tests, subjects respond to a visual or auditory stimulus, receiving information for its position from exteroceptors. There are many situations in real life in which a person has to react to stimuli originating from impulses other than visual or auditory ones. This situation may occur, for example, when a person stumbles. Another advantage of the new test is that it does not require any special construction or equipment except for a common isokinetic dynamometer.

We found that eccentric exercise disturbed position sense. That is, after exercise the subjects felt that knee extensors were longer than they actually were and so they adopted a position representing a shorter muscle length, placing the lower limb in a more extended position. The most relevant studies to ours are those that have measured position sense after non-eccentric exercise. In general, these studies also reported disturbances to position sense at the knee after the non-eccentric exercise. Additionally, studies that eccentrically exercised the flexor muscles of the elbow reported (in agreement to our findings) impairment of position sense after eccentric exercise of the elbow flexors with subjects placing the exercised arm in a more extended position.

Overall, our position sense data indicate that the subjects placed their limb in a more extended position relative to the reference angle. Because it is generally agreed that signals from muscle spindles contribute to the sense of position and movement of the limbs, it has been proposed that the rise in passive tension after eccentric exercise can mechanically unload muscle spindles. Unloading of muscle spindles can lower their passive discharge rates, leading subjects to flex their muscles more by extending the knee joint. In contrast, in a recent investigation, eccentric contractions of cat muscle did not appear to affect the function of muscle spindles. Another possible explanation for subjects thinking that their muscles were longer than they really were is that, during the position sense test, the subjects supported their limb themselves, which means that knee extensors were contracting during angle reproduction. Therefore, at least some spindles were activated. After eccentric exercise, more muscle activation would be necessary to support the limb, leading to a greater degree of spindles activation and perhaps to a shorter muscle length. We are not aware of any other comparable study, and more studies are needed to substantiate unequivocally whether the function of muscle spindles is affected by eccentric exercise.

A quite unexpected finding of the present study is that vision did not alter position sense. It has been reported that the ability to determine the position of the upper limb in space tends to degrade during visual occlusion, implying that proprioception drifts when it is not calibrated by vision. By contrast, other studies failed to reveal a deterioration in ability to estimate upper-limb location when vision was occluded. In all these previous studies, position sense was assessed in the upper limbs and not in the...
lower limbs as in this study. Additionally, in all these previous studies, position sense was assessed by matching one-upper limb posture with the other limb whereas, in the present investigation, position sense was investigated by subjects trying to match an angle previously shown in the same lower limb. As a result, due to these methodological dissimilarities, no direct comparisons can be made between the present study and those mentioned earlier.

Knee Joint Reaction Angle to Release. Control of a single-joint movement is provided by two types of receptors: proprioceptors, which detect stimuli generated by the system itself, and exteroceptors, which detect external stimuli. With the information provided by these receptors, the single joint is able to organize a rapid response to a disturbance in its position. Proprioceptors include muscle spindles, tendon organs, and joint receptors. Exteroceptors include the eyes, ears, and skin.

We found that eccentric exercise increased the reaction angle to release from 0° and 15°. It has been reported that some sarcomeres are disrupted and therefore non-functioning, so that the number of functioning sarcomeres in series can be decreased acutely after eccentric exercise, leading to reduced ability to maintain muscle tension during contraction. This would slow the speed of shortening of a muscle fiber and thus slow the rate of rise of tension. Therefore, the eccentrically exercised muscle cannot equal the tension developed by the undamaged muscle in response to lower-limb release. In addition, the total series compliance of muscle fibers would be expected to be increased due to the presence of disrupted sarcomeres, leading to delayed tension rise in response to stretch. If quadriceps femoris compliance had increased after the eccentric exercise, perhaps quadriceps femoris needed to be stretched further before spindles signalled the fall of the lower limb. Although muscle spindles are considered the most important peripheral receptors for the sensation of position and movement in humans, joint and skin receptors may also contribute. Therefore, disturbances in the signals provided by receptors at the knee joint and skin after eccentric exercise could also contribute to increases in reaction angle to free fall.

Why was there an increase in muscle reaction time only after release from 0° and 15°, and not after release from 30° and 45°? The knee-joint flexion movement produced by the weight of the calf and

**FIGURE 4.** The effect of eccentric exercise on knee-joint reaction angle to release from 0° with (a) or without (b) visual feedback and from 15° with (c) or without (d) visual feedback in the control (dashed curve) and test (solid curve) limb (mean ± SEM). Pre, pre-exercise; Immed, immediately after exercise. *Significantly different from the pre-exercise value (P < 0.05); #significantly different from the control limb at the same time-point (P < 0.05).
foot depends on the cosine of knee-joint angle and it is at a maximum level at $0^\circ$. The difference therefore may be due to the higher velocity of the fall of the lower limb when it falls from full (at $0^\circ$) or almost full extension ($15^\circ$), as compared to angles in more flexed positions (at $30^\circ$ and $45^\circ$). Therefore, it seems that eccentric exercise affects reaction angle of the lower limb only after a release requiring a high-speed response. Type II muscle fibers are mainly responsible for high-speed contractions, and it is well-described that this fiber type is preferentially damaged during eccentric exercise. Consequently, the need for rapid response after fall at or near extension is considerably impaired after eccentric exercise, due to the relatively greater damage of type II fibers. Consequently, the need for rapid response after fall at or near extension is considerably impaired after eccentric exercise, due to the relatively greater damage of type II fibers. Another possible reason for this difference is the higher discomfort the subjects feel due to the muscle damage at angles where the limb is in a more extended position ($0^\circ$ and $15^\circ$ compared to $30^\circ$ and $45^\circ$), because a higher level of contraction is needed to maintain the lower limb in the more extended position.

It is worth noting that joint reaction to release (as was the case also in position sense) is affected by exercise similarly and independently of visual feedback. Hence, based on our findings, it is evident that muscle reacts more rapidly to a stimulus acting on it (free fall) than to a visual stimulus. From a mechanistic point of view, it seems that position sense provided by exteroceptors (i.e., sensors outside of muscle) does not offer a more rapid response than that offered by proprioceptors inside muscle alone. In agreement with our findings, other investigators have found that position sense is not disturbed after visual occlusion.

**Time Course of Changes in Position Sense and Reaction Angle at the Knee to Release.** We observed a different time course of position sense and reaction angle to release from $0^\circ$ and $15^\circ$ after eccentric exercise, which points to differences in the potential mechanisms governing position sense and reaction angle. Position sense, either measured in absolute or actual values, was impaired only immediately after exercise. This finding suggests that the primary mechanism responsible is the accumulation of metabolites that occurs shortly after exercise. This mechanism, however, cannot explain the persistent impairment in reaction angle to release for up to 3 days during recovery, at a time when all exercise-induced metabolites would have been removed. These prolonged changes in reaction angle suggest that muscle damage occurring 24–72 h after exercise is the main contributor to this effect.
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