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ORIGINAL ARTICLE

Damage protective effects conferred by low-intensity eccentric contractions on arm, leg and trunk muscles

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Abstract

Purpose Low-intensity eccentric contractions with a load corresponding to 10% of maximal voluntary isometric contraction strength (10% EC) attenuate muscle damage in a subsequent bout of higher-intensity eccentric contractions performed within 2 weeks for the elbow flexors, knee flexors and knee extensors. However, it is not known whether this strategy could be applied to other muscles. This study investigated whether 10% EC would confer damage protective effect on high-intensity eccentric contractions (80% EC) for nine different muscle groups.

Methods Untrained young men were placed to an experimental or a control group ($n = 12$/group). Experimental group performed 50 eccentric contractions with a load corresponding to 10% EC at 2 days prior to 50 eccentric contractions with 80% EC for the elbow flexors and extensors, pectoralis, knee flexors and extensors, plantar flexors, latissimus, abdominis and erector spinae. Control group performed 80% EC without 10% EC. Changes in maximal voluntary isometric contraction strength (MVC) and muscle soreness, plasma creatine kinase (CK) activity and myoglobin concentration after 80% EC were compared between groups by a mixed-factor ANOVA.

Results MVC recovered faster (e.g., 6–31% greater MVC at 5 days post-exercise), and peak muscle soreness was 36–54% lower for Experimental than Control group for the nine muscles ($P < 0.05$). Increases in plasma CK activity and myoglobin concentration were smaller for Experimental (e.g., peak CK: 2763 ± 3459 IU/L) than Control group (120,360 ± 50,158 IU/L).

Conclusions These results showed that 10% EC was effective for attenuating the magnitude of muscle damage after 80% EC for all muscles, although the magnitude of the protective effect differed among the muscles.

Keywords Lengthening contraction · Delayed-onset muscle soreness · Maximal isometric contraction strength · Creatine kinase · Rhabdomyolysis

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Abbreviations

ANOVA	Analysis of variance
CK	Creatine kinase
CV	Coefficient of variation
DOMS	Delayed-onset muscle soreness
EC	Eccentric contractions
ECM	Extracellular matrix
MVC	Maximal voluntary isometric contraction
R	Intraclass correlation coefficient
SD	Standard deviation

Introduction

Unaccustomed eccentric exercise induces muscle damage represented by a prolonged loss of muscle function, delayed-onset muscle soreness (DOMS), and elevation of muscle proteins such as creatine kinase (CK) and myoglobin in the blood (Hyldahl and Hubal 2014; Lin et al. 2018; Tsuchiya et al. 2018). Thus, when prescribing eccentric exercise to novice individuals, caution is required for possible severe muscle damage that may result in serious consequences such as rhabdomyolysis (O'Connor et al. 2008; Hubal et al. 2010; Rawson et al. 2017). One of the effective strategies to minimize muscle damage is to precondition muscles by low-intensity eccentric contractions prior to higher-intensity eccentric contractions (Chen et al. 2012; Lin et al. 2015).

Chen et al. (2012) reported that performing 30 low-intensity eccentric contractions (EC) with a dumbbell corresponding to 10% of maximal voluntary isomeric contraction (MVC) strength (10% EC) enhanced the recovery of MVC strength at 1–4 days post-exercise by 18–59%, reduced peak muscle soreness by 66%, and decreased peak plasma CK activity by 74% after 30 maximal eccentric contractions (100% EC) of the unilateral elbow flexors performed by the same arm 2 days later. A similar protective effect of 10% EC on muscle damage after 100% EC was also shown for the knee flexors and knee extensors (Lin et al. 2015). However, practical applications of this to resistance exercises performed in a gym have not been explored.

It has been reported that the magnitude of muscle damage is greater for arm than leg muscles after maximal eccentric contractions performed on an isokinetic dynamometer (Jamurtas et al. 2005; Paschalis et al. 2010; Chen et al. 2011). Hyldahl et al. (2017) reported that the magnitude of the repeated bout effect was greater for the elbow flexors than knee extensors. However, no previous study has compared arm, leg and trunk muscles for the protective effect in a practical setting. General guidelines for healthy adults include 8–10 resistance exercises targeting different muscle groups (American College of Sports Medicine 2009). Currently, these exercises do not necessarily emphasize eccentric contractions. However, considering the potent effects of eccentric resistance training on muscle and physical function, insulin sensitivity and blood lipid profile found for older and young adults (Paschalis et al. 2011; Chen et al. 2017a, b), it is possible that eccentric contractions are more emphasized in training routines.

Therefore, the present study investigated the effect of 10% EC on muscle damage induced by higher-intensity eccentric contractions for arm, leg and trunk muscles; the elbow flexors, elbow extensors, pectoralis, knee flexors, knee extensors, plantar flexors, latissimus, abdominis, and erector spinae involved in nine different resistance exercises using machines equipped in a gym. It was hypothesized that the 10% EC would confer potent muscle damage protective effect on all muscles, but the magnitude of the effect would be different among the muscles such that the effect would be less for leg than arm muscles.

Methods

Participants

Twenty-four untrained healthy university students provided informed consent to participate in the study that had been approved by the Research Ethics Committee of National Taiwan Normal University, Taiwan, and an informed consent was obtained from each participant. The study was conducted in conformity with the policy statement regarding the use of human subjects by the 1964 Declaration of Helsinki. Their mean (± SD) age, height, and body mass were 21.6 ± 1.8 years, 172.4 ± 5.9 cm, and 68.8 ± 11.8 kg, respectively. The sample size was estimated using the data from a previous study (Chen et al. 2012) in which the protective effect of 10% EC on 100% EC was investigated for the elbow flexors. Based on the effect size of 1 for a possible difference in MVC strength changes between the conditions with and without 10% EC, it was estimated that at least 8 participants were necessary for each condition, with the alpha level of 0.05 and power ($1-\beta$) of 0.80, using G*Power (G*Power 3.1.9.2, Heinrich-Heine-Universitat Dusseldorf, Dusseldorf, Germany; http://www.gpower.hhu.de/). The participants were placed into a control or an experimental group ($n = 12$/group) by matching the baseline MVC strength of the nine muscles as much as possible. No significant differences in age [$P = 0.099$, Cohen's d (d) = 0.786], height ($P = 0.166$, $d = 0.461$), body mass ($P = 0.302$, $d = 0.289$), MVC strength of all muscles (latissimus: $P = 0.060$, $d = 0.647$—elbow extensors: $P = 0.481$, $d = 0.451$), and other baseline values of the dependent valuables (e.g., muscle soreness: $P = 1.000$) were observed between the groups.

A familiarization session was set at 3 days prior to the first eccentric exercise session, in which the participants experienced the muscle soreness assessments, and performed submaximal isometric contractions at the middle angle of the whole range of motion for each exercise. The investigator demonstrated the nine eccentric exercises.

Study design

The experimental group performed 10% EC (5 sets of 10 contractions) for each of nine resistance exercises; arm curl (targeted muscle: elbow flexors), elbow extension (elbow extensors), chest press (pectoralis), leg extension (knee extensors), leg curl (knee flexors), standing calf raise (plantar flexors), lat pulldown (latissimus), abdominal crunch (abdominis), and back extension (erector spinae) in a counterbalanced order among the participants in the same day. These exercises were followed 2 days later by

5 sets of 10 eccentric contractions for each exercise with a heavier load corresponding to 80% MVC strength (80% EC). The control group performed the 80% EC of the nine exercises without 10% EC.

Eccentric exercise

The 10% EC and 80% EC of nine eccentric exercises were performed on nine commercially available resistance training machines (Cybex International, Inc., Owatonna, MN, USA) set in a gym of the university. Most of the machines such as those for the arm extension, chest press, leg extension, leg curl, standing calf raise, lat pulldown and abdominal crunch included a cam system (https://www.cybexintl.com/sitemap-menu.aspx). To determine the load for each exercise, maximal voluntary isometric contraction (MVC) strength of each targeted muscle was measured on each resistance exercise machine using a loadcell (model: SESB, Delta-Transducer Inc., CA, USA) that was implemented to each machine, and connected to an A/D system (MP150 Data Acquisition and Analysis System, Biopac Systems Inc., CA., USA). The joint angle for the MVC strength measure was at 90° of elbow flexion for the elbow flexors, elbow extensors, pectoralis and latissimus, 70° and 40° of knee flexion for the knee extensors and knee flexors, respectively, 0° of plantar flexion for the plantar flexors, and 50° and 40° of trunk flexion for the abdominis and erector spinae, respectively. The participants were asked to generate maximal voluntary isometric force for 5 s, and this was repeated twice with a 45-s rest between attempts. The peak value during the 5-s contraction was recorded, and the highest value of the two peak values was used to determine the loading weight (80% of MVC strength).

Each contraction lasted for 5 s guided by the investigator who counted “0, 1, 2, 3, 4, 5” for the movement. The participants were instructed to resist the load for whole range of motion for each exercise. The starting and finishing angles of each exercise were 120°–0° for the arm curl, 0°–120° for the elbow extension, 0°–90° of elbow flexion for the chest press, 110°–0° for the leg curl, 0°–110° for the leg extension, 40° of plantar flexion – 25° of dorsiflexion for the calf raise, 90°–0° of elbow flexion for the lat pulldown, 90°–0° of trunk flexion for the abdominal crunch, and 0°–90° trunk flexion for the back extension. After each eccentric contraction at the end of the range of motion, the investigator assisted to set the load to the starting position while the participants were instructed to relax their muscles. The interval between contractions was 15 s, and a 2-min rest between sets was provided. Participants performed the eccentric contractions as instructed, but when they had difficulty controlling the eccentric contractions in 80% EC, the investigator spotted to assist the movement. The total duration of the whole exercise session including the resting time between sets and exercises, and the time taken for the measurements was approximately 4 h.

Dependent variables

The dependent variables consisted of MVC strength, muscle soreness, and plasma CK activity and myoglobin concentration. The re-test reliability based on intraclass correlation coefficient (R) and coefficient of variation (CV) of MVC strength and muscle soreness for the nine muscles was 0.82–0.94, and 8.4–9.8%, and 1.00 and 0%, respectively. R and CV were 0.73 and 9.7% for CK, and 0.75 and 8.7% for myoglobin.

Maximal voluntary isometric contraction strength

MVC strength of the nine corresponding muscles was measured by the load cell system explained above. The measurements were taken twice with a 45-s rest between measures, and the highest value of the two was used for further analysis (Wang et al. 2014; Chen et al. 2015; Shih et al. 2016). For the arm and leg muscles, MVC strength was measured for both limbs together. It should be noted that the cam system used in the machines affected the MVC strength values, resulting in greater values than those measured by an isokinetic dynamometer or other devices that assess MVC strength.

Muscle soreness

Muscle soreness was quantified by a visual analog scale that had a 100-mm continuous line with “not sore at all” on one end (0 mm) and “very, very sore” on the other end (100 mm). Muscle soreness of each muscle for the right and left sides as well as the trunk muscles was assessed, separately, when each muscle was self-stretched for the maximal (Nelson and Kokkonen 2014).

Plasma CK activity and myoglobin concentrations

Approximately 5 ml of venous blood was withdrawn by a standard venipuncture technique from the cubital fossa region and centrifuged for 10 min to extract plasma, and the plasma samples were stored at – 80 °C until analyses. Plasma CK activity was assayed spectrophotometrically by an automated clinical chemistry analyser (Model 7080, Hitachi, Co. Ltd., Tokyo, Japan) using a commercial test kit (Roche Diagnostics, Indianapolis, USA). Plasma myoglobin concentration was measured by an automated clinical chemistry analyser (Model Elecsys 2010, F. Hoffmann-La Roche Ltd., Tokyo, Japan) using a commercial test kit (Roche Diagnostics, Indianapolis, USA) (Tseng et al. 2016; Chen et al. 2018a).

Index of protection

The magnitude of the protective effect (index of protection) was calculated using the following equation: (80% EC of the control group – 80% EC of the experimental group) / 80% EC of the control group × 100 (Chen et al. 2014, 2016). For MVC, the values at 2 days post-exercise were used, and peak values were used for muscle soreness, plasma CK activity and myoglobin concentration.

Statistical analysis

All dependent variables before the 10% EC and 80% EC of the experimental group and 80% EC of the control group were compared by *t* tests. Changes in MVC strength and soreness of each muscle over time following 10% EC or 80% EC were compared by a repeated-measure of one-way analysis of variance (ANOVA). Changes in the dependent variables after 80% EC were compared between the groups by a mixed-design of two-way ANOVA. When a significant interaction effect was found, a Tukey's post hoc test was performed. The effect size for the difference in each variable between the experimental and control groups was calculated using Cohen's d (d), and the effect size was considered as small ($d = 0.2$), medium ($d = 0.5$), and large ($d = 0.8$), respectively (Cohen 1988). Eta-squared values (η^2) were also calculated as measures of effect size when ANOVA was performed, and a value of ~0.02 was considered as a small effect, ~0.13 as a medium effect, and >0.26 as a large effect (Bakeman 2000). A significant level was set at $P \leq 0.05$. The data were presented as mean ± standard deviation (SD).

Results

Changes in dependent variables after 10% EC

No significant changes in MVC strength (elbow extensors: $P = 0.052$, $\eta^2 = 0.206$—knee flexors: $P = 0.860$, $\eta^2 = 0.022$) and muscle soreness (elbow extensors: $P = 0.060$, $\eta^2 = 0.285$—pectoralis: $P = 0.698$, $\eta^2 = 0.014$) of the nine muscles, and plasma myoglobin concentration ($P = 0.234$, $\eta^2 = 0.124$) were observed after 10% EC. However, plasma CK activity increased ($P = 0.042$, $\eta^2 = 0.250$) at 1 (268 ± 152 IU/L) and 2 days (336 ± 270 IU/L) after 10% EC (Table 1).

Changes in dependent variables after 80% EC

No significant differences in the baseline MVC strength (elbow flexors: $P = 0.089$, $d = 0.586$—plantar flexors: $P = 0.412$, $d = 0.130$), soreness of the nine muscles ($P = 1.000$, $d = 1.000$), and plasma myoglobin concentration ($P = 0.535$, $d = 0.670$) before 80% EC were observed between the groups. However, the baseline value of plasma CK activity before 80% EC was higher ($P = 0.019$, $d = 0.960$) for the experimental (336 ± 270 IU/L) than control group (153 ± 11 IU/L).

Figure 1 compares the experimental and control groups for normalized changes in MVC strength of the nine muscles after 80% EC. A significant interaction effect was found ($P < 0.001$, $\eta^2 = 0.457$), and MVC strength recovered faster for the experimental than control group for all muscles (latissimus: $P < 0.001$, $\eta^2 = 0.321$—abdominis: $P < 0.001$, $\eta^2 = 0.659$).

Muscle soreness developed less for the experimental than control group for all nine muscles (pectoralis: $P < 0.006$, $\eta^2 = 0.249$—abdominis: $P < 0.001$, $\eta^2 = 0.703$) as shown in Fig. 2. The peak soreness values of the nine muscles of the experimental group (3 ± 8–29 ± 26 mm) was 8–54% smaller (knee extensors: $P = 0.001$, $d = 0.841$—erector spinae: $P < 0.001$, $d = 1.595$) than those of the control group (42 ± 24–73 ± 22 mm).

Changes in plasma CK activity ($P < 0.001$, $\eta^2 = 0.780$) and myoglobin concentration ($P < 0.001$, $\eta^2 = 0.802$) were smaller for the experimental than control group (Fig. 3). Peak plasma CK activity (2763 ± 3459 IU/L) and myoglobin concentration (185 ± 228 μg/L) of the experimental group were smaller (peak CK: $P < 0.001$, $d = 1.694$; peak myoglobin: $P < 0.001$, $d = 1.869$) than those of the control group (120,360 ± 50,158 IU/L, 3418 ± 687 μg/L).

The magnitude of the protective effect conferred by 10% EC

The protective index ranges 43% (knee flexors)—75% (erector spinae) for MVC strength, and 46% (knee extensors)—92% (abdominis) for muscle soreness (Fig. 4). The protective index for MVC strength was the lowest for knee flexors (43%), and the protective index for muscle soreness was the lowest for knee extensors (46%) among the muscles. The average of the index of the nine muscles for MVC strength (59 ± 12%) was not different ($P = 0.428$, $d = 0.751$) from that of the muscle soreness (69 ± 16%). The magnitude of the protective effect for peak plasma CK activity and myoglobin concentration was 98% and 96%, respectively.

Discussion

The results demonstrated that the 10% EC was effective for enhancing the recovery of MVC strength (Fig. 1), and attenuating the magnitude of muscle soreness (Fig. 2) for all nine muscles. However, the magnitude of the protective effect conferred by the 10% EC was different among the muscles. The 10% EC largely reduced the increases in plasma CK

Table 1 Changes in maximal voluntary isometric contraction (MVC) strength and muscle soreness (Soreness) of the elbow flexors (EF), elbow extensors (EE), pectoralis (PEC), knee extensors (KE), knee flexors (KF), plantar flexors (PF), latissimus dorsi (LAT), abdominis (ABD), and erector spinae (ES), and plasma creatine kinase (CK) activity and myoglobin (Mb) concentration before (Pre), immediately after (Post), and 1 and 2 days after the 10% eccentric exercise

Variables	Pre	Post	1 day	2 days
MVC (kg)				
EF	51.0 ± 4.8 (48.0–54.1)	50.0 ± 4.9 (46.8–53.1)	51.1 ± 4.8 (48.0–54.2)	50.6 ± 4.8 (47.6–53.6)
EE	46.0 ± 4.5 (43.2–48.9)	44.6 ± 4.7 (41.7–47.6)	45.0 ± 4.1 (42.4–47.6)	45.8 ± 5.1 (42.5–49.0)
PEC	101.7 ± 7.7 (96.7–106.6)	100.9 ± 8.4 (95.5–106.2)	102.6 ± 7.9 (97.1–107.6)	100.8 ± 8.2 (95.6–106.0)
KE	159.9 ± 14.4 (150.7–169.1)	159.4 ± 14.8 (150.0–168.8)	160.2 ± 13.9 (151.3–169.1)	159.8 ± 13.7 (151.1–168.5)
KF	77.7 ± 7.0 (73.2–82.1)	76.8 ± 9.2 (71.0–82.7)	76.7 ± 7.9 (71.7–81.7)	77.1 ± 8.7 (71.6–82.6)
PF	125.1 ± 11.5 (117.8–132.4)	124.1 ± 14.9 (114.6–133.6)	122.9 ± 13.8 (114.2–131.7)	125.4 ± 13.2 (116.9–133.8)
LAT	63.9 ± 6.3 (59.9–67.9)	63.0 ± 6.5 (58.9–67.1)	63.5 ± 7.0 (59.0–67.9)	63.9 ± 7.0 (59.5–68.4)
ABD	87.9 ± 8.0 (82.8–93.0)	87.1 ± 8.0 (82.1–92.2)	87.9 ± 8.1 (82.8–93.1)	88.1 ± 8.7 (82.6–93.7)
ES	148.5 ± 13.4 (140.0–157.0)	147.9 ± 13.6 (139.2–156.6)	148.9 ± 12.8 (140.8–157.1)	149.2 ± 14.0 (140.3–158.1)
Soreness (mm)				
EF	0.0 ± 0.0 (0.0–0.0)	–	0.8 ± 2.9 (1.0–2.7)	0.0 ± 0.0 (0.0–0.0)
EE	0.0 ± 0.0 (0.0–0.0)	–	6.3 ± 9.2 (0.5–12.2)	4.2 ± 7.9 (0.9–9.2)
PEC	0.0 ± 0.0 (0.0–0.0)	–	0.9 ± 3.2 (1.1–2.9)	0.5 ± 1.4 (0.4–1.4)
KE	0.0 ± 0.0 (0.0–0.0)	–	0.0 ± 0.0 (0.0–0.0)	0.1 ± 0.3 (0.1–0.3)
KF	0.0 ± 0.0 (0.0–0.0)	–	1.1 ± 3.8 (1.4–3.5)	0.7 ± 2.3 (0.8–2.1)
PF	0.0 ± 0.0 (0.0–0.0)	–	0.0 ± 0.0 (0.0–0.0)	0.0 ± 0.0 (0.0–0.0)
LAT	0.0 ± 0.0 (0.0–0.0)	–	0.9 ± 0.8 (1.1–2.9)	0.8 ± 2.6 (0.9–2.4)
ABD	0.0 ± 0.0 (0.0–0.0)	–	1.1 ± 3.8 (1.3–3.5)	0.7 ± 2.3 (0.8–2.1)
ES	0.0 ± 0.0 (0.0–0.0)	–	0.0 ± 0.0 (0.0–0.0)	0.0 ± 0.0 (0.0–0.0)
CK (IU/L)	168.1 ± 16.0 (157.9–178.3)	–	268.4 ± 152.0* (171.8–365.0)	335.5 ± 269.9* (164.0–507.1)
Mb (μg/L)	23.9 ± 1.2 (23.1–24.7)	–	18.4 ± 9.6 (12.3–24.5)	24.2 ± 8.7 (18.7–29.7)

Values are means ± SD (95% confidence interval)

*Significant ($P < 0.05$) differences from the pre-exercise values. Values are means ± SD (95% confidence interval). *Significant ($P < 0.05$) differences from the pre-exercise values. MVC strength of EF, EE, PEC, KE, KF and PF was measured with both limbs together

activity and myoglobin concentration after 80% EC (Fig. 3). These results supported the hypothesis and showed that the 10% EC conferred potent protective effect on all muscles.

The differences in the MVC strength changes following 80% EC between the groups were most likely due to the preconditioning effect conferred by the 10% EC performed 2 days before the 80% EC. The recovery of MVC strength at 2 days post-exercise was greater by 43% (knee flexors)—75% (erector spinae) for the experimental than control group. No previous study has reported changes in MVC strength following eccentric exercise of the elbow extensors, pectoralis, plantar flexors, latissimus, abdominis and erector spinae with a preconditioning exercise, although three previous studies reported the effect of 10% EC on the elbow flexors (Chen et al. 2012, 2013), and the knee flexors and knee extensors (Lin et al. 2015). It should be noted that these previous studies used a unilateral eccentric exercise, but bilateral eccentric exercises were performed in the present study. Despite this difference, the findings of the present study were in line with those of the previous studies (Chen et al. 2012, 2013; Lin et al. 2015). The present study was the first to show that this was also the case for the elbow extensors, pectoralis, plantar flexors, latissimus, abdominis and erector spinae. It appears that muscle damage can be attenuated by 10% EC performed 2 days prior to 80% EC for all muscles. However, the magnitude of the protection was different among the muscles such that the protective effect on MVC was greater for erector spinae (75%) and latissimus (73%) than the knee extensors (45%) and knee flexors (43%), while that on DOMS was greater for abdominis (92%), latissimus (87%), plantar flexors (77%), erector spinae (72%) and the elbow flexors (70%) in comparison to the knee extensors (46%) and pectoralis (51%).

The 10% EC did not induce muscle soreness for any of the muscles. This is consistent with the findings of the previous studies (Chen et al. 2012, 2013, 2018b; Lin et al. 2015). For example, Chen et al. (2012) reported that peak muscle soreness was 66% less when 10% EC was performed 2 days prior to 100% EC of the unilateral elbow flexors. In the present study, the magnitude of the protective effect on muscle soreness conferred by 10% EC was 70%, 73% and 46% for the elbow flexors, knee flexors and knee extensors,

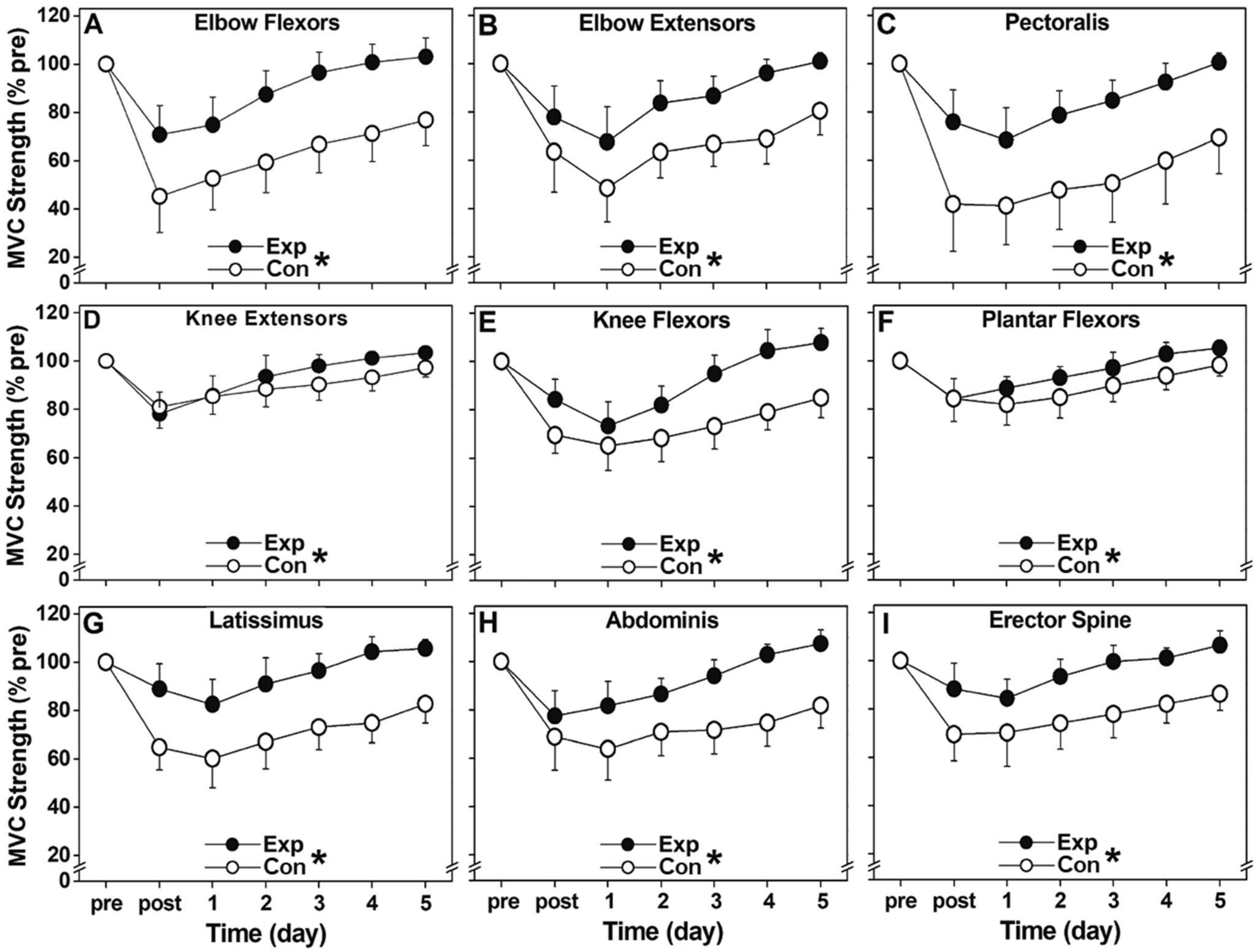


Fig. 1 Normalized changes (mean ± SD) in maximal voluntary isometric contraction (MVC) strength of the elbow flexors (**a**), elbow extensors (**b**), pectoralis (**c**), knee extensors (**d**), knee flexors (**e**), plantar flexors (**f**), latissimus (**g**), abdominis (**h**), and erector spinae (**i**) from the baseline (pre: 100%), immediately after (post), and 1, 2, 3, 4 and 5 days after 80% eccentric exercise for the control group (Con) and the experimental group (Exp). An asterisk (*) indicates a significant difference ($P < 0.05$) between groups based on the interaction effect shown by the ANOVA

respectively. The extent of the protection for other muscles was 58% for the elbow extensors, 51% for pectoralis, 77% for plantar flexors, 87% for latissimus, 92% for abdominis and 72% for erector spinae. The magnitude of the protection on the trunk muscles seemed greater than that of the arm and leg muscles. It has been suggested that the greater protection could be conferred, if the muscles are less exposed to eccentric contractions in daily activities (Chen et al. 2011). This may explain the greater effect for the trunk muscles.

Plasma CK activity increased after 10% EC, but plasma myoglobin concentration did not. The molecular weight of myoglobin is 17.8 kDa, and its half-life is 1–3 h when glomerular filtration rate is normal, while the molecular weight of CK is about 81 kDa and its half-life is approximately 36 h (Beetham 2000). CK is primarily cleared by the reticuloendothelial system, but myoglobin is cleared by the kidneys (Rawson et al. 2017). Thus, it may be that myoglobin also increased, but already retuned to the baseline by the time when the measurement was taken at 1 and 2 days post-10% EC. As shown in Fig. 3, plasma CK activity and myoglobin concentration did not increase significantly after 80% EC for the experimental group. This suggests that the 10% EC abolished the responses of plasma CK activity and myoglobin concentration following 80% EC. Peak plasma CK activity and myoglobin concentration were 98% and 96% smaller, respectively, for the experimental than control group in the present study. These effects seem to be greater than those found for the unilateral elbow flexors (peak CK: 74%, myoglobin: 60%), knee extensors (78%, 71%) and knee flexors (76%, 75%), in which 10% EC (elbow flexors and knee flexors: 30 repetitions, knee extensors: 60 repetitions) were performed 2 days before 100% EC (Chen et al. 2012; Lin

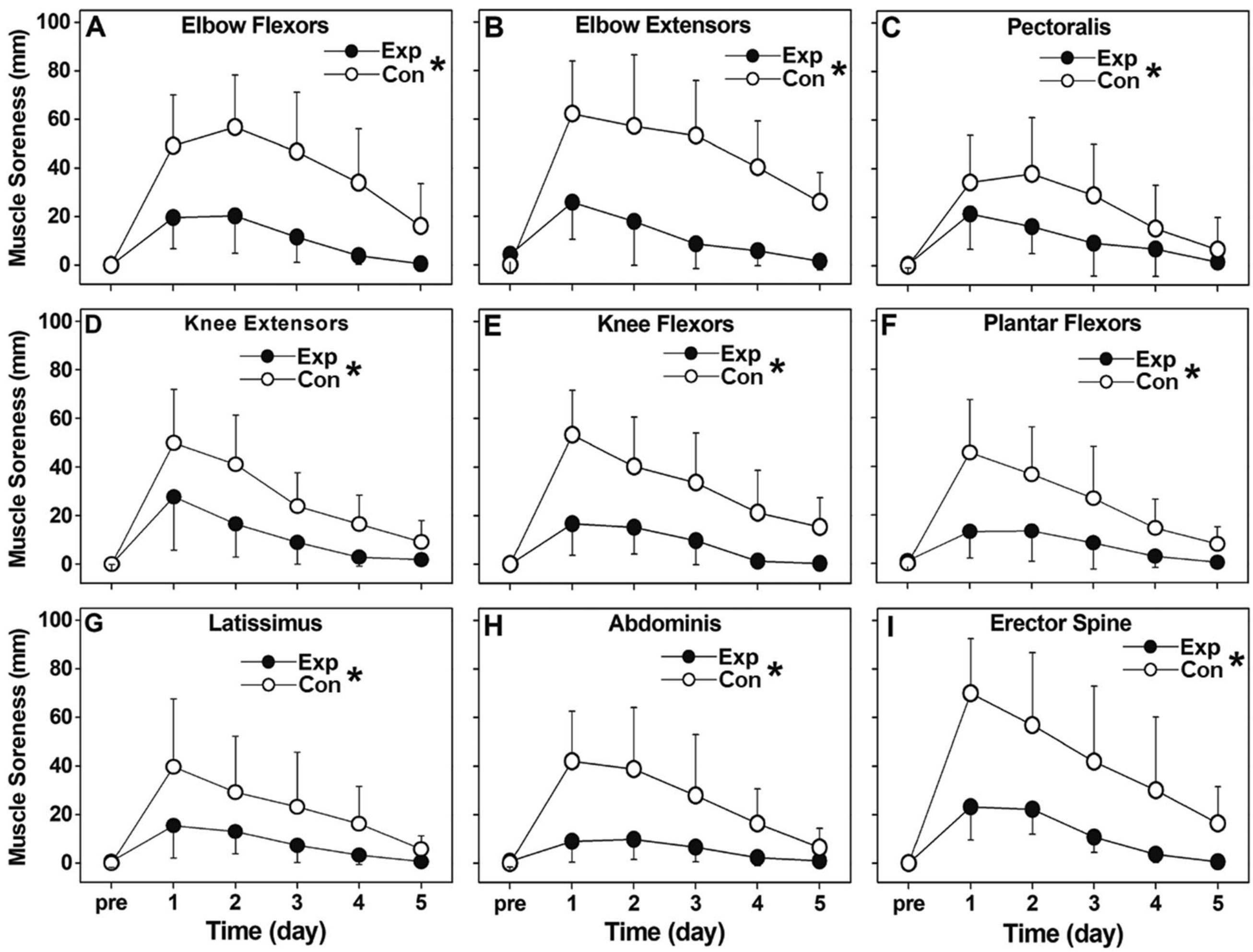
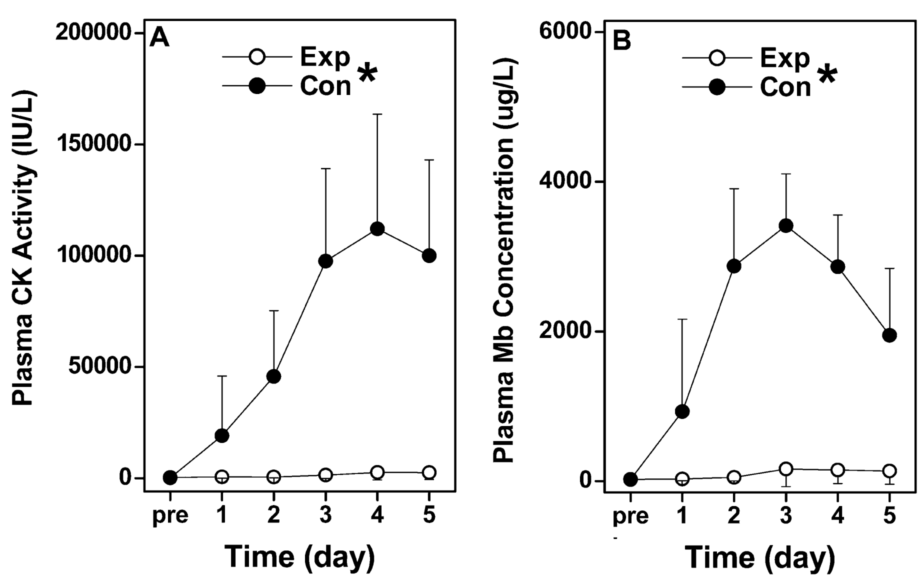


Fig. 2 Changes (mean ± SD) in muscle soreness assessed by a 100-mm visual analog scale of the elbow flexors (**a**), elbow extensors (**b**), pectoralis (**c**), knee extensors (**d**), knee flexors (**e**), plantar flexors (**f**), latissimus (**g**), abdominis (**h**), and erector spinae (**i**) before (pre), and 1, 2, 3, 4 and 5 days after the 80% eccentric exercise for the control group (Con) and the experimental group (Exp). An asterisk (*) indicates a significant difference ($P < 0.05$) between groups based on the interaction effect shown by the ANOVA

Fig. 3 Changes (mean ± SD) in plasma creatine kinase (CK) activity and myoglobin (Mb) concentration before (pre), and 1, 2, 3, 4 and 5 days after 80% eccentric exercise for the control group (Con) and the experimental group (Exp). An asterisk (*) indicates a significant difference ($P <$ 0.05) between exercises based on the interaction effect shown by the ANOVA



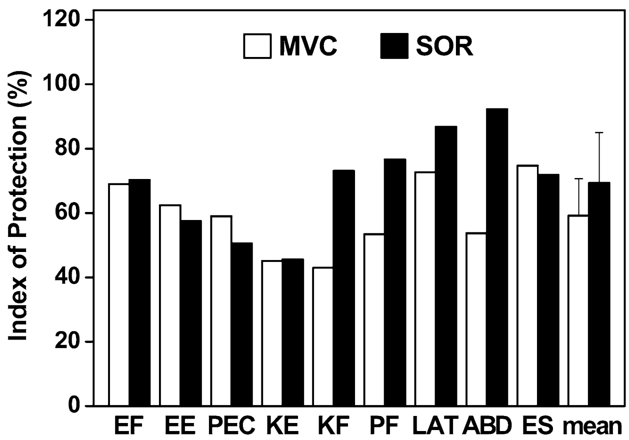


Fig. 4 Index of protective effect of maximal isometric contraction strength (MVC) and muscle soreness (SOR) of the elbow flexors (EF), elbow extensors (EE), pectoralis (PEC), knee extensors (KE), knee flexors (KF), plantar flexors (PF), latissimus (LAT), abdominis (ABD), and erector spinae (ES). The index was calculated by the following formula: (80% EC of Con—80% EC of Exp)/80% EC of Con × 100%, for the magnitude of the decrease in MVC from the baseline at 2 days post-exercise and peak muscle soreness using the average value of the group. The average and standard deviation values of the nine muscles are also included as "Mean"

et al. 2015). It should be noted that the peak plasma CK activity for the control group in the present study (average peak: 120,360 IU/L) was much greater than that of the previous study (6226 IU/L) (Chen et al. 2016). This was likely due to the use of more muscles in one session than that of the previous studies (Chen et al. 2011, 2016). It seems possible that the cumulative effect from different muscles made the protective effect on plasma CK activity and myoglobin in the present study greater than that of the previous studies (Chen et al. 2012; Lin et al. 2015). It should be noted that muscle proteins in the blood increase largely after performing several eccentric exercises of different muscles in a session, which is a risk of rhabdomyolysis. In the present study, many of the participants in the control group had dark urine after the session, showing a symptom of rhabdomyolysis, although no serious case was developed. It seems unlikely that the exercises used in the present study (5 sets of 10 eccentric contractions with a load corresponding to 80% MVC strength for nine different muscles) are performed in a gym. Thus, the results of the present study should be considered as an exaggerated case. However, it should be noted that if low-intensity eccentric exercise was performed at 2 days prior higher-intensity eccentric exercise, the risk was significantly reduced. Actually, it is a general practice that high-intensity eccentric contractions are performed after several sessions of training consisting of lower-intensity eccentric contractions. Thus, if the training principal of progression is followed, severe muscle damage resulting in rhabdomyolysis is avoided.

The mechanisms underpinning the protection conferred by low-intensity eccentric contractions on higher-intensity eccentric contractions are not clear yet, but the findings of the current study provide some clues. Hyldahl et al. (2017) have speculated that the protective effect is a combination of neural adaptations, muscle–tendon complex behavior changes, extracellular matrix (ECM) structural remodeling, and modified inflammatory responses. Since the 10% EC was performed only 2 days before the 80% EC, it seems unlikely that any of structural adaptations were main contributors. It is possible that the protection conferred by 10% EC was more associated with neural adaptations such as increased recruitment of slow-twitch motor units and activation of larger motor unit pool than adaptations at muscle fibers and ECM. It is also possible that inflammatory responses were modified by the 10% EC as if an inoculation effect that triggers the immune system to be better prepared for upcoming events. Yamada et al. (2018) have recently reported that 10 non-damaging eccentric contractions performed 2 days prior to 100 maximal eccentric contractions of rat medial gastrocnemius muscle improved contractile recovery, and this was associated with a heat shock protein-dependent prevention of immune cell invasion resulting in decreased myeloperoxidase-mediated reactive oxygen species production, avoiding cell membrane disruption, calpain activation and degenerative changes in myosin and actin molecules. Regarding the differences in the magnitude of the protective effect among the muscles, it should be noted that the range of motion in the nine exercises did not necessarily induce similar sarcomere or muscle fiber strain among the nine muscles. Thus, mechanical stress to each muscle was likely to be different, which resulted in different magnitude of muscle damage after 80% EC, and different magnitude of the protective effect. It is interesting to investigate the effect of 10% EC on 80% EC among different muscles by matching the decrease in MVC at immediately post-exercise. Definitely, further studies are required to elucidate the mechanisms of the protection.

The present study provides important practical implications. Performing low-intensity eccentric contractions was effective for preventing severe muscle damage. Thus when introducing eccentric resistance exercises, they should be started from very low-intensity. In this way, eccentric resistance exercises can be safely implemented to novice exercisers. Since muscle damage can be easily minimized by preconditioning exercise, the use of eccentric resistance exercises should not be discouraged, and eccentric resistance exercises should be performed more in a gym, because of many positive effects that eccentric resistance training provides (Paschalis et al. 2011; Chen et al. 2017a, b). However, it is not realistic to perform 5 sets of 10 eccentric contractions for several muscles in a session as done in the present study. Performing 2–3 sets of whole body eccentric exercises once or twice a week is possible, which can be completed in 60 min. Further studies are necessary to investigate the effects of whole body eccentric exercise on health, fitness and quality of life.

There are some limitations in the present study. Firstly, the present study used only young men as participants. It is necessary to investigate whether the findings of the present study are applicable for children, women, older individuals, and clinical populations. Secondly, the interval between 10% EC and 80% EC was 2 days in the current study. Previous studies showed that the protective effect conferred by 10% EC lasted for 2 weeks for the elbow flexors (Chen et al. 2012), and 1 week for the knee flexors and knee extensors (Line et al. 2015). Thus, it is important to examine how long the protective effect would last for the other muscles including those investigated in the present study. Thirdly, in the present study, 5 sets of 10 low-intensity eccentric contractions were performed as the preconditioning exercise. It is interesting to investigate if a smaller number of low-intensity eccentric contractions (e.g., 1 set of 10 contractions) are still effective. Lastly, concentric contractions were performed without a load in the present study. However, resistance exercises in a gym normally include concentric contractions with a load. The effects of low-intensity concentric and eccentric contractions on higher-intensity concentric and eccentric contractions, or accentuated eccentric contractions should be investigated in a future study.

Conclusion

It is concluded that performing a bout of 10% EC was effective for attenuating the magnitude of muscle damage after 80% EC for the nine muscles, but the protective effect differed slightly among the muscles. Performing low-intensity eccentric contractions such as 10% EC is an effective strategy to reduce DOMS and strength loss, and prevent rhabdomyolysis after performing any eccentric resistance exercises in a gym.

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Author contributions All authors (MJH, KN, HSW, KWT, TYC, HLC, and TCC) contributed to the data analysis and interpretation of the data, drafting, and revising the manuscript, and approved the final version of the manuscript. The original study design was made by TCC and KN, and discussed with the other authors, and MJH, TCC and HLC performed data collection.

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Data availability The data of the current study are available from the corresponding author on reasonable request.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

Ethical approval All procedures performed in the present study were in accordance with the ethical standards of the institutional research committee and with the 1964 Helsinki declaration.

Informed consent A written informed consent was obtained from each participant participated in the study.

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