muscle cramp, an intense, sudden, painful, and involuntary contraction of skeletal muscle, lasts seconds to minutes.\(^1,2\)

The cramp can contract either the entire muscle or part of it. Muscle cramping that occurs during or immediately after exercise is commonly referred to as exercise-associated muscle cramping (EAMC).\(^3,4\)

Muscle cramping is a very common condition among both sedentary and physically active populations.\(^5\) and EAMC is highly prevalent among athletes.\(^3,4\)

Research has demonstrated the neurogenic origin of muscle cramping,\(^1,2,6,7\) but the details of its etiology are not well understood. Cramping may occur as the result of several underlying medical conditions. There are three theories about the cause of EAMC: (1) dehydration, (2) electrolyte depletion, and (3) altered neuromuscular activation.\(^5\)

The literature contains numerous observational research reports on muscle cramping,\(^3,8-10\) which is difficult to study experimentally, because EAMC is spontaneous and unpredictable.\(^11\)

Three methods have been used to induce a muscle cramp in a laboratory setting: (1) magnetic stimulation, (2) electrical stimulation, and (3) fatiguing muscular exercise. Although magnetic stimulation\(^12\) and electrical stimulation\(^1,11,15\) are reliable methods to induce a muscle cramp, the similarity to an EAMC is not clear. Fatiguing muscular exercise protocols have been attempted, but control of confounding variables is difficult (e.g., hydration, electrolyte imbalance), and the reliability of the method has been questioned.\(^11\)

Jung et al.\(^14\) used an exercise protocol that involved an intense calf muscle-fatiguing procedure, which was 56% effective in inducing a muscle cramp in 13 male participants with a history of EAMC.

Another type of fatiguing muscular exercise for cramp inducement involves a maximum voluntary contraction (MVC) of a muscle in a shortened position. This method was first introduced in 1957 by Norris et al.,\(^7\) who used it with the rectus femoris muscle.
Other studies have tested this method on the flexor hallucis brevis muscle and the triceps surae (gastrocnemius, soleus, and plantaris) muscle group with mixed results. None of the aforementioned studies examined the test-retest reliability of the voluntary contraction model on separate days. With the exception of the study conducted by Norris et al., small sample sizes have been used. Therefore, the purpose of our study was to examine: (1) the ability of the voluntary contraction model to induce a muscle cramp and (2) the test-retest reliability on the voluntary contraction model on subsequent days.

**Procedures and Findings**

Seventy-four healthy individuals (23 ± 8 years of age; 49 males and 25 females) volunteered to participate in the study. Inclusion criteria were: (1) ≥ 18 years of age, (2) physically active status (i.e., approximately 3 days per week), and (3) low-risk classification according to the American College Sports Medicine Risk Stratification. Exclusion criteria were: (1) recent injury or surgery to the lower extremity within the previous 6 months, (2) moderate to severe adverse reactions to muscle cramping, and (3) females who were pregnant. All participants completed a demographic and cramping history questionnaire, and provided written informed consent prior to participation. Sixty-three participants (85%) had previously experienced EAMC, and 46 of those (62%) had experienced EAMC in the calf musculature.

For the cramping procedure, the participant sat on a cushioned laboratory table with the torso supported against a wall. The participant’s right knee was placed in 60° of flexion, with the ankle fully plantar flexed, and the heel maintained on the table surface (Figure 1). This position placed the triceps surae in a shortened and unloaded position. The participant was instructed to maximally contract the right triceps surae musculature with the intent to induce a cramp. We used a stopwatch to time the MVC for 60 seconds or until a cramp occurred. As previously described by Ross and Thomas, we used 3 criteria to identify the onset of a cramp: (1) obvious visual evidence of spasm, (2) unequivocal pain, and (3) sustained spasm when the MVC was terminated. If a cramp occurred, it was immediately relieved by moving the knee into a position of full extension, while simultaneously moving the ankle into a dorsiflexed position, to stretch the triceps surae musculature. After the cramp was relieved, the participants performed the same procedure with the left leg. If a participant cramped in one or both legs, they returned for two more visits at one-week intervals for assessment of the protocol’s reliability. We chose one-week intervals to allow for complete resolution of any triceps surae soreness or fatigue. Participants were asked to not exercise the lower extremities on the day before or on the day of the cramping procedure. We performed Wilcoxon signed-rank tests to assess any differences in cramp occurrence between pairs of testing sessions for both extremities, with an alpha level of $p < .05$.

The MVC procedure induced a cramp within 60 seconds in 31% of participants (23/74), 19% (14/74) cramped in both extremities (“bilateral crampers”), whereas 12% (9/74) cramped in only one extremity (“unilateral crampers”). The dominant leg (i.e., the preferred extremity to perform a kick or to push off during physical activity) was the leg that cramped in all but one of the 9 unilateral crampers. We observed that cramping primarily occurred in the soleus and medial gastrocnemius musculature.

A total of 18 of the 23 crampers (78%) returned to perform the same protocol one week later. Among these 18 participants, all but one reproduced the cramp (97%). Of the 13 (of the 17) participants who reproduced the cramp, 76% did so bilaterally. All 17 of these participants returned one week later for a final visit (2 weeks after the initial testing), and each of them
successfully reproduced the cramp. Once again, 76% of them cramped bilaterally (13/17). The results of the Wilcoxon signed-rank tests demonstrated that there were no significant differences cramping from visit 1 to visit 2 (right leg p = .564; left leg p = 1.000) or from visit 2 to visit 3 (right leg p = .564; left leg p = .564).

**Discussion**

The MVC procedure was successful in generating cramping of the triceps surae musculature in 31% of cases (23/71), which was better than that reported in previous research. Norris et al. were the first to test MVC procedure for inducing a cramp in the rectus femoris muscle of 115 healthy, male participants. Muscle cramping occurred in only 18% of the participants before an exercise bout, but the rate rose to 26% immediately after 20–30 minutes of exercise. Bertolasi et al. reported that 7 of 10 participants cramp in the flexor hallucis brevis muscle. Ross and Thomas tested the MVC procedure on the triceps surae muscle group in healthy subjects who had a history of triceps surae cramping, and reported that only 4 of 7 were able to induce a cramp in the medial gastrocnemius.

Among the participants who experienced cramping in our study, 97% (17/18) we able to reproduce the cramping in both of 2 subsequent trials. All 13 participants who cramped bilaterally during the initial testing demonstrated bilateral cramping during both of the 2 subsequent trials. Furthermore, 89% of the participants who experienced cramping (16/18) reported a history of EAMC, with occasional to very frequent occurrence of muscle cramps. Our findings suggest that the MVC procedure provides a reliable method for inducement of cramping in individuals who are prone to EAMC.

Miller and Knight reported high intersession reliability (0.99) over 5 consecutive days of inducing cramping of the flexor hallucis brevis through an electrical stimulation procedure. Minetto et al., and Stone et al. reported similar results for similar procedures. Recent studies have used electrical stimulation or a combination of MVC and electrical stimulation to study the possible causes of EAMC (e.g., dehydration, neuromuscular fatigue). The threshold electrical current frequency (Hz) at which a muscle will cramp has been shown to correspond to an individual’s predisposition to cramping. However, muscular fatigue and cramping induced by electrical stimulation may differ from that which is induced by exercise. Therefore, a procedure for inducing cramping that more closely resembles that which occurs during exercise may be useful for future research examining EAMC.

Participants in our study were only allowed one attempt to induce a cramp once each of the three testing sessions. Other studies using the MVC procedure involved multiple attempts to induce a cramp. Future research should compare single versus multiple MVC attempts to induce cramping. The hydration status of our participants was not measured during the initial testing session, but urine specific gravity (USG) was measured at the two follow-up sessions for another study. All participants were asked to report in a hydrated state, which was confirmed by a USG value < 1.02. Future studies of the MVC cramping procedure should control for hydration, electrolyte imbalance, and prior muscular fatigue. Although more research is needed, athletic trainers and therapists may consider using the MVC cramping procedure as a screening tool for identification of athletes with a predisposition for EAMC.

**References**


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