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Effects of Post-Race Nutritional Intervention on Delayed-Onset Muscle Soreness and Return to Activity in Ironman Triathletes

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Effects of Post-Race Nutritional Intervention on Delayed-Onset Muscle Soreness and Return to Activity in Ironman Triathletes

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ABSTRACT

Effect of Post-Race Nutritional Intervention on Delayed-Onset Muscle Soreness and Return to Activity in Ironman Triathletes

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CONTEXT: Ironman triathletes often experience delayed-onset muscle soreness (DOMS) after races. Post-exercise nutritional interventions have been shown to be an effective recovery strategy for DOMS, however little is known on how post-race nutritional intervention affects DOMS in Ironman triathletes.

OBJECTIVE: To examine the effect of a post-race nutritional intervention on DOMS and ability of triathletes to return to activity.

DESIGN: Randomized field study.

SETTING: 2013 Lake Placid Ironman triathlon.

PATIENTS OR OTHER PARTICIPANTS: Thirty-six (males: n=30, females: n=6) triathletes participated (mean±SD; age=38±9 y, height=178±9 cm, weight=76.9±11.1 kg, body fat=12.2±5.4%, finish time=732±108 min).

INTERVENTION: Subjects were randomly assigned to either an intervention or control group by finish time. The intervention group received recovery shakes (540 kcal, 90g carbohydrate, 40g protein, 2g fat) both 1-hour and 3-hours post-race.

MAIN OUTCOME MEASURES: We used a 100mm-visual analogue scale (VAS) and 11-point global rating of change (GRC) to measure DOMS in standing position (static) and sitting-to-standing motion (active). GRC scores measured change in DOMS compared to previous time point. DOMS was evaluated at 11 time points (pre-race, 1h, 3h, 12h post-race, and everyday for up to 7 days (1-7d) post-race) using paper-based and online surveys. Return to activity questionnaires were used to assess days returning to activity, length, intensity, and composition of activities. Activity intensity was measured with a 15-point rated perceived exertion (RPE) scale. Subjects completed return to activity questionnaires via online survey for 2 weeks post-race. Energy intake on the race day was monitored using diet log. Two-way ANOVA (group x time) was used to compare outcomes between groups over time and independent t-tests were utilized for group comparisons.

RESULTS: Static and active VAS scores significantly increased from pre-race (intervention: 3±5cm, 2±4cm; control: 3±4cm, 3±3cm respectively) to 1-hour post-race, which represented peak static and active VAS values (intervention: 50±19cm, 52±23cm; control: 46±24cm, 47±26cm, $P<0.001$, respectively). Both static and active VAS values remained significantly elevated from pre-race until 4 days post-race (intervention: 10±14, 12±16; control: 6±10, 5±11, $P<0.05$ respectively). Negative GRC values only occurred 1-hour post-race in both intervention (-4±1) and control (-3±1) and demonstrated improvement at all other time points. VAS and GRC showed no differences between groups any time point ($P>0.05$). No significant differences occurred for days returning to activity (intervention: 4±4d; control: 4±2d), activity intensity (intervention: 10±3, control: 10±4) or composition of activity between groups ($P>0.05$). However, activity length was significantly longer for intervention group (1.2±0.5h) than control group (0.8±0.4h, $P<0.01$). Although post-race energy intake revealed similar total calories between groups (intervention: 1862±766 kcal, control: 1959±1306 kcal, $P>0.05$), protein intake was significantly higher in intervention group (101±37 kcal) than control group (71±48 kcal) while fat intake was significantly lower in intervention group (33±24 kcal) than control group (78±60 kcal) ($P<0.05$).

CONCLUSIONS: DOMS increased dramatically in response to the race and gradually subsided by 4 days post-race regardless of treatment group. Within the context of this study, the post-race nutritional intervention did not result in differences on DOMS and return to activity compared to control despite it has changed composition of macronutrient intake.

REVIEW OF LITERATURE

This review of current literature consists of two sections. First, Ironman triathletes are discussed focusing on physiological demands of Ironman triathlon and physiological influences after an Ironman race. Second, recovery from Delayed-Onset Muscle Soreness (DOMS) is addressed focusing on different recovery strategies. Finally, nutritional intervention for DOMS is reviewed focusing on modes of nutritional supplements.

Ironman Triathletes

<u>Ironman Triathlon</u>

Ironman triathlon is one of the most challenging worldwide endurance events. The race consists of three consecutive events; 3.86 km of swimming, 180.25 km of cycling, and 42.20 km of running. The popularity of Ironman triathlon has dramatically increased since the very first race held in Hawaii in 1978. About 50,000 triathletes participate in Ironman triathlon races throughout the world each year. [1] Only 2,000 qualified triathletes are able to compete at the Ironman World Championship in Hawaii. [2] Most Ironman events start at 7:00am and have cut-off times, which are 2:20 hours (9:20am) for swim, 10:30 hours (5:30pm) for bike, and 17 hours (midnight) for run. Elite triathletes take approximately 8 hours to finish a race while other triathletes may take as many as 17 hours. [3]

<u>Physiological Demands of Ironman Triathlon</u>

Due to prolonged duration of the Ironman triathlon race, athletes are placed several physiological loads, including energy demands, thermal stress, hydration demands, oxidative stress, and muscle damage. [4] Some of these physiological demands are altered depending upon race location, race day weather, or seasons.

Energy Demands

To maintain optimal performance, Ironman triathletes have to sustain a high rate of energy expenditure for extended periods of time. [5] Athletes also need to keep their energy supply to meet the energy demands during a race. A previous study has described energy intake, energy expenditure, and the resulting energy balance during an Ironman triathlon race (Table 1). [6] Energy expenditure ratios for each Ironman event components were 8% for swim, 54% for bike ride, and 38% for run.

Table 1. Energy expenditure, energy intake, and energy balance in male and female Ironman triathletes (mean ± SD, kcal)[6]

	Males	**Females**
Energy Expenditure	10,036±931*	8,570±1,014
Swim	768±97	737±148
Bike	5,384±553*	4,683±551
Run	3,875±585*	3,097±657
Energy Intake	3,940±868	3,115±914
Bike	2,896±836	2,233±627
Run	1,049±267	883±347
Energy Balance	-5,973±1,274	-5,123±1,193

*Significant difference between males and females ($P<0.05$)

During this Ironman race, triathletes obtained approximately 40% of total energy expenditure from food and fluids and the other 60% from their endogenous fuel stores. Most energy consumption occurred during the cycling segment as opposed to the running segment, which accounted for 73% of total energy intake (Table 1). From the perspective of macronutrient proportion, carbohydrate (CHO) consisted of 94% of total energy intake while protein and fat consisted of 4% and 2% of total energy intake, respectively. [6]

Thermal Stress

Environmental conditions significantly affect performances of Ironman athletes, thus thermoregulation is one of the most challenging aspects of Ironman race. Depending upon ambient temperature and humidity, triathletes could be exposed to the risk of both hypothermia and hyperthermia during a race.

Although most triathlon swim events have been held at water temperature between 13-32°C, optimal water temperature is between 25.5-28°C to prevent hypothermia and hyperthermia. [7] Due to high gradient of heat transfer in the water compared with in the air, the potential for hypothermia or hyperthermia increases when water temperature considerably differs from the optimal range during swimming. [8] In Ironman triathlon, wetsuits are permitted if water temperatures are below 24.5°C. [9] The use of a wetsuit in cold water attenuates body heat loss and prevents hypothermia (Figure 1). [10] With a cycling section following a swim in cold water (5-15°C), there is an increased risk of hypothermia, especially in the early stage, although body temperature may rise with continued biking. Increased convective heat loss, low ambient temperature, and rain while cycling may also result in hypothermia. [10] During the running section, triathletes with dehydration and exhaustion have higher possibility of hypothermia when ambient temperature is low. Significant decreases in rectal temperature after a race are reported with athletes who significantly dropped their pace in the last segment of running due to fatigue or injuries.[11]

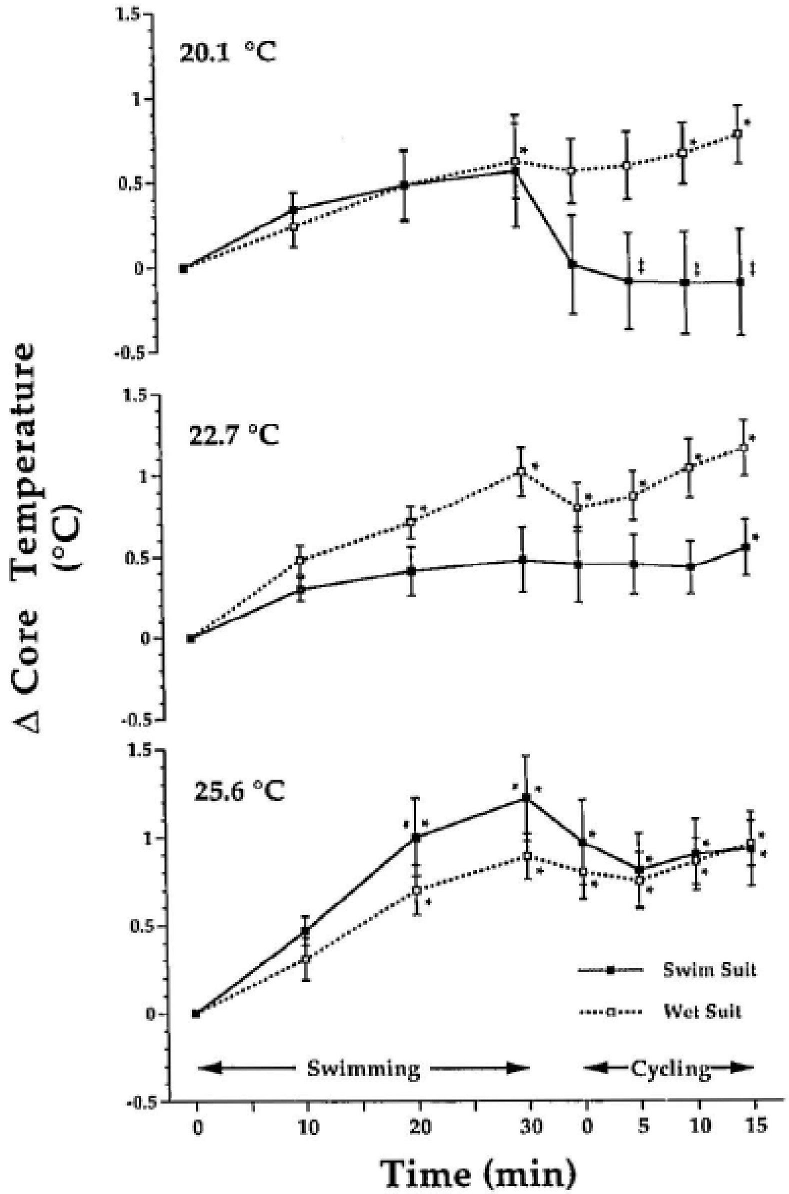

Figure 1. Change in core temperature from pre-immersion in the 20.1, 22.7, and 25.6°C trials during swimming and cycling. * $p < 0.05$ from pre; ‡ $p < 0.05$ from wet suit at 20.1, 22.7, and 25.6°C and swim suit at 25.6°C; # $p < 0.05$ from swim suit at 20.1 and 22.7°C[10]

Swimming in water temperature above the optimal range results in a significant increase in body temperature.[12] Therefore, the use of wetsuits is prohibited in water temperatures above 28.8°C.[9] Due to the inability to intake fluid during the swim segment, dehydration may compromise body heat loss and increase risk of hyperthermia (Figure 2).[13,14] During the cycling segment, high ambient temperature and relative humidity can interfere with heat dissipation from the body. However, the potential for heat stroke is higher during the run segment compared with swim and bike segments because triathletes are more likely to start the running segment dehydrated, and the run segment occurs during the hottest time of the day. [7]

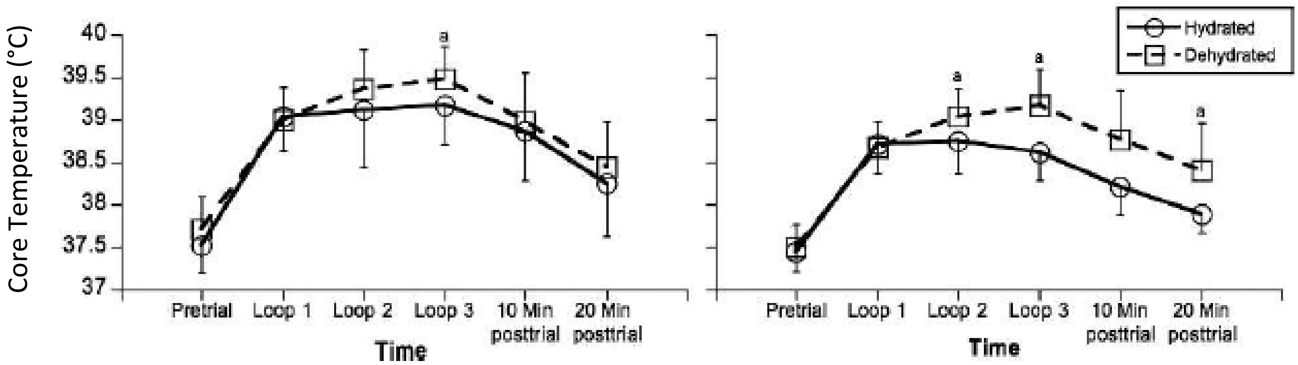

Figure 2. Core body temperature throughout race (A) and submaximal trials (B) between hydration states. [a] $p \leq 0.05$ for the same time point between hydration states[14]

Hydration Demands

During exercise, repetitive muscular contractions generate heat in the body and raise body temperature. As body temperature elevates, venous blood flow to the skin increases to dissipate heat through convection, evaporation, and radiation. In hot environments, evaporation becomes the primary mechanism of dissipating heat. [15] Therefore, sweat production increases in order to prevent elevation in body temperature, which may result in dehydration and a loss of sodium. [16]

Body fluid loss during exercise is determined based on body mass, exercise intensity, and ambient temperature and humidity. [17] When ambient temperature is high, triathletes can lose fluid between 1,000-2,500 ml/h. [18] To maintain fluid balance, triathletes generally replace the fluid loss with water or sports drinks during a race. A previous study indicated that Ironman triathletes lost body fluid during the swim and run segments and gained it during the bike segment (Table 2). [19]

Table 2. Fluid balance and weight change in Ironman triathletes. (n=18)[19]

	Median	**Range**
Fluid Intake (ml/h)		
Bike	889	601 – 1,310
Run	632	238 – 1,129
Fluid Loss (ml/h)		
Bike	808	469 – 1,083
Run	1,021	404 – 1,801
Weight Change (kg)	-2.5	-4.0 – 1.5
Swim	-1.0	-2.0 – 0.5
Bike	0.5	-1.0 – 3.0
Run	-2.0	-3.5 – 1.5

The fluid loss during swimming resulted from inability to ingest fluids while the fluid loss during running resulted from intolerance of athletes to drink a large amount fluid while running fast. [7] The fluid gain during the cycling segment occurred because athletes might attempt to recover from dehydration due to swimming and prevent dehydration in the subsequent running segment. In addition, the sweat rate tended to be lower on the bike than on the run because convective heat loss increased because of the greater facing wind speeds generated in cycling. [19] In order to prevent excessive dehydration, the hydration guideline by American College of Sports Medicine recommends that athletes should adequately replace fluids to keep body weight loss less than 2% of baseline body weight during exercises. [20] The bike section is the best opportunity for Ironman triathletes to replace fluid loss during race.

Ironman triathletes need to be cautious about not only the risks of dehydration, but also the risks of overhydration. The overloading of fluid and profuse sweat sodium losses during ultraendurance events can contribute to exercise-associated hyponatremia. [21] Athletes with low body weight, slow performance pace, excessive drinking behavior, use of anti-inflammatory drugs, and female sex have greater risks of exercise-associated hyponatremia.[22]

Oxidative Stress

Reactive oxygen species (ROS) are produced in the body as a result of increased oxygen consumption from aerobic exercises. [23] Under some circumstances, ROS can assist to repair damaged tissue and destroy harmful microorganisms through respiratory burst activity and phagocytosis. [24] However, excessive ROS generated during prolonged exercise, such as Ironman triathlon, can impair vital cellular structures and increase oxidative stress. [25] To protect healthy cells from oxidative stress, human body has the antioxidant defense system consisted of antioxidant enzymes, several vitamins or their precursors, glutathione, and other low-molecular-weight antioxidants. [26] The capacity of the antioxidant defense system is relatively small, thus during ultraendurance events, oxidative cellular damages occur due to excessive ROS production and dysfunction of the antioxidant defense from inactivation or nutritional deficiency. [27] The cellular and oxidative damages by ROS have appeared in relevant to immune suppression, resulting in development of pathological conditions such as upper respiratory tract infections.[28]

Muscle Damage

Strenuous physiological loads from prolonged periods of exercise in Ironman triathlon contribute to muscle damage. Two basic mechanisms are combined to explain the occurrence of exercise-induced muscle damage; mechanical stress and metabolic stress mechanism. [29] In the mechanical stress mechanism, damage to skeletal muscle fibers is caused by mechanical shear forces generated during race, especially the repetitive pounding that occurs while running. Eccentric exercise, such as downhill running, and unaccustomed exercise often result in significant muscle damage. [30] A previous study suggested that muscle damage in Ironman triathlon might mainly occur from the run segment. [16] In the metabolic stress mechanism, muscle damage resulted from disturbance in cellular metabolism from extensive endurance exercise. Muscle glycogen deletion and insufficient ATP production are the primary factors of the metabolic stresses, as well as ischemia, hypoxia, ion concentration changes, and accumulation of waste products.[31] Those mechanical and metabolic stresses contribute to DOMS after Ironman race.

Physiological Responses after Ironman Triathlon

Inflammatory Responses

Due to various physiological demands during Ironman triathlon, inflammatory responses occur in the body of Ironman triathletes. These inflammatory responses may last several days after race. Although there are several studies that investigated inflammatory responses after ultra-endurance events,[32-34] there is limited data observing physiological stress responses after an Ironman triathlon.

A previous research examined systemic inflammatory responses and muscular stress for 19 days after an Ironman triathlon.[32] The study reported that total leukocyte counts, myeloperoxidase (MPO), polymorphonuclear (PMN) elastase, cortisol, creatine kinase (CK) activity, myoglobin, interleukin (IL)-6, IL-10, and high-sensitive C-reactive protein (hs-CRP) significantly increased immediately after the race compared to pre-race.[35] Although CK activity, myoglobin, IL-6, and hs-CRP had decreased 5 days post-race, they remained significantly higher than pre-race (Figure 3). After 19 days of the race, most blood parameters had returned to pre-race values. However, MPO and PMN elastase had significantly recused below pre-race values, while myoglobin and hs-CRP stayed significantly higher than pre-race (Table 3). These data demonstrated that the initial systemic inflammation provoked by an Ironman triathlon rapidly diminished within 24 hours post-race. However, a low-grade systemic inflammation lasted for at least 5 days after the race. Although a temporary dysfunction of the immune system was observed using biomarkers for systemic inflammation, pathological symptoms of infections or diseases were not taken into account in this study.

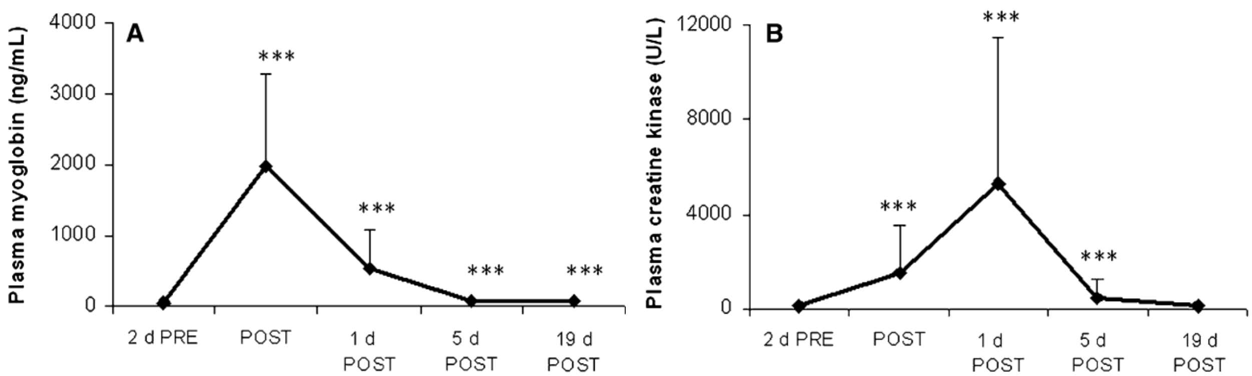

Figure 3. Changes in plasma myoglobin concentration (A) and plasma creatine kinase activity (B) 2 days pre-race, immediately post-race, 1 day post-race, 5 days post-race, and 19 days post-race.
***Significantly different from pre-race values ($p < 0.001$) [35]

Table 3. Plasma values of MPO, PMN elastase, cortisol, testosterone, and ration of testosterone and cortisol (n=42; Mean±SD)[35]

	Pre	**Post**	**1 Day Post**	**5 Days Post**	**19 Days Post**	**Time Effect (*p*)**
MPO (µg/L)	57±31	253±122*	97±82*	61±58	41±25*	<0.001
PMN elastase (µg/L)	46±23	239±137*	95±104*	44±31	36±16*	<0.001
Cortisol (nmol/L)	282±112	957±696*	149±66*	249±107	273±110	<0.001
Testosterone (nmol/L)	11.4±5.6	5.3±3.6*	5.5±2.9*	12.7±6.9	12.3±6.3	<0.001
Testosterone Cortisol Ratio	0.040±0.037	0.006±0.009*	0.037±0.027	0.051±0.036	0.045±0.032	<0.001

*Significantly different from pre-race values ($p < 0.001$)

There is another study that investigated inflammatory response and oxidative stress after an Ironman triathlon. [36] The results showed significant increases in thiobarbituric acid levels, lipid hydroperoxide content, protein carbonylation, superoxide dismutase, catalase, tumor nectosis factor alpha (TNF-α), IL-6, and IL-10 post-race compared to pre-race. The Increases in biomarkers post-race indicated that oxidative stress and systemic inflammation were induced by the Ironman triathlon. However, this study did not observe the alterations of biomarkers following days of the race in order to assess recovery.

Delayed-Onset Muscle Soreness

DOMS is defined as the sensation of discomfort or pain in the skeletal muscles that occurs following eccentric or unaccustomed muscular exercise. [37] The onset occurs around 24 hours after completing the exercise session, and generally peaks within 72 hours and gradually resolves in 5 to 7 days. Common symptoms of DOMS include pain, stiffness, swelling, and loss of muscle function. DOMS sometimes differentiates from immediate or acute muscle soreness, which is the other type of exercise-induced muscle soreness. [38] Despite of the frequent incidence of DOMS, the mechanism of DOMS has not been fully understood. There are 6 competing theories for the mechanism DOMS; lactic acid, muscle spasm, connective tissue damage, muscle damage, inflammation, and enzyme efflux. None of these theories are sufficient enough to explain the mechanism of DOMS by itself, thus it is common to name two or more theories to explain DOMS.[39,40]

Although previous research utilized different kinds of pain scales to assess DOMS after long distance triathlons, [4,41-43] a 10 mm visual analogue scale (VAS) was most commonly used. [41,42] The VAS has been proven to be a valid and reliable tool in order to quantify pain [44] and used in many studies following DOMS inducing exercises. [41,42,45,46] Previous studies that measured DOMS with a VAS after Ironman races demonstrated that pre-race DOMS was significantly lower than immediately, 1-day, and 2-day post-race. (Figure 4)[41,42]

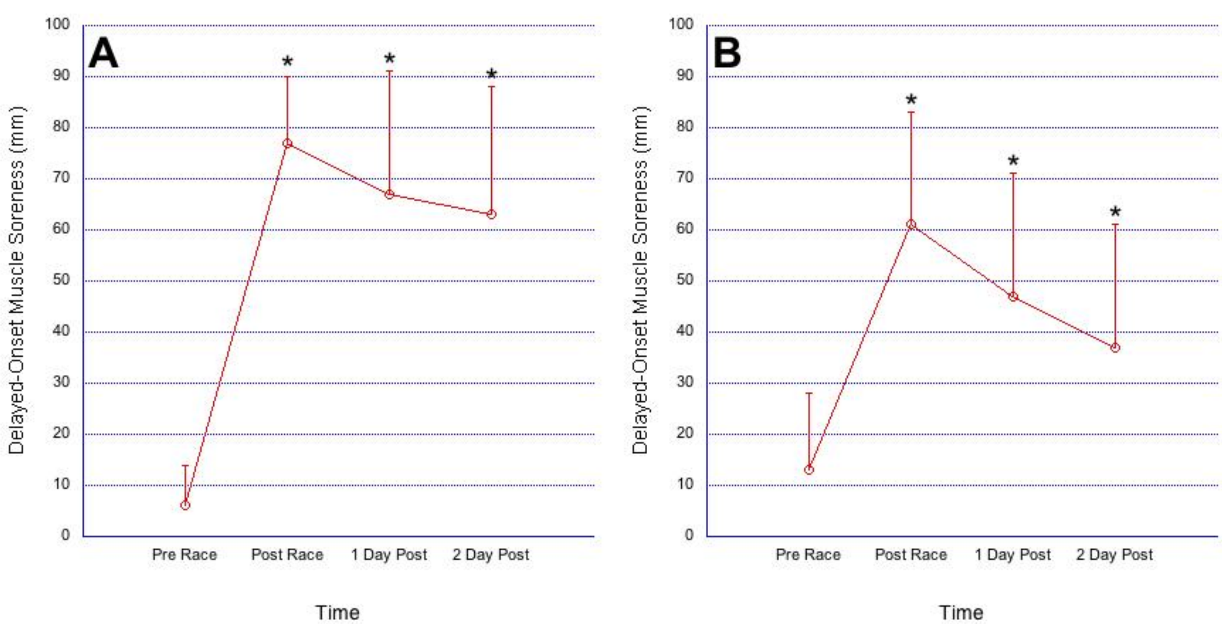

Figure 4. Visual analogue scales for delayed-onset muscle soreness after the 2011 (A) and 2012 (B) Ironman World Championships. * Significantly different from pre-race value (P<0.05) [41,42]

A study by Suzuki at al.[4] measured muscle soreness using a verbal rating scale after an Ironman race and indicated that muscle soreness immediately post-race and 1 day post-race were significantly higher than pre-race. This study also assessed biochemical markers of muscle damage and muscle function in relation to DOMS. Myoglobin, CK, lactate dehydrogenase, aspartate aminotransferase, and alanine aminotransferase were sampled as biochemical markers. The results reported that there was a lack of correlation between DOMS and biochemical markers. The authors explained that the lack of correlation might be because DOMS occurs with an inflammatory response, which may not be proportional to the muscle damage severity. This result is supported by a previous study that also examined the relationship between blood markers and DOMS. (Table 4)[47] Muscle function was measured with maximum isometric strength and vertical jump height in this study. Despite both maximum isometric strength and vertical jump height significantly decreased 1 day post-race compared to pre-race, there was a lack of correlation between DOMS and muscle function. In this study however, muscle soreness and function were not followed longer than 1 day post-race, limiting the analysis to this time frame.

Table 4. Correlation between muscle soreness and other indicators of muscle damage. SOR-Pal: mean soreness with palpation of the elbow flexors 1-4 days post-exercise, SOR-Ext: mean soreness when extending the elbow joint 1-4 days post-exercise, SOR-flx: mean soreness when flexing the elbow joint 1-4 days post-exercise, CK: plasma creatine kinase activity. *P<0.05[47]

	CK peak	**CK D1-4**
SOR-Pal	0.06	0.01
SOR-Ext	0.23*	0.19*
SOR-Flx	0.22*	0.19*

Ironman race results in a significant increase in inflammatory responses and DOMS. Those physiological changes remain for several days following race. A few studies have observed DOMS after Ironman races. However, to our knowledge, no study has been investigated recovery from DOMS more than 2 days after an Ironman triathlon.

Common Recovery Methods for DOMS

Numerous treatment strategies have been introduced to alleviate symptoms of DOMS and recover normal muscle function as quickly as possible. Some recovery interventions include cryotherapy, massage, stretching, compression garment, low-intensity exercise, and nutritional supplements. The efficacy and impact on DOMS vary depending on the interventions.

Cryotherapy

Cryotherapy is one of the most common interventions that have been used to treat DOMS. The superficial cold application results in decreased temperature of skin, subcutaneous tissues, muscles, and joints. Cutaneous receptors stimulated by the decrease in tissue temperature excite the sympathetic adrenergic fibers and cause vasoconstriction of local arterioles and venules. [39] In addition, cooled cells slow their rate of metabolism and decrease the occurrence of secondary cell hypoxia. [48] Both vasoconstriction and reduced metabolic rate of cells contribute to prevent further edema formation and decrease inflammatory processes.

Although several systematic reviews have been investigated the effects of cryotherapy on DOMS, the results have been inconsistent. Some systematic reviews supported that cyrotherapy is a beneficial strategy to reduce DOMS after strenuous exercise. [49-51] Conversely, the others concluded that cryotherapy is ineffective in the management of DOMS. [51,52] Most articles agreed that there is inconclusive evidence to support the use of cryotherapy for recovery in term of muscle strength, joint range of motion, and physiological parameters of DOMS. [49,51,52] However, methodological heterogeneity among studies exists regarding cooling agent, cooling duration, the frequency of cold application, and timing of application.

A previous study examined the effect of cryotherapy immediately following an Ironman triathlon on DOMS. [41] Immersion tubs with cold water at 10°C were used for 10 minutes as a cryotherapy intervention. This research reported that cold-water immersion immediately after race did not attenuate DOMS in Ironman triathelets. (Figure 5)

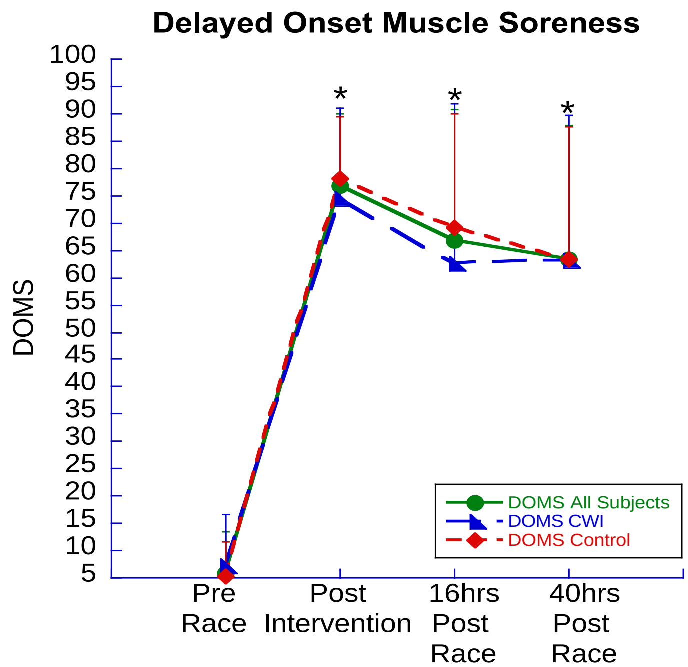

Figure 5. Delayed-Onset Muscle Soreness after 2011 Ironman World Championship between cold water immersion and control groups. *Significantly different from pre-race value based on all subjects.[41]

Massage

Massage has been used as a treatment for DOMS since antiquity. [53] It is proposed to increase local blood and lymph flow, decrease edema production, reduce muscle tone, enhance performance, and improve mood in addition to attenuation of DOMS. [54] The primary therapeutic massage strokes include effleurage, petrissage, friction, percussion, and vibration. [55] Combination of effleurage, petrissage, and vibration is often chosen as a massage intervention in research. [51,52,54] Three systematic reviews reported a positive evidence suggesting that massage attenuated DOMS. [51,52,54] Also, a meta-analysis demonstrated that post-exercise massage benefited in preventing reduction of muscle strength. [51] However, there were no evidence indicating that massage restored ROM and a conflicting evidence for the efficacy of massage on physiological parameters of DOMS.[52]

Stretching

Pre-exercise stretching had been believed as a prophylactic method for DOMS because it reduces muscle stiffness and makes muscle more durable to eccentric contractions, thereby resulting in decreasing muscle damage. [56] On the other hand, Post-exercise stretching is thought to alleviate the muscle spasm, which is one of the mechanisms of DOMS, consequently relieving DOMS. [52] Two recent meta-analyses reported that none of four stretching programs, combining of single or repeated, and pre- or post-exercise, showed a significant effect on muscle soreness or muscle strength. [51,57] A systematic review also concluded that there is little evidence that supports the effects of stretching on muscle soreness, muscle strength and ROM.[52]

Compression Garment

Compression has been used as one of the applications in RICE (Rest, Ice, Compression, Elevation) in order to reduce swelling during injury care for many years. [55] Recently, compression with compression garments has been used in sports. Compression garments are marketed as a means of performance enhancement and post-exercise recovery aid.

A recent study that assessed the efficacy of compression tights on DOMS after 100 plyometric drop jumps demonstrated that compression tights group had significantly lower perceived muscle soreness 1, 24, 48, and 72 hours post-exercise compared with non-compression tights group. [58] Another study that examined perceived muscle soreness between compression tights and control groups after 6 sets of 10 repetitions at 100% body weight followed by 5 seconds of one repetition maximum eccentric squat, reported no evidence that compression tights attenuated DOMS after the workout. [59] Although several studies have investigated using different type of compression garments, [60-63] there is a lack of consensus in the literature as to the effects and mechanisms of compression garments on DOMS.

Low-Intensity Exercise

Low-intensity exercise after strenuous workout, as known as active recovery, has been considered as one of the most effective treatment for relieving DOMS.[37,64] Low-intensity exercise is known to promote removal of lactate and metabolic byproducts after exercises by increasing blood flow.[64] It is also suggested that low-intensity exercise has an analgesic effect by increasing endorphin release.[56] A systematic review concluded that low-intensity exercise had some short-term effects to attenuate DOMS based on three randomized controlled trials.[52] However, the results from a meta-analysis reported that there was no significant effect of low-intensity exercise on DOMS and muscle strength.[51] The mode, duration, and timing of low-intensity exercises used in the studies were inconsistent. Therefore, further studies are necessary to provide evidences for the effects of low-intensity exercise intervention on DOMS.

Nutritional Intervention for DOMS

Nutritional supplementation has been one of popular interventions for DOMS. Supplements of carbohydrate (CHO), protein (PRO), and antioxidants (AOX), such as vitamin C and E, have been studied in relevance to recovery for DOMS. Prolonged strenuous exercise results in muscle damage, muscle protein degradation, and a depletion of glycogen stores in muscle and liver.[65] The primary purpose of CHO ingestion post-exercise is to restore muscle glycogen quickly and to improve the quality of the following exercise.[66] The magnified requirement for protein is due to increased muscle and whole-body turnover in addition to increased oxidation of amino acids during and after exercise.[65] AOX have been proposed to restrict excessive ROS generation after prolonged exercise. Excessive ROS impose oxidative stress on the tissue, resulting in temporary immune impairment.[28] However, the influences of ROS on DOMS remain unclear.[56] Studies that examined the effects of post-exercise nutritional supplementation on DOMS are listed on Table 5.

Table 5. Studies examining post-exercise nutritional interventions on attenuation of DOMS

First Author	Subjects	Damaging Exercise	Nutritional Intervention	Mode	Amount	Frequency	Timing	Ratio (CHO:PRO)	DOMS
Cockburn (2008)[67]	24 physically active males	6 sets of 10 reps eccentric-concentric knee flex on Cybex	1) CHO+PRO 2) CHO+PRO 3) CHO 4) Control	1) Chocolate Milkshake 2) Milk 3) Sports drink 4) Water	1) 118g CHO+33g PRO 2) 49g CHO+34g PRO 3) 64g CHO 4) Water	2	Immediately and 2 h after exercise	N/A	No significant differences among treatment groups at any point
Goh (2012)[46]	12 male cyclists	Ex1) 1 h high-intensity cycling intervals Ex2) simulated 20 km time trial	1) CHO 2) Low CHO+High PRO 3) High CHO+Low PRO	Beverages	1) 75g CHO 2) 8g CHO+55g PRO 3) 45g CHO+25g PRO	3	Immediately and 2 h after ex1, and immediately after ex2	N/A	No significant differences among treatment groups at any point
Green (2008)[45]	18 female recreational athletes	30 min intermittent downhill run	1) CHO 2) CHO+PRO 3) Placebo	Beverages	1) 1.2 g/kg CHO (x2), 0.6 g/kg CHO (x1) 2)1.2g/kg CHO+0.3 g/kg PRO (x2), 0.6 g/kg CHO+0.15 g/kg PRO (x1) 3) Noncaloric	3	Immediately, 30 min, and 60 min after run	4:1	No significant differences among treatment groups at any point
Luden (2007)[68]	36 NCAA Division I runner (11 males, 12 females)	Normal team training	1) CHO 2) CHO+PRO+AOX	Beverages	1) 1.46 g/kg CHO 2) 1.46g/kg CHO+0.365g/kg PRO+Vit C&E	5	within 30 min after each training section	4:1	Significantly lower after 5 d with CHO+PRO+AOX compared with CHO
Millard-Stafford (2005)[69]	8 runners (5 females, 3 males)	Ex1) 21 km run at 70% VO_2max followed by RTF at 90% VO_2max Ex2) RTF at 90% VO_2max	1) CHO+PRO+AOX 2) High CHO 3) Low CHO	Beverages	1) 0.8g/kg CHO+0.2g/kg PRO 2) 1.0/kg CHO 3) 0.6g/kg CHO	3	Immediately and 1h after Ex1, and after Ex2	4:1	CHO+PRO was significantly lower compared to high CHO. No significant difference between low and high CHO groups
Millard-Stafford (2005)[69]	24 runners (9 females, 15 males)	Ex1) 21 km run at 70% VO_2max followed by RTF at 90% VO_2max Ex2) RTF at 90% VO_2max	1) CHO+PRO+AOX 2) High CHO 3) Low CHO	Beverages	1) 0.8g/kg CHO+0.2g/kg PRO 2) 1.0/kg CHO 3) 0.6g/kg CHO	3	Immediately and 1h after Ex1, and after Ex2	4:1	CHO+PRO was significantly lower compared to high CHO. No significant difference between low and high CHO groups
Romano-Ely (2006)[70]	14 males	Bike ride to fatigue at 70% VO_2max	1) CHO+PRO+AOX 2) CHO	Beverages	1) 0.6g CHO+0.15 PRO+VitC&E, 1.49g/kg CHO+0.39g/kg PRO+Vit C&E 2) 0.8g CHO, 1.96g/kg CHO	2	During and after exercise	4:1	Peak DOMS was significantly lower in CHO+PRO+AOX than CHO
Saunders (2009)[71]	13 male cyclists	Computer-simulated 60 km cycling time trials	1) CHO 2) CHO+PRO	Beverages	1) 132g CHO 2) 132g CHO+ 32g PRO	12	During (x11) and after (x1) exercise	4:1	Post-exercise muscle soreness significantly increased in CHO group but not CHO+PRO group compared with pre-exercise
White (2008)[72]	27 untrained males	50 eccentric quadriceps contraction on Cybex	1) CHO+PRO 2) CHO+PRO 3) Placebo	Beverages	75g CHO+23g PRO	1	1) Before exercise 2) After exercise 3) Neither	3:1	No significant differences among treatment groups at any point

CHO Supplements

Although it is proven that CHO ingestion immediately after prolonged exercise increases muscle glycogen synthesis rates and attenuates muscle protein breakdown, [73] effects of CHO ingestion on DOMS have not been extensively examined. A previous study observed effects of post-exercise CHO ingestion on muscle soreness after 30 minutes of downhill treadmill running. The results indicated no significant difference in muscle soreness immediately post-exercise, and 1 day, 2 day, and 3 day post-exercise compared with placebo ingestion (Figure 6). [45] Other studies that investigated if pre-exercise CHO ingestion attenuates DOMS after downhill treadmill running, found no effect of pre-exercise CHO ingestion on DOMS. [74,75] Therefore, further research is needed to determine the effects of CHO supplementation on DOMS.

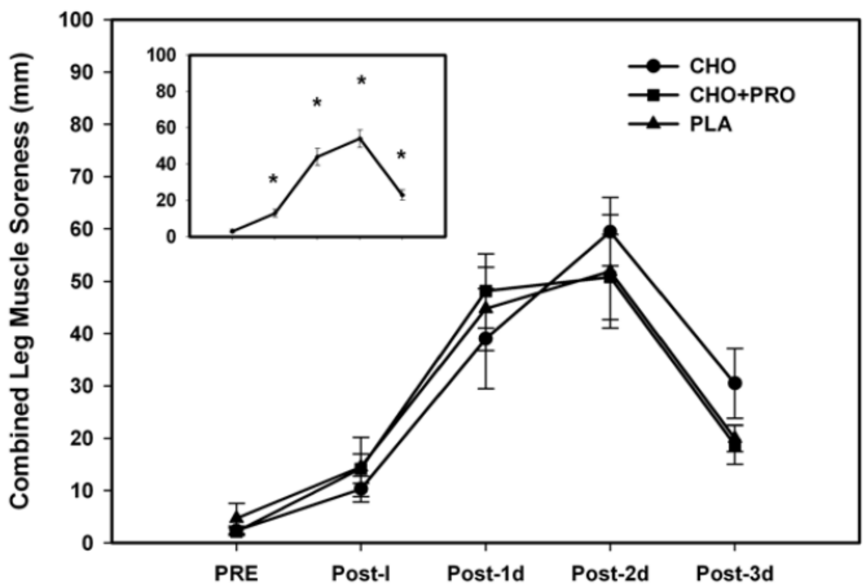

Figure 6. Lower extremity muscle soreness in carbohydrate (CHO), carbohydrate-protein (CHO+PRO), and placebo (PLA) groups at baseline (PRE), immediately after (Post-I), and on the days (Post-1d, Post-2d, and Post-3d) after downhill treadmill run. Inset shows data combined across groups. (mean ± SD, n=18)[45]

CHO+PRO supplements

Combined ingestion of a small dosage of PRO with CHO less than 1.0 g/kg/h has been shown to accelerate muscle glycogen synthesis after exercise. [73] However, the effects of post-exercise ingestion of

CHO and PRO on DOMS remain controversial based on previous studies.[45,46,67,72] Green et al.[45] used 30 min downhill treadmill running to examine post-workout muscle soreness comparing 3 beverage interventions (CHO, CHO-PRO, Placebo). There was no significant difference on muscle soreness among the interventions immediately post-exercise, and 1 day, 2 day, and 3 day post-exercise. Goh et al.[46] compared 3 calorically similar beverage interventions (CHO only, high CHO-low PRO, low CHO-high PRO), using two bouts of approximately 1 hour of high-intensity cycling intervals with 4 hours of recovery period between the bouts. The findings demonstrated no difference in muscle soreness at pre-exercise 1 (PreEx1), pre-exercise 2 (PreEx2), and 24 hours post-exercise (24Post) among 3 interventions (Table 6).

Table 6. Rating of muscle soreness in carbohydrate (CHO), low carbohydrate and high protein (LCHP), and high carbohydrate and low protein (HCLP) groups after cycling interval bouts (mean ± SD, n=12, mm)[46]

	PreEx1	PreEx2[a,b]	24Post[c]
CHO	10±11	36±18	25±23
LCHP	13±10	33±15	19±12
HCLP	16±17	39±19	25±17

[a] PreEX2 > PreEx1; [b] PreEx2 > 24Post; [c] 24Post > PreEx1

However, Saunders et al.[71] reported that coingestion of CHO and PRO significantly attenuated an increase in DOMS after a 60 km cycling time trial, while CHO ingestion showed a significant increase in DOMS. Therefore, additional data is required to determine if coingestion of CHO and PRO attenuate DOMS.

CHO+PRO+AOX

Isolated ingestion of CHO and coingestion of CHO and PRO do not appear to benefit to decrease in DOMS. However, several researchers reported that combined ingestion of CHO, PRO and AOX might produce synergistic effects in attenuating DOMS.[68-70] Luden et al.[68] investigated that the effects of post-exercise CHO+PRO+AOX beverage on muscle soreness in cross-country runners. Subjects ingested CHO only or CHO+PRO+AOX beverage immediately after each training session for six days. The results showed that muscle soreness was significantly lower in CHO+PRO+AOX intervention than CHO intervention after the training on Day 5. Romano-Ely et al.[70] compared the effects of two different beverages (CHO only or CHO+PRO+AOX) on muscle soreness after two bouts of high intensity cycling to fatigue. Subjects consumed the beverage every 15 minutes during exercise and immediately following the first bout. They found that muscle soreness was significantly lower in combined beverage than CHO only beverage 24 hours post-exercise. Muscle soreness returned to the baseline 72 hours after exercise (Figure 7).

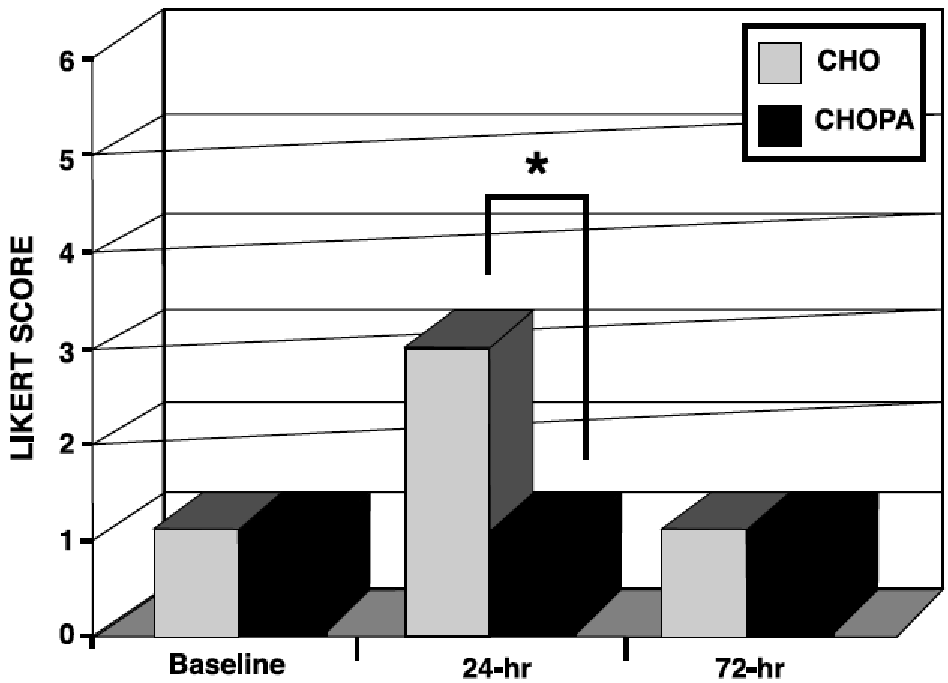

Figure 7. Median muscle soreness in Carbohydrate (CHO) and Carbohydrate-protein-antioxidant (CHOPA) trials at baseline, 24h, and 72h. $^{*}p < 0.05$ between treatments[70]

Timing of Supplementation

Timing of supplementation has been studied from the perspective of muscle glycogen synthesis post-exercise. Muscle glycogen synthesis after exercise takes place in two different phases. The first phase with rapid synthetic rates lasts the first 30-60 minutes after exercise, followed by the second phase with significantly slower synthetic rates,[73] but still greater than the normal rates[76] The rapid synthesis appears to be independent of blood insulin levels while the slower synthesis is characterized as the insulin dependent. CHO intake within 30 minutes post-exercise is reported to increase muscle glycogen synthesis rates compared with 2 hours post-exercise because of higher muscle insulin sensitivity in the early period after exercise. [77] Therefore, it is recommended that the time to start CHO restoration is within the first two hours after cessation of exercise.[78]

Amount/Frequency/Ratio of Supplementation

Amount, frequency, and ratio of supplements are often suggested for the purpose of maximizing post-exercise muscle glycogen restoration. It is proposed that optimal amount of CHO to maximize muscle glycogen replenishment post-exercise is 1.2 g/kg body weight (BW) every 15-30 minutes. [66] 0.2-0.5 g/kg BW protein added to CHO has been demonstrated to increase glycogen synthesis compared with CHO alone. [79] However, If CHO intake reaches 1.2 g/kg BW every 15-30 minutes, ingestion of protein with CHO does not further enhance muscle glycogen synthesis post-exercise. [80] Protein intake with CHO might increase muscle glycogen synthesis rates post-exercise when CHO is ingested less than 1.0g/kg BW. [73] To accelerate muscle glycogen synthesis, co-ingestion of CHO and PRO at a ratio of 3:1 (CHO:PRO) is recommended. [81] However, previous study that examined the influence of different ratios of CHO-PRO supplements (CHO:PRO 2:1, 3:1, 4:1) on muscle damage biomarkers and DOMS indicated that there was no difference between different ratios of CHO-PRO supplements on muscle soreness and biomarkers. Despite all 3 ratios of supplements decreased muscle damage markers 24 hours after exercise, they did not influence muscle soreness post-exercise.[82]

Due to biochemical evidences of post-exercise nutritional intervention, it is believed that nutritional supplementation after exercise may attenuate DOMS. Previous findings over the effect of post-exercise nutritional intervention on DOMS remain inconsistent. Moreover, post-exercise nutritional intervention for recovery from DOMS has been often studied combined with nutritional intervention during exercise or between bouts of exercises, however there are only a few studies purely focusing on post-exercise nutritional intervention. To our knowledge, post-race nutritional intervention for DOMS has not investigated in specific to Ironman triathletes.

Conclusion

Ironman triathletes spend approximately 8,000-10,000 kcal to complete a race. Even considering energy intake from food and drinks during the race, total energy balance post-race becomes approximately negative 5000-6000 kcal. Under such circumstances, muscle damage may be accelerated due to insufficient muscle glycogen, in addition to muscle damage caused by substantial mechanical stress during an Ironman triathlon. Data has shown that blood markers indicating muscle damage and inflammation significantly increase after the race, and then rapidly diminish within 24 hours post-race. However, low level of inflammation has been demonstrated to last for at least 5 days post-race. [35] Although Ironman triathletes often experience DOMS during this period, there is no data examining DOMS longer than 1 day after Ironman triathlon.

To attenuate DOMS after Ironman race, nutritional intervention is commonly used as well as other recovery interventions. Post-exercise ingestion of CHO, PRO, or both is evidenced to accelerate muscle glycogen and protein synthesis and prevent muscle protein breakdown. However, limited data is available in respect to nutritional intervention for recovery of DOMS. To our knowledge, no study has yet examined the effects of post-exercise nutritional intervention on DOMS in Ironman triathletes.

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INTRODUCTION

The Ironman triathlon is an ultra-endurance event that combines three distinct events. It consists of a 3.86 km swim, a 180.25 km bicycle ride, and a 42.20 km run, raced in that order without a break. This prolonged endurance exercise imposes substantial physiological demands on athletes' bodies, including energy demands, thermal stress, hydration demands, oxidative stress, and muscle damage[1,2] Therefore, Ironman triathletes often experience physiological repercussions such as Delayed-Onset Muscle Soreness (DOMS) for several days after the race. [1,3]

Several studies have reported a significant increase in biomarkers for inflammation and muscle damage immediately after Ironman triathlon.[1,3,4] The inflammatory responses rapidly diminished within 24 hours post-race, nevertheless, a low-grade inflammation lasted for at least 5 days after the race.[3] In correlation to increased inflammation and muscle damage biomarkers, a significant increase in DOMS has been observed immediately after the Ironman race and remained significantly elevated up to 2 days after race.[1,5,6] However, to our knowledge, there is no data examining DOMS after an Ironman triathlon longer than 2 day post-race.

It is important for Ironman triathletes to recover from muscle damages induced by a race and return to training in order to maintain their cardiovascular abilities and prepare for a next race. Various interventions are used to promote a quicker recover from DOMS. Common recovery interventions include cryotherapy, massage, stretching, compression garments, low-intensity exercise, and nutritional supplements.[7-9] Post-race nutritional needs are large, and as such, ingestion of carbohydrate (CHO) and protein (PRO) are needed by Ironman triathletes. It is evident that combined ingestion of CHO and PRO within few hours after exercise increases muscle glycogen and PRO synthesis and improves intramuscular PRO balance.[10] Although it is believed that post-exercise ingestion of CHO and supplements attenuate DOMS, only a few studies have specifically ingested those supplements after eliciting muscle damage. A previous study purely focusing on the effects of post-exercise ingestion of

CHO and PRO on DOMS reported that supplementation of CHO, PRO, or combination of two did not influence on DOMS after downhill treadmill running.[11] Another study demonstrated that co-ingestion of CHO and PRO following isokinetic eccentric exercise attenuated decreases in isokinetic muscle outputs and increase in blood markers for muscles damage but did not affect DOMS[12] These studies only observed DOMS following a much shorter event compared to an Ironman, and only measured it at one or two muscle groups during a movement, such as standing up or stepping down.

The evidence for effects of post-exercise nutritional supplement on DOMS remains controversial. Moreover, there is limited data available observing DOMS over an extended period of time after an Ironman race, where physiological damage may be greater. Therefore, the purpose of this study is to examine the effect of post-race co-ingestion of CHO and PRO on DOMS and the ability of triathletes returning to activity after an Ironman triathlon. We hypothesize that nutritional intervention will promote recovery from DOMS and facilitate a quicker return to activities in Ironman triathletes.

METHODS

Study Design

The protocol followed a randomized counter balanced design in a field setting. Participants in the 2013 Ironman Lake Placid were recruited to participate. The subjects were divided into two groups; a control group that received no intervention, and an intervention group that received a commercial recovery beverage following the race. For the main outcome measures, DOMS was evaluated via a Visual Analogue Scale (VAS) and Global Rating of Change (GRC).

Race

The Ironman triathlon race took place in Lake Placid on July 28, 2013 starting at 7:00 am. The race consisted of a 3.86 km swim, a 180.25 km bicycle ride and a 42.2 km run. Weather was cloudy with occasional rain. The highest temperature was 73 °F, the lowest temperature was 57 °F, and average humidity was 87 %.

Subjects

Thirty-six triathletes (Male: 30, Female: 6) competing in the 2013 Lake Placid Ironman triathlon volunteered to participate in this study (Table 1). Each subject completed medical and training history questionnaires to ensure that they met the following criteria: 1) no chronic health problems, 2) no previous history of exertional heat stroke with in the past 3 years, 3) no history of cardiovascular, metabolic or respiratory disease, 4) no current musculoskeletal injury that limits physical activity, 5) no known food allergies or intolerances, including but not limited to, lactose, milk PRO, nuts, and gluten, 6) planned to complete the Ironman race within 13 hours, and 7) was not pregnant at the time of the race. Prior to participation, subjects signed an informed consent form and were familiarized with the testing procedures. This study was approved by the Institutional Review Board at the University of Connecticut.

Table 1. Demographic Characteristics (mean ± SD, n=36)

	Age (years old)	Height (cm)	Weight (kg)	Body Fat (%)
Intervention (n=15; male=12, female=3)	35 ± 9	177 ± 10	75.7 ± 11.8	10.1 ± 3.1
Control (n=21; male=18, female=3)	41 ± 7	179 ± 8	77.8 ± 10.7	13.6 ± 6.2

Experimental Procedure

Data collection began 1 day prior to the race. Anthropometric measurements (height, weight, body composition), VAS, GRC, and a sit-and-reach test were completed for baseline measures and to familiarize the subjects with study procedures. Body composition was measured with a skinfold caliper. On the race day, baseline measurements for VAS and sit-and-reach test were taken prior to the race. In addition, a diet log for the day before race was recorded by subjects. During the race, subjects were not stopped/interrupted for any study procedures. Upon finishing the race, subjects were randomly assigned to either the intervention or control group by finish time and sex, so that every other female or male subject was assigned to the same group. This helped to create homologous groups based on the ability, sex and race performance of subjects. Official finish times for the race were obtained from the Ironman website for statistical analysis.[13] Both groups completed a diet log for food consumed during the race. The intervention group was asked to ingest two recovery beverages (described below) within 1 hour post-race. In addition, subjects completed a sit-and-reach test, VAS, and GRC after which they were allowed to leave. All subjects were asked to return 3-hour post-race to fill out questionnaires for VAS and GRC. At this time, the intervention group ingested another two recovery beverages. Sit-and-Reach test was not performed due to an equipment issue at this time. All subjects were allowed to consume food and fluid ad libitum anytime. The following morning (12h post), all subjects were asked to return to collect VAS, GRC, sit-and-reach test measures and provide a diet log for all items consumed following the race. All other data collection following 12h post race was done via the online survey system

(Qualtrics, Provo, UT) which was used everyday up to 7 days post-race for return to activity questionnaires, VAS and GRC at 11 time points (1, 2, 3, 4, 5, 6, 7, 8, 10, 12, 14 days post-race). The schematic illustration of the testing protocol is shown in Figure 1.

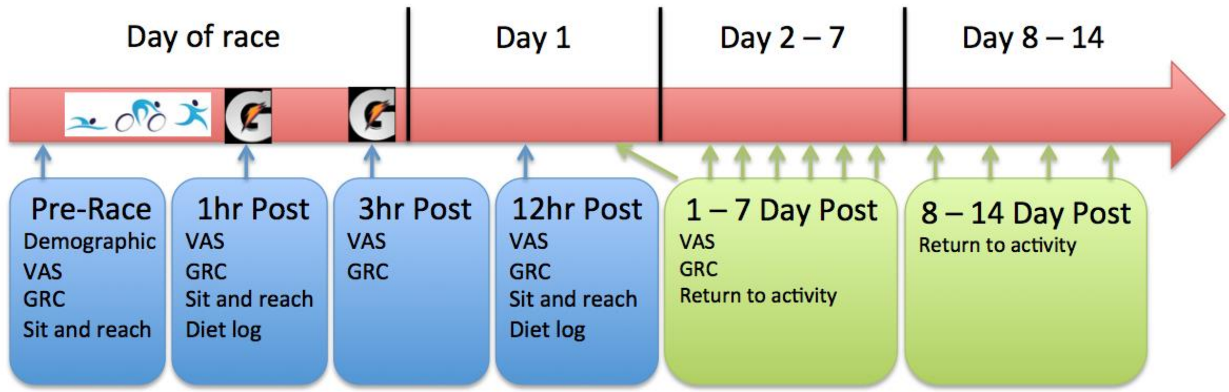

Figure 1. Schematic of testing protocol

Nutritional Intervention

A FDA approved recovery beverage (Gatorade Company, Chicago, IL) was used for post-race nutritional intervention to replenish carbohydrate and PRO stores. Per bottle (330ml), each recovery beverage contained 270 kcal (CHO 45 g, PRO 20 g, fat 1 g). PRO in recovery shake consisted of milk and whey PRO. The intervention group ingested 2 bottles of recovery beverage within 1 and also 3 hours post-race, for a total of 4 bottles, 1080 kcal, 180 g of CHO, 80 g of PRO, and 4 g of fat. All procedures took place under the supervision of the research team who also ensured that subjects were consuming the recovery beverage as prescribed.

Muscle Soreness Measurement

VAS and GRC was used to assess DOMS in a paper form for on-site data collection and digital form for online surveys. Paper-based VAS consisted of a 10 cm line with “no soreness” (0 cm) on the left end and “unbearable pain” (10 cm) on the right end. Subjects put a vertical mark on the VAS to rate their perceived muscle soreness. Digital VAS was identical to the paper-based VAS except subjects moved a pointer to rate their DOMS (Appendix A). Both paper-based and online GRC consisted of a 11 point scale with “very much worse” on the left, “unchanged” on the middle, and “completely recovered” on the right as recommended by the previous study (Appendix B).[14] Subjects rated the change of soreness compared to baseline or the last measurement. DOMS was assessed at 5 body regions (whole body, anterior and posterior thighs, calves, and lower back) while standing up straight (static) and standing up from a chair (active).

Flexibility Measurement

Sit-and-reach test was used to measure hamstring, hip, and lower back flexibility following the standard procedures recommended by American College of Sports Medicine.[15] The subject was instructed to remove their shoes, sit at a right angle with legs extended, feet positioned against the measuring box, and toes pointed upward. The subject then slowly reached forward with both hands as far as possible and held the position for 2 seconds. Fingertips of both hands should be in contact with the measuring portion. The most distant point reached with the fingertips was measured. Subjects performed two trials and the higher score was recorded.

Return to Activity

Subjects reported their Daily physical activity, including type, length, and intensity of exercises for 2 weeks after race via the online survey system (Appendix C). From the data, the first day of return to activity and total activities during the first week after race were analyzed.

Diet Log

Food and fluid intakes for the day before race and the day of race were recorded on diet log. Subjects were asked to keep time, type of food or fluid, and amount as detailed as possible. The nutrition software (The Food Processor; ESHA, Salem OR) was used to calculate consumed calories, CHO, PRO, and fat.

Statistical Analysis

Means and standard deviations were computed for each dependent variable. A repeated measures two-away ANOVA (group x time) for VAS and sit-and reach test was performed. Independent t-tests were used to determine differences in subject demographics, finish time, GRC, delta scores for the sit-and reach test, return to activity parameters, and nutritional intakes. For all analyses, the alpha level was set at $P<0.05$. Data was analyzed with the statistical analytical software (SPSS Version 21; IBM Corporation, Armonk, NY) Hedge's effect size was calculated for VAS, GRC, and nutritional intakes.

RESULTS

There was no significant difference in demographic characteristics between groups (P>0.05) (Table 1). Both groups had similar finish times (Intervention: 712±103 mins, Control: 747±112 mins, Average: 732±108 mins) (P>0.05).

Visual Analogue Scale

The scores of VAS significantly increased 1-hour post-race compared to pre-race for both static and active DOMS at all body regions (P<0.05) (Figure 2 & 3). VAS 1-hour post-race at all body regions represented the peak value for both static (whole body: 48±22 mm, anterior thighs: 45±25 mm, posterior thighs: 44±28 mm, calves: 44±27 mm, lower back: 27±24 mm) and active (whole body: 49±25 mm, anterior thighs: 56±25 mm, posterior thighs: 47±30 mm, calves: 36±24 mm, lower back: 28±24 mm) DOMS. After 1-hour post-race, DOMS slowly declined but still remained significantly elevated for several days. Static DOMS in calves and lower back returned to the pre-race value three days after race followed by whole body and posterior thighs (5 days) and anterior thighs (6 days) while active DOMS in lower back returned to the pre-race value three days after race followed by calves (4 days), whole body (5 days), and anterior and posterior thighs (7 days). However, there was no difference in static and active DOMS between intervention and control groups at any time points (P>0.05). Due to none of the significance between groups Hedge's effect size was performed. (Table 2)

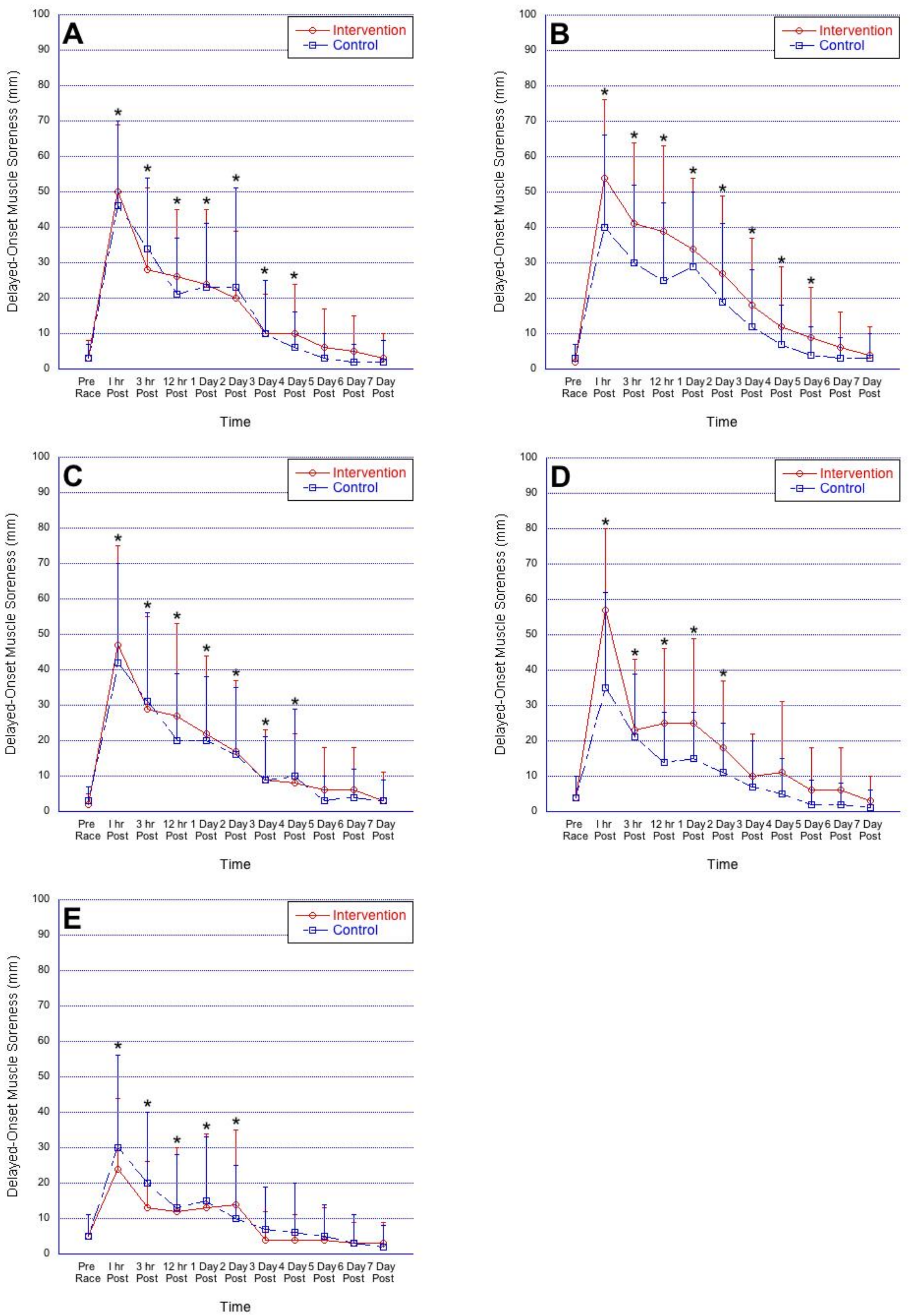

Figure 2. Visual analogue scales for static delayed-onset muscle soreness in whole body (A), anterior thighs (B), posterior thighs (C), calves (D), and lower back (E) after Ironman triathlon. (mean ± SD, n=36) *Significantly different from pre-race value in both groups (P<0.05)

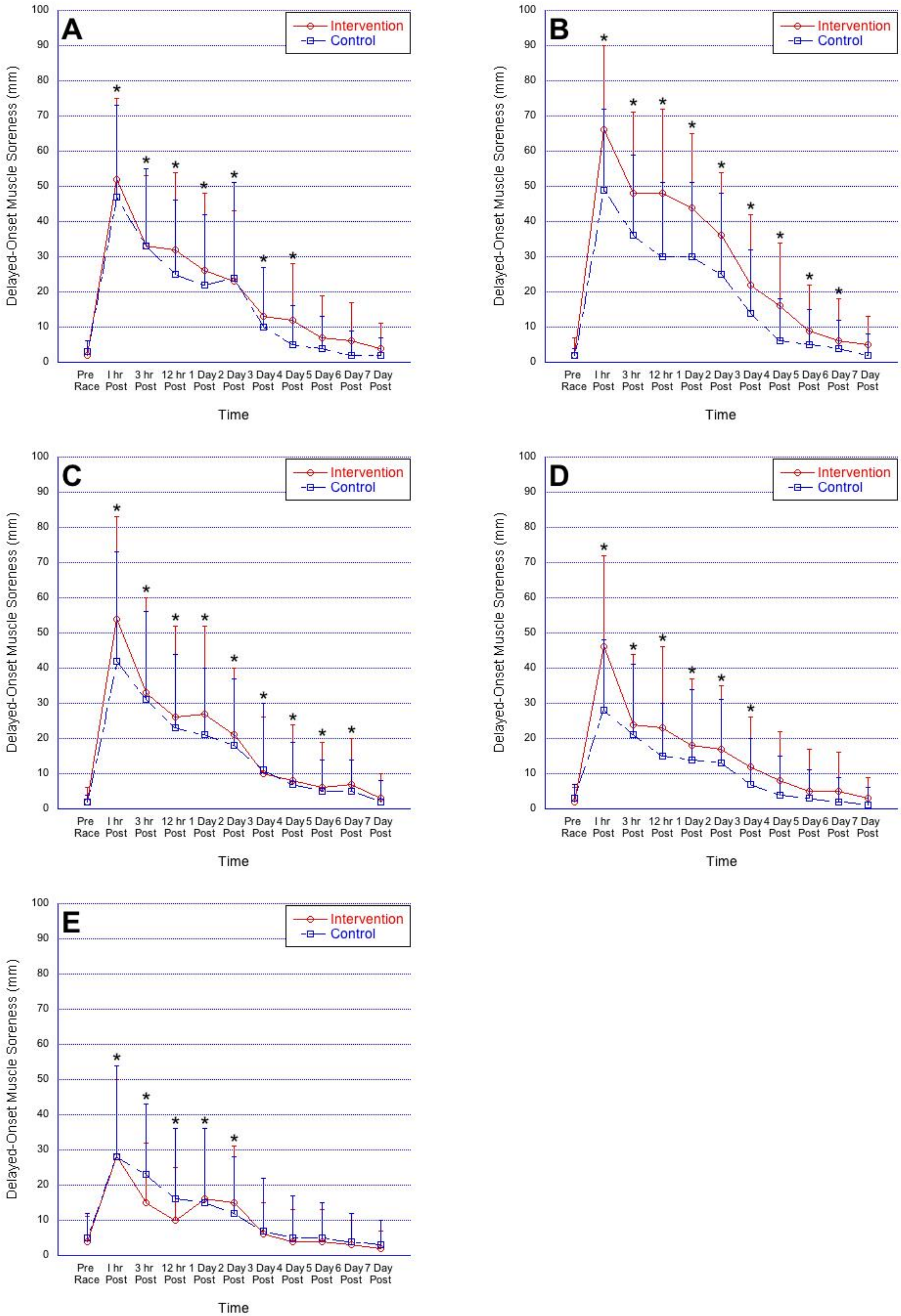

Figure 3. Visual analogue scales for active delayed-onset muscle soreness in whole body (A), anterior thighs (B), posterior thighs (C), calves (D), and lower back (E) after Ironman triathlon. (mean ± SD, n=36) *Significantly different from pre-race value in both groups ($P<0.05$)

Table 2. Hedge's effect sizes for mean differences between groups for visual analogue scale

VAS for Static DOMS

	Whole Body	Anterior Thigh	Posterior Thigh	Calves	Lower Back
Pre-Race	-0.07	0.12	0.34	0.08	-0.01
I-hr Post	-0.20	-0.58	-0.16	-0.87	0.25
3-hr Post	0.29	-0.49	0.09	-0.11	0.38
12-hr Post	-0.27	-0.61	-0.32	-0.59	0.05
1-Day Post	-0.02	-0.22	-0.10	-0.55	0.07
2-Day Post	0.11	-0.36	-0.04	-0.42	-0.24
3-Day Post	-0.06	-0.31	-0.02	-0.23	0.21
4-Day Post	-0.34	-0.36	0.12	-0.41	0.19
5-Day Post	-0.27	-0.46	-0.27	-0.42	0.15
6-Day Post	-0.52	-0.40	-0.22	-0.47	-0.04
7-Day Post	-0.19	-0.24	-0.13	-0.27	-0.04

VAS for Active DOMS

	Whole Body	Anterior Thigh	Posterior Thigh	Calves	Lower Back
Pre-Race	0.16	-0.03	0.23	0.15	0.17
I-hr Post	-0.21	-0.70	-0.41	-0.80	0.00
3-hr Post	0.02	-0.53	-0.06	-0.14	0.43
12-hr Post	-0.30	-0.78	-0.14	-0.45	0.33
1-Day Post	-0.19	-0.66	-0.29	-0.23	-0.05
2-Day Post	0.05	-0.53	-0.17	-0.22	-0.24
3-Day Post	-0.16	-0.44	0.08	-0.40	0.08
4-Day Post	-0.47	-0.64	-0.08	-0.29	0.07
5-Day Post	-0.37	-0.39	-0.10	-0.27	0.15
6-Day Post	-0.39	-0.20	-0.18	-0.26	0.11
7-Day Post	-0.36	-0.39	-0.13	-0.26	0.19

Global Rating of Change

GRC for static DOMS demonstrated negative scores only for 1-hour post-race and positive scores for other time points. (Figure 4) Data of GRC for active DOMS 1- and 3-hour post-race was missed. Significant differences in static GRC between groups occurred in anterior thighs and claves 1-hour post-race and posterior thighs 2-day post-race while active GRC showed significant differences in whole body and calves 1-day post-race and anterior and posterior thighs 2-day post-race. ($P<0.05$) (Figure 5) Hedge's effect size was shown in Table 3.

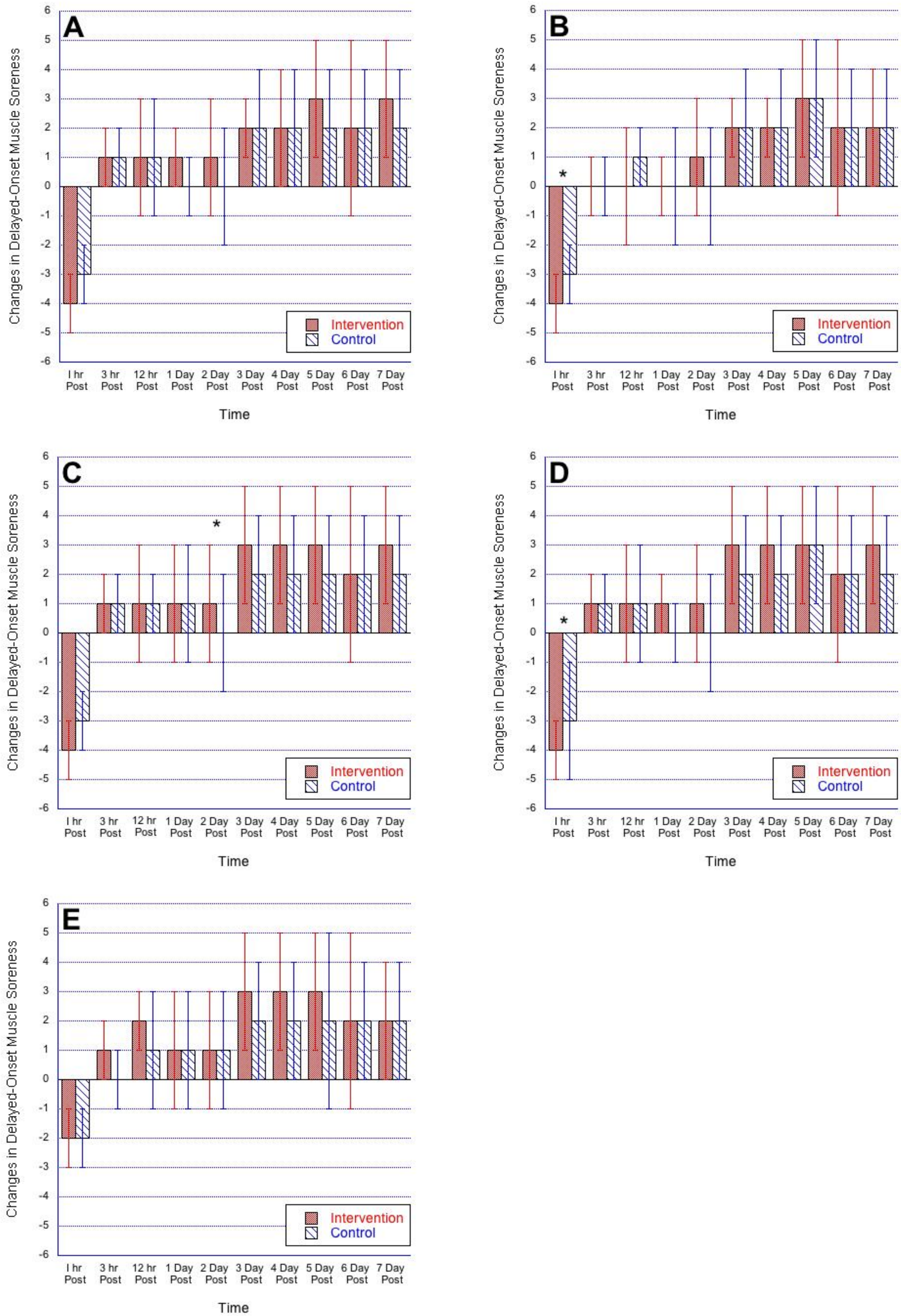

Figure 4. Global rating of change for static delayed-onset muscle soreness in whole body (A), anterior thighs (B), posterior thighs (C), calves (D), and lower back (E) after Ironman triathlon. (mean ± SD, n=36) * Significantly different between groups ($P<0.05$)

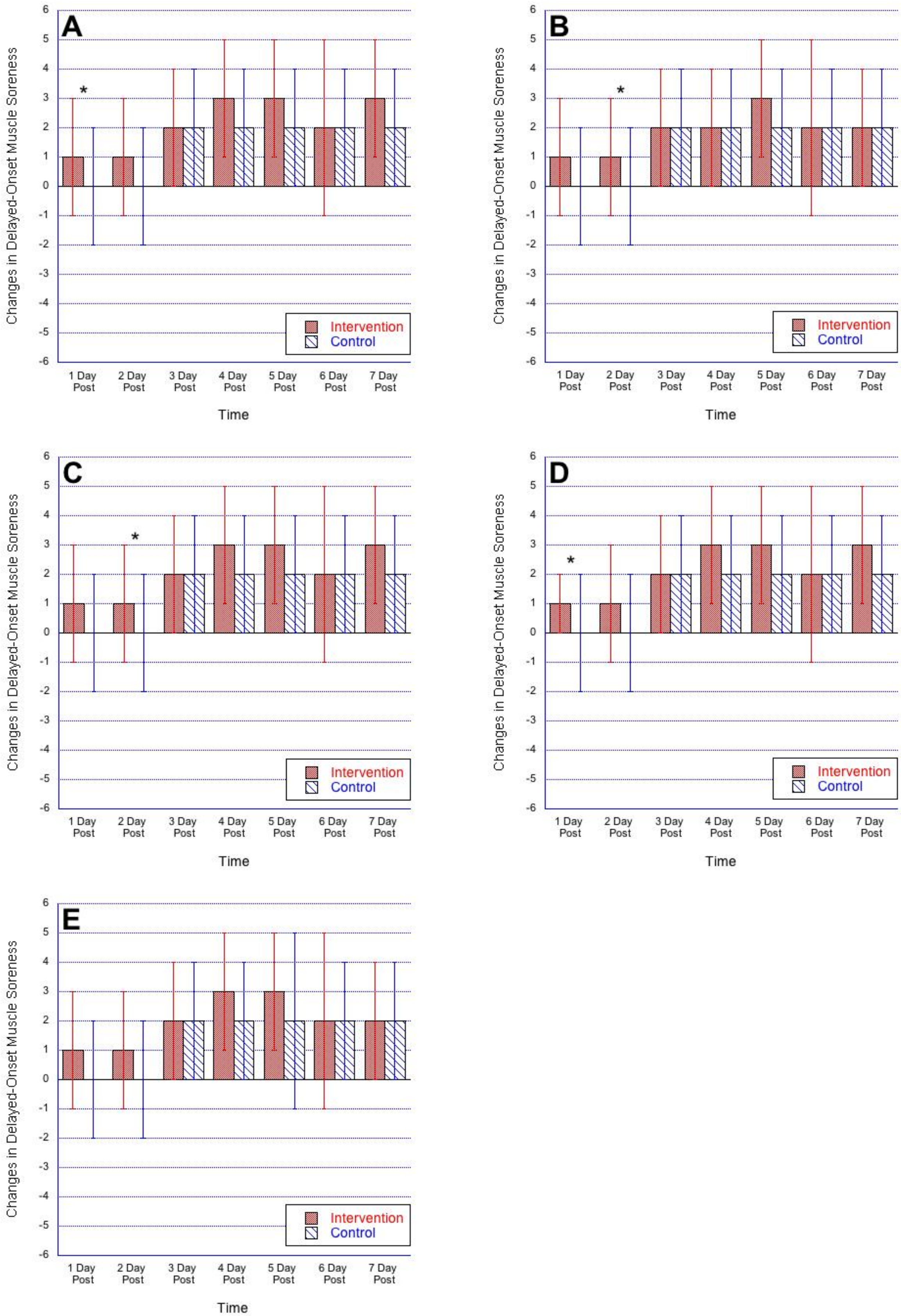

Figure 5. Global rating of change for active delayed-onset muscle soreness in whole body (A), anterior thighs (B), posterior thighs (C), calves (D), and lower back (E) after Ironman triathlon. (mean ± SD, n=36) * Significantly different between groups (P<0.05)

Table 3. Hedge's effect sizes for mean differences between groups for global rating of change

GRC for Static DOMS

	Whole Body	Anterior Thigh	Posterior Thigh	Calves	Lower Back
I-hr Post	0.54	0.90	0.45	1.03	0.01
3-hr Post	-0.21	-0.12	-0.38	0.21	-0.64
12-hr Post	0.06	0.30	0.02	-0.10	-0.25
1-Day Post	-0.52	-0.30	-0.20	-0.50	-0.03
2-Day Post	-0.53	-0.67	-0.71	-0.44	-0.11
3-Day Post	-0.23	-0.34	-0.35	-0.44	-0.18
4-Day Post	-0.24	-0.28	-0.62	-0.55	-0.40
5-Day Post	-0.09	0.01	-0.20	-0.31	-0.27
6-Day Post	0.15	-0.04	0.08	0.03	0.19
7-Day Post	-0.19	-0.05	-0.21	-0.22	-0.10

GRC for Active DOMS

	Whole Body	Anterior Thigh	Posterior Thigh	Calves	Lower Back
1-Day Post	-0.90	-0.47	-0.44	-0.67	-0.12
2-Day Post	-0.42	-0.75	-0.71	-0.34	-0.23
3-Day Post	-0.22	-0.16	-0.22	0.05	-0.07
4-Day Post	-0.35	-0.28	-0.60	-0.66	-0.39
5-Day Post	-0.12	-0.11	-0.28	-0.30	-0.24
6-Day Post	0.05	-0.08	-0.03	-0.12	0.11
7-Day Post	-0.22	-0.08	-0.06	-0.25	-0.16

Sit-and-Reach Test

Sit-and-reach scores were significantly lower at 1-hour post-race and 12-hour post-race compared to pre-race, however there was no significant difference between groups at any time point. ($P<0.05$) (Figure 6) Changes in sit-and-reach score from pre-race revealed no significant difference between groups. (P>0.05)

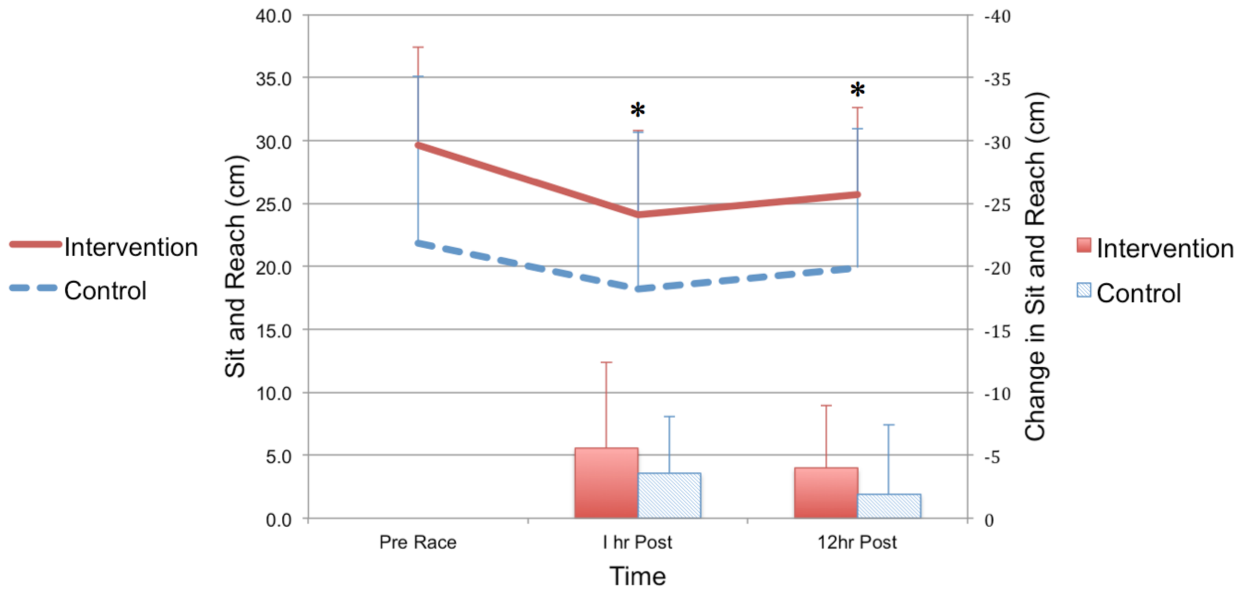

Figure 6. Sit-and-reach test and its changes after Ironman triathlon. (mean ± SD, n=36) *Significantly different from pre-race value in both groups (P<0.05)

Return to Activity

For the first day of return to activity, intervention group exhibited significantly longer activity length than control group. (P<0.05) (Table 4) However, there were no significant differences in days for return to activity, RPE, and type of activities. (P>0.05) In total activities in the first week, average RPE was significantly higher in control group than intervention group. (P<0.05) (Table 5) There was no significant difference in days, length, and type of activities. (P>0.05) In addition, training history questionnaire revealed that there was no difference in average hours per week and type of activities. (p>0.05) (Table 6)

Table 4. First day of return to activity after Ironman race (mean ± SD, n=36) * Significantly different between groups (P < 0.05)

	Return to Activity (days)	Total Activity Hours (hrs)	RPE	Swim (hrs)	Bike (hrs)	Run (hrs)	Resistance Training (hrs)	Other Exercises (hrs)
Intervention (n=15)	4 ± 4	1.2 ± 0.5 *	10 ± 4	0.1 ± 0.2	0.3 ± 0.5	0.0 ± 0.0	0.2 ± 0.4	0.6 ± 0.8
Control (n=21)	4 ± 2	0.8 ± 0.4	10 ± 3	0.2 ± 0.3	0.2 ± 0.4	0.1 ± 0.4	0.1 ± 0.2	0.2 ± 0.3

Table 5. Total activities during the first week after Ironman race (mean ± SD, n=36) * Significantly different between groups (P < 0.05)

	Total Activity Days (days)	Total Activity Hours (hrs)	Average Activity Hours per Day (hrs)	Average RPE	Swim (hrs)	Bike (hrs)	Run (hrs)	Resistance Training (hrs)	Other Exercises (hrs)
Intervention (n=15)	3 ± 2	5.0 ± 5.4	1.2 ± 0.9	9 ± 2 *	1.0 ± 1.6	1.3 ± 1.9	0.5 ± 0.7	0.2 ± 0.5	2.0 ± 3.2
Control (n=21)	4 ± 2	6.2 ± 10.1	1.6 ± 2.5	11 ± 2	1.4 ± 2.7	2.5 ± 5.3	1.3 ± 1.1	0.6 ± 1.8	0.6 ± 0.7

Table 6. Training history in Ironman triathletes (mean ± SD, n=36)

	Average Hours per Week (hrs)	Swim (hrs)	Bike (hrs)	Run (hrs)	Resistance Training (hrs)
Intervention (n=15)	16.1 ± 4.0	3.2 ± 1.8	7.9 ± 2.3	4.2 ± 1.0	0.8 ± 0.9
Control (n=21)	14.3 ± 2.5	2.4 ± 1.1	7.0 ± 1.7	4.2 ± 1.0	0.7 ± 0.7

Energy Intake

Diet record analysis calculated energy intake on day before race, race day, during race and after race. (Table 7) The results revealed significant differences in CHO, PRO and fat on the race day, and PRO and fat after race between groups. (P<0.05) Total calorie intake did not differ between groups anytime (P>0.05). Hedge's effect size supported the statistical findings for energy intake. (Table 8) Intervention group obtained 58±15 % of total calories, 64±14 % of CHO, 74±12 % of PRO, and 17±12 % of fat from recovery beverage after race. The ratio of CHO to PRO in intervention group was 3:1 while that in control group was 4:1. Beside energy intake, energy intake per body weight was calculated, which demonstrated significant difference in CHO, PRO, and fat on the race day, CHO during race, and PRO and fat after race. (P<0.05) (Table 9) Energy intake differences in males and females are shown in Table 10 and energy intake per hour during race is shown in Table 11.

Table 7. Energy intake day before race, race day, during race, and after race in Ironman triathletes (mean ± SD, n=36) * Significantly different between groups (P<0.05)

Day Before Race

	Total Calories (kcal)	Carbohydrate (g)	Protein (g)	Fat (g)
Intervention (n=15)	2794 ± 942	383 ± 164	114 ± 48	92 ± 30
Control (n=21)	3003 ± 942	396 ± 137	122 ± 37	104 ± 41

Race Day

	Total Calories (kcal)	Carbohydrate (g)	Protein (g)	Fat (g)
Intervention (n=15)	5581 ± 887	1087 ± 170*	163 ± 32*	66 ± 26*
Control (n=21)	5069 ± 1687	888 ± 297	132 ± 52	103 ± 57

During Race

	Total Calories (kcal)	Carbohydrate (g)	Protein (g)	Fat (g)
Intervention (n=15)	3034 ± 912	697 ± 200	37 ± 28	15 ± 10
Control (n=21)	2629 ± 956	566 ± 199	43 ± 22	16 ± 18

After Race

	Total Calories (kcal)	Carbohydrate (g)	Protein (g)	Fat (g)
Intervention (n=15)	1997 ± 567	294 ± 73	111 ± 18*	37 ± 23*
Control (n=21)	1859 ± 1271	226 ± 173	67 ± 47	72 ± 57

Table 8. Hedge's effect size for mean differences between groups for energy intake

	Total Calories	Carbohydrate	Protein	Fat
Day Before Race	0.22	0.09	0.19	0.33
Race Day	-0.36	-0.79	-0.69	0.79
During Race	-0.43	-0.66	0.24	0.07
After Race	-0.13	-0.48	-1.16	0.76

Table 9. Energy intake per body weight day before race, race day, during race, and after race in Ironman triathletes (mean ± SD, n=36) * Significantly different between groups (P<0.05)

Day Before Race

	Total Calories (kcal/kg)	Carbohydrate (g/kg)	Protein (g/kg)	Fat (g/kg)
Intervention (n=15)	37 ± 13	5.2 ± 2.4	1.5 ± 0.6	1.2 ± 0.3
Control (n=21)	39 ± 14	5.2 ± 2.0	1.6 ± 0.5	1.4 ± 0.6

Race Day

	Total Calories (kcal/kg)	Carbohydrate (g/kg)	Protein (g/kg)	Fat (g/kg)
Intervention (n=15)	76 ± 17	14.7 ± 3.3 *	2.2 ± 0.5 *	0.9 ± 0.4 *
Control (n=21)	66 ± 23	11.5 ± 3.9	1.7 ± 0.8	1.3 ± 0.8

During Race

	Total Calories (kcal/kg)	Carbohydrate (g/kg)	Protein (g/kg)	Fat (g/kg)
Intervention (n=15)	40 ± 12	9.3 ± 2.6 *	0.5 ± 0.4	0.2 ± 0.1
Control (n=21)	34 ± 11	7.2 ± 2.2	0.6 ± 0.3	0.2 ± 0.2

After Race

	Total Calories (kcal/kg)	Carbohydrate (g/kg)	Protein (g/kg)	Fat (g/kg)
Intervention (n=15)	28 ± 10	4.1 ± 1.4	1.5 ± 0.4 *	0.5 ± 0.3 *
Control (n=21)	25 ± 18	3.0 ± 2.4	0.9 ± 0.6	0.9 ± 0.8

Table 10. Energy intake in male and female Ironman triathletes (mean ± SD, n=36) * Significantly different between groups (P<0.05)

Day Before Race

	Total Calories (kcal)	Carbohydrate (g)	Protein (g)	Fat (g)
Males (n=30)	3053 ± 942*	409 ± 153	123 ± 40	104 ± 37*
Females (n=6)	2230 ± 538	300 ± 48	94 ± 43	70 ± 22

Race Day

	Total Calories (kcal)	Carbohydrate (g)	Protein (g)	Fat (g)
Males (n=30)	5553 ± 1150*	1018± 212	144 ± 45	94 ± 52
Females (n=6)	3930 ± 1934	737 ± 406	140 ± 63	57 ± 21

During Race

	Total Calories (kcal)	Carbohydrate (g)	Protein (g)	Fat (g)
Males (n=30)	2972 ± 854*	661 ± 178*	41 ± 24	16 ± 17
Females (n=6)	1928 ± 976	421 ± 242	41 ± 30	16 ± 6

After Race

	Total Calories (kcal)	Carbohydrate (g)	Protein (g)	Fat (g)
Males (n=30)	2027 ± 1019	265 ± 142	89 ± 41	63 ± 51
Females (n=6)	1363 ± 965	203 ± 145	71 ± 54	30 ± 19

Table 11. Energy intake per hour during race in male and female Ironman triathletes (mean ± SD, n=36) * Significantly different between groups (P<0.05)

	Total Calories (kcal/hour)	Carbohydrate (g/hour)	Protein (g/hour)	Fat (g/hour)
Males (n=30)	247 ± 69*	55 ± 15	3.3 ± 1.9	1.3 ± 1.2
Females (n=6)	165 ± 103	37 ± 25	3.1 ± 2.0	1.3 ± 0.6

DISCUSSION

The purpose of this study was to examine the effects of post-race nutritional intervention on DOMS and return to activity. Similar to previous studies investigating DOMS in triathletes,[5,6] DOMS significantly increased immediately after race compared to pre-race and remained significantly elevated up to 2 – 6 day post-race depending on body regions. Our primary findings demonstrated that, within the confines of this study, the ingestion of a recovery beverage after Ironman race did not attenuate DOMS or result in a quicker return to activity in the intervention group. However, the nutritional intervention resulted in a significant increase in PRO intake and decrease in fat intake post-race.

Physiological Effects of Recovery Beverage

Post-race nutritional beverages aim to facilitate recovery from DOMS by replenishing intramuscular glycogen and improving muscle PRO balance between PRO synthesis and breakdown, which could enable Ironman triathletes to return to training quicker and provide longer preparation for the next race. Eccentric contractions during prolonged endurance exercises result in increased PRO breakdown rate and stimulated PRO synthesis in skeletal muscles.[16,17] Without nutrient intake, muscular catabolism occurs because muscle PRO balance remains negative after strenuous exercises.[17] Therefore, increasing in availability of intramuscular PRO is essential to repair damaged muscle tissues. Ingestion of CHO after resistance exercise has been shown to improve muscle PRO balance by suppressing muscle breakdown but have little effects on PRO synthesis.[18] However, despite an increased muscle PRO balance, intake of CHO alone does not return PRO balance; the muscle is in a catabolic state.[18] On the other hand, post-exercise PRO ingestion is shown to improve muscle PRO balance, by increasing the PRO synthesis rate but it does not alter muscle breakdown rate.[19] A previous study reported that infusion of amino acids after resistance exercise amplified muscle PRO synthesis by 200%.[20] Miller at al.[21] demonstrated that ingestion of combined CHO and PRO after resistance exercise had the largest net PRO balance followed by PRO alone and CHO alone. This increase in PRO balance with combined ingestion of CHO and PRO was also due to enhanced PRO synthesis, which results from synergistic effect of insulin stimulation and adequate intramuscular PRO availability. This data suggests that PRO and CHO may have positive effects on recovery within an exercise session and timing of its ingestion.

DOMS After Ironman Race

Within this study observed the highest value of DOMS immediately after race, which then gradually subsided and returned to the pre-race value 2 to 6 days after race. A previous study that used downhill treadmill running as a DOMS inducing exercise showed DOMS significantly elevated immediately after the exercise but continued to rise and peaked 2 days post-exercise.[11] This is in opposition to the peak value we observed for our DOMS data, but may have occurred because Ironman triathlon is an extremely extended exercise that causes magnificent muscle damages during race. Our results support previous studies reporting the height value for DOMS immediately after race in Ironman triathletes.[5,6] Those studies used VAS to measure only static DOMS for whole body observing 77±13 mm[6] and 61±23 mm[5] as the peak values, which were greater than that in this study (48±22 mm). Although the reason the previous studies demonstrated a higher value for DOMS remains unclear, potential explanations may be due to a different competition level or environmental conation. Both of the previous studies were conducted at the Ironman World Championships in Kailua-Kona, Hawaii in October. Only qualified elite triathletes are able to participate in the Ironman World Championships, therefore average finish time of the subjects in the previous study (663±85 min) was faster than the current study (732±108 min).[6] Since subjects in previous studies completed the race with higher intensity compared to those in this study, they might report higher values for DOMS. The influence of exercise intensity on DOMS in Ironman triathletes needs to be addressed in future research.

Muscle soreness was measured using VAS and GRC for static and active DOMS in this study. VAS for static and active DOMS demonstrated a similar trend (Figure 2 & 3). VAS scores of anterior and posterior thighs took 2 to 4 days longer to return to the pre-race value compared to calves and lower back. Those muscles may have received more damages due to use as primary muscles during biking and running and have had delayed recovery due to frequent uses in activities of daily living. Active VAS scores in anterior and posterior thighs and calves remained significantly elevated 1 to 2 days longer than static VAS scores in those body regions. This is likely because the motion standing up from a chair while assessing active DOMS recruited contractions of lower extremity muscles.

Nutritional Intervention on DOMS

Even though post-exercise ingestion of combined CHO and PRO has been shown to be beneficial for improving muscle PRO balance and DOMS our results did not demonstrate an effect on DOMS measures. One potential explanation for this finding is that subjects in the control group consumed extra energy on their own, which supplemented energy intake similarly to that from recovery beverages in the intervention group. Post-race energy intake revealed no significant difference in total calories and CHO between groups. (Table 5) However intervention group consumed significantly higher PRO and less fat than control group. This is probably due to 58±15 % of the post-race calorie intake in the intervention group being from the recovery beverage, containing high PRO and low fat compared to a general meal control group consumed.

A study by Goh at al.[22] reported that ingestions of similar caloric loads but different proportion of PRO and CHO did not alter attenuation in DOMS. They examined the effects of isocaloric recovery beverages with different proportions of CHO and PRO following cycling exercise on DOMS scores. Recovery beverages consisted of 2:1 ratio of CHO to PRO (45g CHO, 25g PRO) or 1:7 ratio of CHO to PRO (8g CHO, 55g PRO) containing an overall 285-300kcal. They found that there was no significant difference in DOMS between recovery beverages up through 1 day after the exercise bout. DOMS was not observed more than 1 day after the cycling exercise. Similarly, Sandi et al.[23] compared the effect of 3 different ratios of CHO-PRO beverages on DOMS induced by resistance exercise. CHO-PRO beverages with 4:1, 3:1, or 2:1 ratio of CHO to PRO were ingested before and during the exercise. The total volume of CHO-PRO beverages was determined by body mass thus they were not isocaloric. Their results revealed no significant difference in DOMS between different ratios of CHO-PRO beverages over 2 days after exercise. In our study, subjects consumed 3:1 ratio of CHO to PRO for the intervention group and 4:1 ratio for control group after race. DOMS responses were similar despite the intervention group ingesting a greater amount of PRO post-race. Therefore we suggest that the ratio of CHO and PRO in recovery beverages may not effect attenuation in DOMS, however the intake of some amount of PRO may still prove beneficial.

When ingesting combined CHO and PRO post-exercise, optimal amount of PRO to maximize muscle PRO balance remains controversial. Beelen at al.[10] suggested that ingestion of 20g of PRO is sufficient enough to stimulate muscle PRO synthesis within the first 2 hours after exercise. In contrast, some previous literature reported that PRO balance improves as energy intake increases regardless of the volume of PRO intake, thus energy content rather than macronutrient content of a recovery beverage is critical in determining muscle PRO balance.[24,25] Improvement in muscle PRO balance with increased energy intake post-exercise may promote recovery from DOMS. However, to our knowledge, no study has been done to examine the effect of various caloric intakes from co-ingestion of CHO and PRO post-exercise on DOMS. In the present study, boluses of recovery beverage were ingested in purpose of amplifying post-race caloric intake with a PRO rich beverage. Despite recovery beverage ingestion, subjects had similar post-race energy intake between groups. This is likely because we did not place any restriction on subject's food and fluid intake following the study protocols post race, and allow subjects to recover outside of the study as they normally would. Therefore further research is warranted to determine optimal amount of PRO and its effects on DOMS, especially within the Ironman population.

Energy Intake

Kimber at al.[26] investigated energy intake, expenditure and balance during Ironman race. The results showed Ironman triathletes had energy intake at 3940±868 kcal for males and 3115±914 kcal for females, energy expenditure at 10036±931 kcal for males and 8570±1014kcal for females, and energy balance at -5973±1274 kcal for males and -5123±1193 kcal for females. Energy intake in this study (Males: 2972±854 kcal, Females: 1928±976 kcal) was considerably smaller than that in the previous study. With the assumption that subjects in this study had similar energy expenditure to previous study, energy intake on race (Males: 5553±1150 kcal, Females: 3930±1934 kcal) was not sufficient to replenish energy deficiency due to race. Thus, it is likely that Ironman triathletes restored this energy deficiency day after race, however more data needed to determine energy replenishment strategy in Ironman athletes.

According to the American College of Sports Medicine (ACSM) position stand for nutrition and athletic performance, PRO intake at 1.2 to 1.4 g/kg/day or slight above is recommended for ultra-endurance athletes and CHO intake at 6 to 10 g/kg/day is recommended for general athletes.[27] Considering energy intake day before race, subjects in this study had appropriate PRO intake (Intervention: 1.5±0.6 g/kg/day, Control: 1.6 ± 0.5 g/kg/day) but slightly lower CHO intake than the recommended amount (Intervention: 5.2±2.4 g/kg/day, Control: 5.2±2.0 g/kg/day). CHO intake at 60 to 70 g/hr is recommended during Ironman race,[28] but our findings demonstrated lower CHO intake with 55±15 g/hr in males and 37±25 g.hr in females. Total CHO intake during race was also lower in this study (Males: 661±178 g, Females: 421±242 g) compared to a study by Kimber at al. (Males: 939±222 g, Females: 753±226 kcal).[26] For post-exercise ACSM recommends to consume 1.0 to 1.5 g/kg of CHO during first 30 minutes, and again every 2 hours for 4 to 6 hours and 0.2 to 0.5 g/kg of PRO added to CHO although these recommendations are not specific to ultra-endurance athletes. In addition Millard-Stafford at al.[29] suggested 1.2 to 1.5 g/kg/hr of CHO intake within the first few hours after endurance exercise. To meet those recommendations the amount of CHO ingested by subjects in this study (Males: 4.1±1.4 g/kg, Females: 3.0±2.4 g/kg) might not sufficient enough. In contrast post-race PRO intake was higher than the ACSM recommendation.[27]

Return to Activity

Return to activity questionnaires were used in our study to investigate the length that it took for the Ironman triathletes to resume physical activity after race, what type of activities they prefer to perform for the first exercise sessions post-race, and how/if DOMS influenced return to physical activity. We hypothesized that a recovery beverage would attenuate DOMS, which would enable Ironman triathletes to achieve a quicker return to activity. However, we found that there was no significant difference in days returning to activity between groups. Although the intervention group showed significantly longer activity duration on the first day of return to activity, this data may not be clinically meaningful because both groups demonstrated similar level of DOMS and the total duration of individual activities did not significantly differ between groups over the recovery period examined. Total activities in the first week post-race also did not reveal significant differences in total days, duration, and types of activities between groups. Average RPE was significantly lower in intervention group but it does not seem related to recovery beverage ingestion. Both groups performed shorter duration of activities with intensity of very light to fairly light post-race exercise sessions compared to pre-race exercise sessions. This may indicate Ironman triathletes performed active recovery exercises in order to attenuate DOMS.

Sit-and-Reach Test

As supplemental data we measured flexibility of hamstrings and lower back with sit-and-reach test. A previous study reported that people with stiffer hamstrings experienced greater muscle soreness after an eccentric exercise.[30] Therefore, we hypothesized that intervention group would have higher (better) sit-and-reach test score if post-race nutritional intervention attenuated DOMS. Our data demonstrated that sit-and-reach test scores were significantly lower 1-hour and 12-hour post-race than pre-race, however there was no significant difference between groups. This supported the previous finding that there were negative moderate correlations ($-0.41 < r < -0.51$) between DOMS and muscle stiffness over 4 days following eccentric exercise.[31]

Limitations

There were several limitations in this study. First, we did not control diet outside of the research parameters. This resulted in the two groups matching energy intake, but with the ingestion of the recovery beverage we were able to successfully have a significantly greater PRO intake for our intervention group. Ideally we would have been able to completely control and match dietary intake of our subjects for all of the days we collected data. Therefore, our subject's nutrition on the immediate days following our study may have also had an effect we did not control for. Our study did not have a cross over design, allowing a lot of variability within groups and lowering the statistical power, however we did attempt to limit this via the group assignment upon subjects crossing the finish line. The same protocol as this study could be performed in a laboratory setting, however that setting will be difficult to replicate weather conditions, and for triathletes to maintain their motivation and maximize their efforts. Without DOMS induced by an actual Ironman race, we are not accurately able to determine the effects of recovery beverages on DOMS after Ironman race.

Second, this was not a double-blinded study since no placebo beverages were used due to budgetary and practicality issues (we would have had to create this beverage). We were not able to make non-caloric or non-PRO based beverages similar taste and texture to the recovery beverages with our limited budget. Also, we avoided liability for providing handmade placebo beverages under the field condition where data was collected.

Third, there were potentials that energy intake was underestimated. As discussed above subjects in this study had considerably less energy intake during race than that in the previous study.[26] Immediately after race subjects were asked to recall food and fluid intake during race in this study while the previous study collected data for race nutrient intake at 6 points on the racecourse and immediately after finishing the race. In addition diet log day before race and post-race were recorded by subjects in this study. Thus, our energy intake data may include flaws because food and fluid portions in diet log may have not been recorded precisely.

Finally, Ironman triathletes sometimes use pain medications and therapeutic intervention to alleviate muscle soreness during and after race. A previous literature evidenced the analgesic effects of Non-Steroidal Anti-Inflammatory Drugs (NSAIDs) following DOMS inducing exercise when DOMS is substantial. [32] Therapeutic interventions such as cryotherapy, massage, and stretching were known to attenuate DOMS after strenuous exercise. [7,33,34] Use of NSAIDs was not restricted in this study to allow subjects to compete the race with their normal routines. Indeed, 10 subjects reported use of over-the-counter NSAIDs during the race and 13 subjects took NSAIDs following days after race. We are not able to discuss the effect of NSAIDs on our data for DOMS since time interval between ingestion of NSAIDs and DOMS measurement was unknown. Due to a lack of control, use of therapeutic interventions was not restricted. Twenty-six subjects reported to perform various kinds of therapeutic intervention over days after race. Therefore, perception of DOMS might be altered due to use of NSAIDs or therapeutic interventions.

Conclusion

Ingestion of recovery beverages has altered macronutrient composition of energy intake post-race. Despite the change in nutritional intake, post-race nutritional intervention did not attenuate DOMS or promote a quicker return to activity in Ironman triathletes. Double-blinded research that controls energy intake is needed in the future in order to examine effects of recovery beverages on DOMS. This research will eliminate placebo effects and potential bias due to recovery beverages, and also help to determine how increase in energy intake from post-race nutritional intervention affects DOMS.

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Appendix A

Visual Analogue Scale

1. Have you taken any medications to reduce pain today? *(circle)* YES / NO
   If yes, please list what and when you have taken and the dose.

____

____

____

____

2. On the horizontal line below please put a small vertical line across the line that best describes the pain you currently feel. A vertical mark on the extreme LEFT side of the line would indicate that you are experiencing "no pain"; a vertical mark on the extreme RIGHT side of the line would indicate that you are experiencing "unbearable pain". If your degree of pain is somewhere in between these two extremes, please mark it at the place that most accurately describes your current pain level.

   A. Please mark the line to indicate the pain that you are currently experiencing in the body part while maintaining a standing position.

Whole Body	**No Pain** ├──────────┤ **Unbearable Pain**
Calves	**No Pain** ├──────────┤ **Unbearable Pain**
Anterior Thighs	**No Pain** ├──────────┤ **Unbearable Pain**
Posterior Thighs	**No Pain** ├──────────┤ **Unbearable Pain**
Lower Back	**No Pain** ├──────────┤ **Unbearable Pain**

B. Please mark the line to indicate the pain that you are currently experiencing in the body part when standing up from a chair.

Whole Body	**No Pain** **Unbearable Pain**
Calves	**No Pain** **Unbearable Pain**
Anterior Thighs	**No Pain** **Unbearable Pain**
Posterior Thighs	**No Pain** **Unbearable Pain**
Lower Back	**No Pain** **Unbearable Pain**

Appendix B

Global Rating of Change Scale

On the horizontal lines below please circle a number that best describes how you feel compared to yesterday. Circling "0" means that you feel the same. Circling a positive number indicates you feel better, where circling a negative number indicates that your condition has worsened.

1. Please rate the pain that you are currently experiencing in the body part while maintaining a standing position compared to yesterday (circle a number)

Whole Body

-5 -4 -3 -2 -1 0 1 2 3 4 5

Very much Worse — Unchanged — Completely Recovered

Calves

-5 -4 -3 -2 -1 0 1 2 3 4 5

Very much Worse — Unchanged — Completely Recovered

Anterior Thighs

-5 -4 -3 -2 -1 0 1 2 3 4 5

Very much Worse — Unchanged — Completely Recovered

Posterior Thighs

-5 -4 -3 -2 -1 0 1 2 3 4 5

Very much Worse — Unchanged — Completely Recovered

Lower Back

-5 -4 -3 -2 -1 0 1 2 3 4 5

Very much Worse — Unchanged — Completely Recovered

2. Please rate the pain that you are currently experiencing in the body <u>when standing up from a chair compared to yesterday</u> (circle a number)

Whole Body

-5	-4	-3	-2	-1	0	1	2	3	4	5
Very much Worse					Unchanged					Completely Recovered

Calves

-5	-4	-3	-2	-1	0	1	2	3	4	5
Very much Worse					Unchanged					Completely Recovered

Anterior Thighs

-5	-4	-3	-2	-1	0	1	2	3	4	5
Very much Worse					Unchanged					Completely Recovered

Posterior Thighs

-5	-4	-3	-2	-1	0	1	2	3	4	5
Very much Worse					Unchanged					Completely Recovered

Lower Back

-5	-4	-3	-2	-1	0	1	2	3	4	5
Very much Worse					Unchanged					Completely Recovered

Appendix C

Return to Training Questionnaire

Thank you for taking our Return to Training Questionnaire. It will take approximately 5-10 minutes to complete this questionnaire.

Your participation in this study is completely voluntary. There are no foreseeable risks associated with this project. However, if you feel uncomfortable answering any questions, you can withdraw from the survey at any point. Your survey responses will be strictly confidential and data from this research will be reported only in the aggregate. Your information will be coded and will remain confidential.

If you have questions at any time about the survey or the procedures, you may contact the Korey Stringer Institute Research Team at (860) 486-0265 or by email at lakeplacidstudy@gmail.com. Thank you so much for your time and support. Please start with questionnaire now.

What is your subject number?

How many hours of training did you perform today?

Of these hours, what percentage of them were comprised of swimming ___________________%

Of these hours, what percentage of them were comprised of biking________________________%

Of these hours, what percentage of them were comprised of running_____________________%

Of these hours, what percentage of them were comprised of resistance training____________________%

Of these hours, what percentage of them were comprised of other physical activity____________________%

Did you encounter any set backs during your training today?

1. Yes
2. No

Overall, how satisfied are you with your training today?

Extremely satisfied	Very satisfied	Satisfied	Unsatisfied	Extremely unsatisfied
×	❑	❑	❑	❑

Overall, how would you describe the intensity of your training today? (Circle a number)

RATING OF PERCEIVED EXERTION SCALE

6
7 Very, Very Light
8
9 Very Light
10
11 Fairly Light
12
13 Somewhat Hard
14
15 Hard
16
17 Very Hard
18
19 Very, Very Hard
20