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1. Impact of Physical Activity Trajectories on Colon Cancer Risk

Christopher, Cami[1], Matthews, Charles[2], Saint-Maurice, Pedro[2], and Keadle, Sarah, Ph.D.[1]
California Polytechnic State University San Luis Obispo, San Luis Obispo, CA[1]
National Cancer Institute, Bethesda, MD[2]

BACKGROUND:

Colorectal cancer is a major public health and clinical concern, as it is the third leading cause of cancer in men and women in the United States.[1] The current United States' Physical Activity Guidelines found evidence that engaging in moderate-vigorous physical activity (MVPA) at recommended amounts reduces colon cancer risk.[2,15] In a pooled analysis of 1.4 million adults, those who engaged in high levels of leisure-time physical activity had a 16% reduction in colon cancer risk.[3] Increasing time spent in MVPA, vigorous physical activity, recreational physical activity, and regular walking, have all been shown to lower colon cancer risk.[3-8] There is sufficient evidence of the inverse, dose-response relationship between physical activity levels and colon cancer risk, supporting approximately a 25% reduced risk between the most active and least active populations.[6,9] While numerous types of activities and intensity levels are linked with reduced colon cancer risk reduction, the duration and dosage of physical activity needed to reduce risk is not well established.[6] Current literature is inconclusive on how changes in physical activity levels impact colon cancer risk and whether physical activity levels earlier, throughout, or later in the life course are most protective.[4,6,10] Understanding the stage in the life course that physical activity is most critical to minimize colon cancer risk and the dosage of physical activity needed is critical to develop interventions and disseminate prevention messages.

PURPOSE:

Therefore, the purpose of our study is to evaluate whether maintenance of and changes in physical activity levels over time, as measured over the life course as trajectories,[11] are associated with colon cancer risk. We hypothesize that sustained maintenance of sufficient physical activity through the lifespan would result in the strongest risk reduction.

METHODS:

The participants in our study are from the NIH-AARP Diet and Health Study cohort.[12] In 1995-96, 566,398 AARP members (aged 50-71 years) from six states and two metropolitan areas completed a baseline questionnaire. In 1996-1997, those who were free of colon, breast, or prostate cancer at the time of the baseline questionnaire were sent a risk factor questionnaire (RFQ) that included detailed questions about physical activity and diet.[12] There were 334,905 men and women who completed both the baseline and RFQ. In 2004, a follow-up questionnaire about physical activity levels, and other lifestyle factors was sent to living participants. The NIH-AARP study was approved by the Special Studies Institutional Review Board of the US National Cancer Institute, and all participants provided informed consent by completing and returning the baseline questionnaire. Individuals were excluded if: the RFQ was completed by a proxy (N= 10383), previous history of cancer (N = 18330), missing physical activity levels (N = 8901), or poor health (N = 4093). These exclusions resulted in an analytic sample size of N = 293,198. Follow-up time was calculated from completion of the RFQ until (any) colon cancer diagnosis, death, or end of study follow-up (12/31/2011). On the RFQ, participants self-reported their physical activity levels at four distinct time periods: ages 15-18, 19-29, 35-39 and over the past 10 years. Participants were asked “How often did you participate in moderate-vigorous activities” between each of the age ranges.[13] Reponses options included none, rarely, <1, 1-3, 4-7 and > 7 h/wk.

We used latent class trajectory models to identify trajectories of physical activity at four points in time.[13-14] The current PA guidelines of a minimum of 150 min per week of moderate-intensity activity, equivalent to 2.5 h/week,[15] was the cutoff separating “low” from “high” physical activity levels in the results. Cox proportional hazards models were diagnosis or end of follow-up, whichever occurred first. No deviations in the proportional hazards assumptions were observed (all P-values >0.1). We tested the variables in Table 1 as potential confounders. used to estimate hazard ratios (HR) and 95% confidence intervals (CI) in SAS version 9.4 (SAS Proc Phreg). The underlying time metric was calculated from age at RFQ to age at cancer.

RESULTS:

From the baseline questionnaire in 1995/96 to 2001, there was a total of 5,072 incident cases of colon cancer (NIH-AARP), and an average follow-up of 13.1 years. We observed seven unique physical activity trajectories, which we grouped into three broader patterns: maintainers, increasers, and decreases. *Maintainers* were those who reported fairly consistent activity patterns at three activity volumes: 1) Consistent low: low activity 1h/wk (referent), 2) Consistent high: high activity levels (~7 h/week), and 3) Moderately active: meeting PA recommendations ranging from ~2.5 to ~6 h/week. *Increasers* were those activity increased over time 4) Early increasers: <2 h/week activity during the teenage years and then ≥5 h/week of activity through

20’s and later in life and 5) Later increasers: gradual increase in activity from <2 to 6 h/week beginning in the 30s. *Decreasers* reported activity declined over time.

6) Early decreasers: >6 h/week activity in the teenage years and then a decrease to <2 h/week activity after age 39 and 7) Later decreasers: gradual decrease from >6 to 1 h/week activity. Comparing demographic characteristics across these seven trajectories, we found that a greater percentage of men consistently maintained physical activity levels that meet guidelines compared to women, and a greater percent of men report decreasing activity levels over the life course (Table 1). Women reported more of an increase in physical activity levels over the life course, with low activity in the teenage years followed by higher physical activity levels.

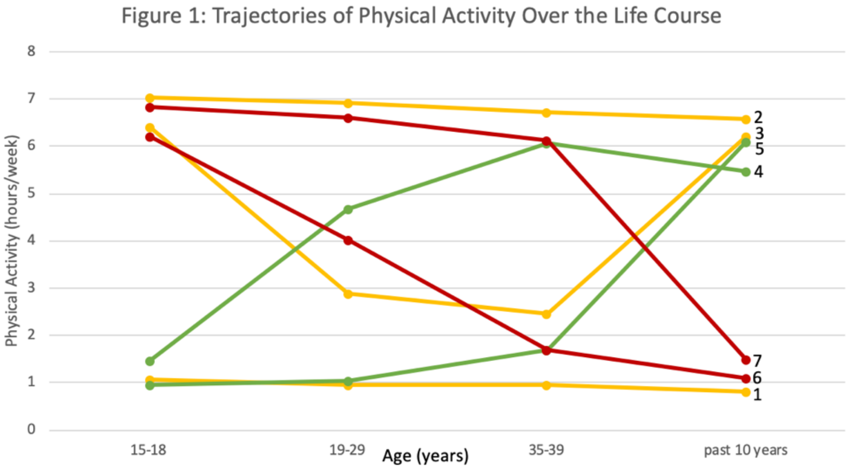
Figure 1: Trajectories of Physical Activity Over the Life Course

In adjusted analyses (Table 2), compared to those with consistently low physical activity patterns (group 1), among those who maintained consistently high physical activity there was a 14% lower risk of colon cancer (HR = 0.86, 95% CI 0.79–0.93) and those who reported a U-shaped pattern (moderate levels of physical activity) had a 17% lower risk of colon cancer (0.83, 95% CI 0.73–0.95). Those who increased physical activity earlier in life (group 2) had a 10% reduced risk (though not significant), and those who increased later in life had a 15% reduced risk (0.85, 95% CI 0.75 – 0.98). Those who decreased activity over time showed higher risks of colon cancer, with a 13% elevated cancer risk for those who decreased activity levels early in life to below physical activity guidelines (1.13, 95% CI 1.03-1.24).

Table 1: Demographics and characteristics by physical activity trajectory at baseline

	MAINTAINERS			INCREASERS		DECREASERS	
	Referent (consistent low)	Consistently High	Moderately Active	Increasing early	Increasing later	Decreasing early	Decreasing later
N (%)	55605 (19.0)	91417 (31.2)	17198 (5.9)	28630 (9.8)	16172 (5.5)	47487(16.2)	36689(12.5)
Age at RFQ (mean, sd)	62.7 (5.4)	63.1 (5.2)	62.9 (5.2)	62.9 (5.4)	63.1 (5.3)	62.1 (5.4)	63.0 (5.2)
BMI, kg/m^2 (mean, sd)	27.3 (5.1)	26.4 (4.2)	26.0 (3.8)	26.1 (4.5)	25.6 (4.0)	27.8 (4.9)	28.1 (5.2)
Sex, Male (%)	51.4	60.5	75.2	38.7	56.5	69.2	58.6
Race, Non-Hispanic White (%)	91.1	93.8	94.1	93.3	93.0	92.0	92.8
Education, College degree (%)	37.5	41.3	55.6	35.6	45.7	45.9	39.5
Physical Activity, hrs/week							
15-18 y (mean, sd)	1.06 (1.06)	7.02 (0.85)	6.42 (1.00)	1.48 (0.81)	0.96 (0.91)	6.22 (1.38)	6.83 (1.24)
19-29 y (mean, sd)	0.96 (1.04)	6.91 (1.00)	2.9 (1.96)	4.66 (2.18)	1.04 (1.00)	4.03 (2.19)	6.62 (1.10)
30-39 y (mean, sd)	0.94 (1.12)	6.72 (1.12)	2.45 (1.79)	6.07 (1.25)	1.70 (1.43)	1.68 (1.02)	6.12 (0.92)
40-61 y (mean, sd)	0.82 (0.89)	6.57 (1.00)	6.21 (0.96)	5.48 (2.13)	6.09 (0.91)	1.10 (0.89)	1.48 (0.81)
Red Meat Intake, g/day (mean, sd)	19.1 (24.7)	19.9 (23.3)	18.7 (21.7)	16.3 (20.2)	16.1 (20.7)	21.8 (24.1)	21.2 (23.8)
Current Smoker (%)	11.6	10.7	6.2	9.9	5.8	12.3	14.5
Never Smoker (%)	38.9	36.5	32.4	40.4	36.1	33.5	32.0
Excellent/Very Good Health (%)	47.9	62.4	66.4	60	64.3	48.4	44.3
Fair/Poor Health (%)	13.7	8.1	6.4	8.6	7.3	13	16.8
Previous Colonoscopy (%)	13.4	14.15	15.1	13.1	14.98	13.9	14.0

Table 2: Hazard ratios for lifetime physical activity trajectories with colon cancer incidence

	MAINTAINERS			INCREASERS		DECREASERS	
	Referent (consistent low)	Consistently High	Moderately Active	Increasing early	Increasing later	Decreasing early	Decreasing later
N	54629	89944	16920	28172	15909	46551	36001
Cancers	976	1473	278	458	263	936	688
Model 1*	1.0	0.86 (0.79, 0.93)	0.83 (0.73, 0.95)	0.90 (0.81, 1.01)	0.85 (0.75, 0.98)	1.13 (1.03, 1.24)	1.06 (0.96, 1.17)
Model 2#	1.0	0.87 (0.80, 0.94)	0.87 (0.76, 0.99)	0.92 (0.82, 1.03)	0.89 (0.78, 1.03)	1.13 (1.03, 1.23)	1.04 (0.94, 1.14)

*Model 1 was adjusted for age and sex. #Model 2 was adjusted for M1 + education, smoking, alcohol, processed meat.

DISCUSSION:

After adjusting for potential confounders, we found that compared to those reporting consistently low physical activity over the life course, those who maintained physical activity over time had a 14-17% lower risk of colon cancer. Those who decreased physical activity over time had a higher risk of colon cancer and those who increased activity had a protective association. These findings suggest that, compared to consistently engaging in little or no exercise, maintaining high physical activity and increasing activity through adulthood may reduce colon cancer risk. Our research supports known protective factors of physical activity (AICR) and reaffirm the importance of the recommended physical activity guidelines. Our data suggest further insight into the importance of physical activity over a sustained period of time to preserve health and minimize colon cancer risk.

Strengths of our study include the large, prospective sample and reported physical activity levels at four distinct ages. Our data were collected from individuals who were healthy at baseline and participants were followed up for disease outcomes over time. Limitations include that physical activity was self-reported and may have changed in the interval between the time of the RFQ and diagnosis. While utilizing trajectories may give a better picture of the effects of patterns in lifelong activity, physical activity was recalled by participants at the specified time intervals. There is a chance it may be misreported or differentially reported by BMI status. The categories of physical activity were also crude measures, with limited categorical choices for respondents, which may limit the assessment of precise physical activity levels.

CONCLUSION:

Our study suggests that consistent participation in physical activity throughout the life course may be most protective of colon cancer risk and incidence, while increasing activity levels from low activity levels has the potential to reduce colon cancer risk. Studies with more detailed information on physical activity at multiple points over the life course are needed to confirm our study's findings, better understand the necessary dosage of physical activity needed to mitigate risk of developing colon cancer, and determine whether there is a critical period of life beyond where one cannot reverse effects of an inactive and sedentary lifestyle.

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2. Similar Perceptual Responses to Reduced Exertion High Intensity Interval Training (REHIT) in Adults Differing in Cardiorespiratory Fitness

Clausen, Rasmus, Marroquin, Joel, Arthur, Baliegh, Stiles, Kevin, and Astorino, Todd, Ph.D., FACSM
California State University San Marcos, San Marcos, CA

Introduction

Regular physical activity (PA) aids in the primary and secondary prevention of cardiovascular disease, diabetes, and some cancers and reduces all-cause mortality (23). Despite these well-known benefits, participation in PA remains low as only 50% of adults complete 150 min/wk of moderate intensity continuous training (MICT) or 75 min/wk of vigorous activity (3). When activity is assessed with accelerometry, participation in PA is as low as 4% (21).

The current PA guidelines including high volume MICT and resistance training require about 4 h/wk which is unrealistic for adults as “lack of time” is cited as the primary reason for low PA (22). Recently, high intensity interval training (HIIT) has been proposed as a more time efficient mode of exercise that elicits similar, and/or superior changes in health-related adaptations compared to MICT (24, 10). Yet, most HIIT regimens require 30-40 minutes to perform which is time intensive. Reduced Exertion High Intensity Interval Training (REHIT), a form of sprint interval training (SIT), requires only 2-3 supramaximal 20-second sprints within a 10-minute training session. Recently, completion of 8 wk of REHIT elicited superior cardiorespiratory and health-related adaptations than MICT (4).

The implementation of sprint interval training such as REHIT has been questioned due to the fatigue and discomfort associated with supramaximal exercise. These concerns are based on the dual-mode theory which states that above-threshold work rates, as seen in REHIT, are associated with hyperventilation and concurrent blood lactate accumulation leading to negative affective valence and overall displeasure (6).

Most studies examining perceptual responses to REHIT utilized small and homogenous samples with similar physical activity status, which limits our ability to assess if cardiorespiratory fitness (CRF) mediates perceptual responses. The current study compared changes in affective valence and enjoyment to a single session of REHIT in adults with varying CRF. It was hypothesized that individuals with above average CRF will exhibit higher affective valence and enjoyment compared to those with below average CRF.

Methods

Participants: Eighty-five healthy adults free of lower extremity injury who had never performed REHIT participated in the study. Each participant initially completed the International Physical Activity Questionnaire and provided written informed consent. To categorize individuals as having below (25 men and 17 women, VO_2max = 32.6 ± 5.0 mL/kg/min) and above average CRF (19 men and 24 women, VO_2max = 41.3 ± 5.8 mL/kg/min), we used VO_2max norms from maximal cycle ergometry acquired in 4,494 men and women ages 20-79 years (11).

Baseline testing: Participants visited the laboratory on two occasions. The first visit consisted of a 2 min warmup at 40-70 W followed by incremental exercise (20-35 W/min) until volitional exhaustion on an electrically-braked cycle ergometer (Velotron Dynafit Pro, RacerMate, Seattle, WA) to assess VO_2max. Heart rate (HR) was measured continuously using telemetry (Polar, Woodbury, NY), and gas exchange data were acquired using a metabolic cart (ParvoMedics True One, Sandy, UT). RPE (Borg CR-10 scale ref to Borg 1998) and affective valence (+5 to -5; 8) were obtained at rest and every minute of exercise to familiarize participants with reporting perceptual responses.

REHIT: Participants returned at least 48 h later to perform a single session of REHIT. The session included a 3-minute warm-up at load equal to body mass in kg followed by two 20 second “all-out” sprints at 5% body mass, with 3 minutes of active recovery between the first and last sprint. Strong verbal encouragement was provided and was standardized across sessions. Rating of perceived exertion (RPE) and affective valence were assessed at rest, during the warmup (2:30), after sprint 1 (3:20), halfway in recovery 1 (4:50), after sprint 2 (6:40), halfway in recovery 2 (8:10), and at 10 min. Blood lactate concentration was measured at rest, after sprint 1, and then at 10 min. Five minutes after the session, participants were asked to rate their enjoyment using the Physical Activity Enjoyment Scale (PACES) (12).

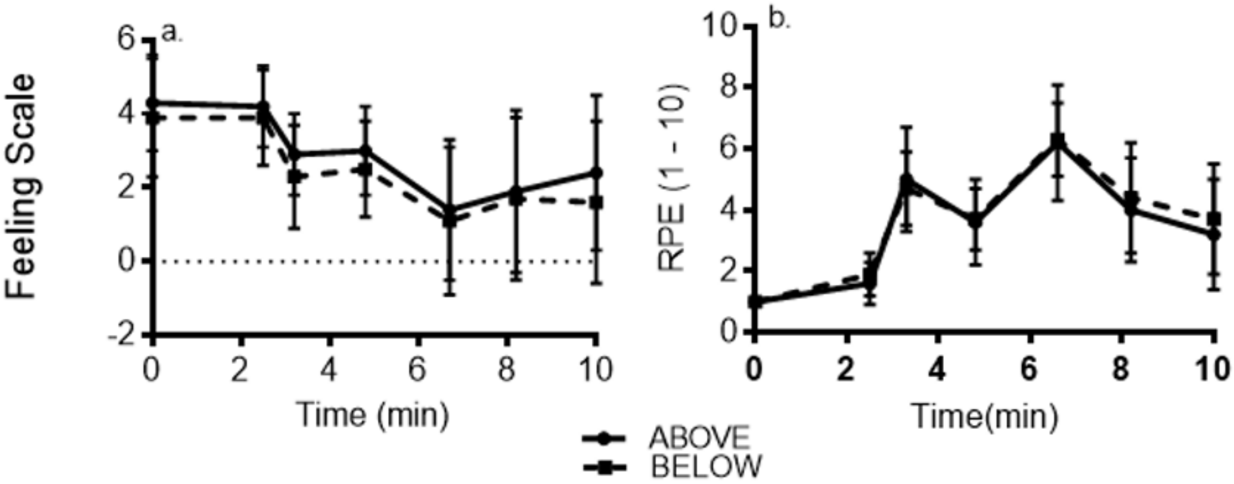
Data analysis: Data were evaluated in SPSS Version 24.0 (Armonk, NY) and are presented as mean ± SD. We used the Shapiro-Wilks test to assess normality. Differences in physiological variables between groups were determined using independent t-test. Two-way ANOVA with repeated measures was performed to identify differences in perceptual responses and BLa. We used the Greenhouse-Geisser correction to account for the sphericity assumption of unequal variances across groups. Tukey’s post hoc test was performed to identify significant differences between means, and effect size was assessed using Cohen’s d. Pearson pairwise correlation was used to determine relationship between variables. Significance level was set at $p < 0.05$.

Results:

Heart Rate and Power Output: Peak HR observed during REHIT was equivalent to 94% HRmax. Peak (7.6 ± 1.1 W/kg vs. 7.0 ± 1.3 W/kg, p = 0.03, d = 0.6; 7.3 ± 1.0 vs. 6.7 ± 1.2 W/kg, p = 0.02, d = 0.6) and mean (6.2 ± 1.1 W/kg vs. 5.6 ± 1.2 W/kg, p = 0.02, d = 0.6; 5.9 ± 1.0 vs. 5.0 ± 1.2 W/kg, p = 0.01, d = 0.9) power output from sprint 1 and 2 differed between groups.

Change in Affective valence, RPE, and enjoyment: Affective valence changed significantly during REHIT (p < 0.001), yet there was no group X time interaction (p = 0.86). However, affective valence tended to be higher in the above vs. below average CRF group. Affective valence declined from warmup to sprint 1, and it was lowest immediately after sprint 2 (1.4 ± 1.9 and 1.1 ± 2.0 in above and below average CRF group, respectively). RPE increased significantly during REHIT (p < 0.001) and there was no group X time interaction (p = 0.41). RPE peaked after sprint 2 and was equal to 6.2 ± 1.9 and 6.3 ± 1.3 in participants with above and below average CRF. Enjoyment (PACES) was not different (p = 0.64, d = 0.10) in adults with above (93.2 ± 20.8) vs. below average (91.1 ± 16.4) CRF.

Figure 1: Change in affective valence and RPE during REHIT in persons with above and below average CRF.



Blood lactate concentration: Blood lactate concentration increased markedly in response to REHIT (p = 0.001). Participants with below average CRF tended to exhibit lower BLa than participants with above average CRF (p = 0.06).

Discussion

Our results show no effect of CRF on perceptual changes in response to a session of REHIT. However, affective valence was positive representing “fairly good”, indicating that low-volume SIT is not seen as aversive in individuals with below average fitness as previously reported (8). In fact, compared to other results (7, 18, 20), our data suggest that REHIT is less aversive than higher volume SIT.

Our data refute the hypothesis that individuals with above average CRF would exhibit higher affective valence and enjoyment versus individuals with below average CRF. One possible explanation to these results is the lack of significant difference in BLa between groups (p = 0.06). It has been shown that BLa is strongly related to changes in affective valence during acute HIIT and SIT (1). Thus, the similar BLa between groups could explain the similar changes in affect. We found a significant association between change in affect and peak BLa across all participants (r = -0.29, p = 0.01).

Our enjoyment (PACES) values are similar to values reported by others (18, 19, 20). Across studies, lowest enjoyment was reported in response to high volume Wingate-based SIT. Conversely, the highest enjoyment occurred in protocols with intervals of only 5 s. These findings suggest that total work volume and sprint duration mediate changes in enjoyment and should therefore be modified when designing SIT protocols to foster participants' enjoyment. Our peak RPE values of 6.2 – 6.3 on the CR-10 scale are similar to those reported by others (14, 19) of 6.5 – 7.5 during low-volume SIT with 10 – 20 s bouts. Near maximal RPE scores have been reported with higher volume SIT (25, 7), demonstrating that RPE is also mediated by volume.

The present study has some limitations. Participants were young and healthy; thus, it is unknown how older individuals or individuals with chronic disease respond to REHIT. Also, our method of separating groups may be inadequate as an individual with CRF just below average may not differ much from another individual who is just above average. In addition, we did not measure future intention to perform REHIT.

Overall, CRF did not modify perceptual responses to a single session of REHIT. Despite no difference in affective valence between groups, adults with below average CRF had higher frequency of negative scores, highlighting the necessity for exercise professionals to individualize REHIT for their clients to ensure higher pleasure. We encourage future research to investigate future intention to perform REHIT, and if performing REHIT on different modalities and in more diverse samples reveal similar results.

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3. Optimal Distance for Normal Gait Speed Testing

Saavedra, Rosalba[1], Bischoff, Brian[1], Weiss, Elijah[2], Kim, Steven[3], and Martin, Eric, Ph.D.[1]
Kinesiology Department, California State University Monterey Bay, Monterey Bay, CA[1]
Department of Biology and Chemistry, California State University Monterey Bay, Monterey Bay, CA[2]
Department of Mathematics and Statistics, California State University Monterey Bay, Monterey Bay, CA[3]

Introduction

In the USA, the population is becoming less healthy and physically active.[1-4] Over half of adults were overweight or obese in 2014,[3] and only 1 in 5 adults met the 2008 Physical Activity Guidelines.[2] As these health issues become more prevalent, healthcare professionals will need to test clients in order to perform primary and secondary prevention interventions. One tool healthcare workers can use to screen clients for functional status and disease risk is a walking speed test.[5-7] Walking speed tests can predict current functional independence and future health deterioration, potentially screen for chronic lifestyle diseases such as hypertension, and help with clinical decision making such as whether someone will be homebound, their likelihood of hospitalization and the location of release after hospital visits.[5,7,8]

Recently, Alves and colleagues [5] reviewed the use of walking speed tests for examining cardiovascular disease events and health risk factors in older adults. The studies reviewed used different test distances. In eight of the studies, the distances ranged from 2.44-4.6m, and in five they ranged from 6-6.15m. One study utilized a 20 meter test, and another used either 2.4m or 6m depending on self-rated fitness levels. Alves et al. [5] concluded that although walking speed tests generally offer many benefits to assess people's health, they also display a large variation in results when different versions of this test were compared because there is no set protocol to conduct a walking speed test. This is significant to them because different protocols generate a gap in knowledge of and a questioning in the test's accuracy.[5]

One issue raised by Alves et al.'s review [5] is what component of fitness is being measured. By the name, the tests claim to be testing speed, however, based on the distances of the tests, they are likely testing acceleration instead. Acceleration and speed are separate components of fitness. There may be more variability in acceleration measurements due to each individual's strength, power, flexibility, and neurological control related to gait. For example, a person who may exhibit a shuffling gait pattern at acceleration may resolve to have a normal stride length by the time they achieve their normal walking speed. Acceleration could be examined as its own concept, however, the current idea is to measure speed because of the consistency speed measurements can provide for clinical use.

Middleton et al. [8] published a white paper on the efficiency of walking speed for health examination. This walking test is 20m total, however, only the middle 10m of it is used to measure walking speed; the first and last 5m are used to accelerate and decelerate walk pace. The first 5m is used to measure acceleration rather than speed in a walking speed test because it is space for one to increase their momentum in order to achieve a true consistent walking speed by 10m. The walking speed test will be potent as long as there is room for acceleration and deceleration.[8] It is important to realize what is a true walking speed change and what is measurement error to efficiently and effectively provide a health screening.[8]

Alves et al.[5] and Middleton and colleagues [8] argue that although walking speed tests are powerful tools for health screenings, the variation of protocols present different cutoff points in health within each test. Longitudinally, decline in walking speed can be a sign for potential problems that can affect people's health.[5, 8] However there is still a gap in knowledge and no standard method on how to conduct a walking speed test that can provide consistent results and that is effective for determining exact health outcomes. This gap generates a confusion when a walking test is used as a health screening tool and it weakens the usefulness of this clinical measure. It is important that a standardized walking test needs to be established and incorporated into the practices of health care professionals and people assessing their own health, however, it is unknown what exact distance of gait speed test most validly represents overall gait speed. Therefore, the purpose of the current study was to determine an optimal distance to calculate gait speed that can be used to standardize walking tests in clinical settings.

Methods

Participants were full or part time students at a California State University in California who could walk without any walking aid. This project was approved by the Committee for the Protection of Human participants. All participants provided written informed consent before commencing the assessments. Participants were asked to attend one session at the Exercise Physiology laboratory. Participants were instructed to refrain from eating, smoking, or ingesting caffeine or alcohol within 3 hours of their testing session, or from exercising prior to their testing session, and to wear athletic shoes and clothing. After 5 minutes of seated rest, participants were assessed for resting blood pressure and heart rate. They were then assessed for height using a stadiometer, and weight and body fat percentage using a Tanita BF-350 Total Body Composition Analyzer (Tanita, Tokyo, Japan).

Participants were brought outside to a level concrete sidewalk that we permanently marked to indicate distances from a starting line. We marked -30 cm, 0 m, 5 m, 10 m, and 20 m. Sets of Brower Timing Gates (Brower Timing Systems, Draper, USA) were placed at the starting line and at the 5, 10, and 20m marks.

Participants were informed of the walking test procedures; participants were instructed to begin walking when they felt comfortable. They were instructed to walk at their normal pace on the concrete passing through each set of timing gates. Participants were instructed to walk down and touch the water fountains beyond the last timing gates to ensure they would not slow down before completing the test. When ready, they started with their toes on the -30 cm line (i.e. 30 cm from the first timing gate) per standard procedure,[9] and began the test at their volition. Participants only completed a single trial, as our previous research has shown that measuring normal walking speed with the Brower Timing gates shows near perfect reliability.[10]

Note that each participant walked through all three segments (0-5m, 5-10m, and 10-20m), and the timing gates recorded gait speed of each individual at each segment. Therefore, a mixed effect model was used in order to account for the correlated data (i.e., accounting for one's own gait speed in the prior segment). Using the model, we estimated the average gait speed at each segment and the average difference between the three segments. We used R version 3.5.0, and we used lme4 and lmerTest packages to complete the analyses.

Results

Thirty six students completed the assessment (24 female, 11 male, 1 declined to answer; mean age = 21.5 ± 2.6 years, height = 168.8 ± 10.4 cm, mass = 77.2 ± 19.3 kg). Students walked 1.361 meters per second (m/s) on average between 0-5 meters, 1.449 m/s between 5-10 meters, and 1.467 m/s between 10-20 meters (Figure 1). A 95% confidence interval (CI) was used for this study. For the 0-5 meter segment, the CI was calculated between 1.292-1.429 m/s; for the 5-10 meter segment, the CI was 1.380-1.517 m/s; and for the 10-20 meter segment the CI was 1.398-1.535 m/s. Comparing segment 0-5m to segment 5-10m, the estimated difference was 0.088 m/s with a 95% CI between 0.062-0.079 m/s with a p-value < 0.0001. Comparing segment 0-5m to segment 10-20m, the estimated difference was 0.106 m/s with a 95% CI between 0.079-0.132 with a p-value of <0.0001. Comparing segment 5-10m to segment 10-20m the estimated difference was 0.018 m/s with a 95% CI between -0.009-0.044 m/s with a p-value of 0.18.

Discussion

Comparing segments 0-5m and 5-10m the walking speed of the 5-10m segment was faster than the walking speed of the 0-5m segment. This result is expected; because subjects start from no momentum, it takes time and distance for them to accelerate to their normal walking speed. The 0-5m segment shows that subjects are increasing their speed from a standing point. However when comparing the 5-10m segment to the 10-20m segment, results display a consistency in walking speed. This shows that the 5-10m segment is sufficient to provide an accurate representation of average walking speed in a test.

Previous work has studied the practical utility of different lengths when conducting gait speed tests. Kon and his fellow researchers[11] studied the validity and reliability of using a normal-speed four meter walk test and found it to be reliable, but they did not compare different lengths of walk tests. In Karpman et al.[12], their research team performed both four and 10 meter walk speed trials at the subjects' usual pace and found that both tests could be used in a clinical setting. Peters and colleagues [13] suggested that a 10 meter walk test be the preferred method of gait speed testing as opposed to the 4 meter walk test. This was concluded because they had found a lack of concurrent validity for the 4 meter test to predict gait speed obtained from the 10 meter test while walking at the patients' normal gait speed. Our results support the findings of the Peters and colleagues [13] article who found testing under 5 meters to be statistically different, but our results differs from both Karpman et al.'s [12] and Kon et al.'s [11] findings that supported the use of 4 meter gait speed testing.

An aspect that previous research studies did not include but was included in ours was the comparison to a walk test above 10 meters. Our research included a longer segment of measurement (10m -20m) which helps determine a more accurate representation of a person's average gait speed. Comparing this longer walking speed distance with the 0-5m and 5m-10m segments strengthened the argument for the 5m-10m walk test trials and weakened the support for tests under 5 meters.

Conclusion

Testing patients in clinical settings using walk speed tests under 5 meters is not advised because a patient will still be accelerating to their actual walking speed. The most efficient distance would be testing them in the segment between 5-10 meters.

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SWACSM Graduate Student Award Competition – Oral Presentations 2019

1. Validity and Inter-Rater Reliability of a Customized Submaximal Cycle Ergometer Test

Fretti, Sarah, M.S., Kantor, Michael, M.S., Gubler, Coral, PT, Ph.D., Pettitt, Robert, Ph.D., FACSM
Rocky Mountain University of Health Professions, Provo, UT

Background

Maximal oxygen update ($\dot{V}O_{2max}$) is one of the best predictors of cardiovascular fitness (CRF).[1] Importantly, low CRF is a superior independent risk factor of all-cause mortality.[1–3] A maximal graded exercise test (GXT) is the most common method for determining $\dot{V}O_{2max}$; however, the GXT requires specialized equipment and may require the supervision of a physician for individuals at higher risk of adverse events.[4] Submaximal exercise testing is less restrictive due to the ability to exercise at a lower intensity and is safer for those with a certain risk criterion who may need supervision.[5] Therefore, submaximal exercise testing is preferred for determining CRF in the general population.

Oxygen uptake ($\dot{V}O_2$) kinetics modeling has emerged as an alternative for validation of submaximal testing, omitting the need for a full exertion stress test.[6] Based on the results of a customized exercise test, $\dot{V}O_2$ kinetics modeling can be used to quantify the change in $\dot{V}O_2$ from baseline to steady state and the time constant of $\dot{V}O_2$ kinetics (τ), along with the absence or presence of the $\dot{V}O_2$ slow component during exercise exceeding gas exchange threshold (GET).[6] The customized submaximal exercise test (CSET) has been validated to estimate $\dot{V}O_{2max}$ and has demonstrated more accurate estimates than the YMCA test in comparison to "true" $\dot{V}O_{2max}$.[6,7] The YMCA test was reported to underestimate and correlate poorly with "true" $\dot{V}O_2max$ (ICC= 0.27, CV = 15.2%), whereas the CSET did not differ (p=0.50) from true $\dot{V}O_{2max}$ and demonstrated a moderate correlation (ICC = 0.72, CV = 11.3%).[7] While the CSET has been validated using treadmill and cycle ergometer, no previous literature has analyzed the inter-rater reliability of the CSET.

Purpose

The purpose of this study was to test the inter-rater reliability of the CSET[7] and their respective ability of two testers to estimate "true" $\dot{V}O_{2max}$.

Research Design and Methodology

To date, 3 men and 4 women (age 34 ± 10 y, weight 81.6 ± 12.6 kg, height 176.0 ± 10.6 cm) completed all phases of the study. We recruited a wide range of ages and fitness levels to ensure generalization of the results. The experimental design included two separate visits to the laboratory. Visit 1 included completion of two CSETs by two testers. The two testers conducted the tests in counterbalanced fashion to avoid an order effect. Visit 2 consisted of the GXT with verification bout to assess 'true' $\dot{V}O_{2max}$. The GXT was conducted by the same researcher for all subjects. The study was approved by our institutional review board and all subjects provided their informed consent.

The CSET consisted of two 3-minute (min) stages estimated at 35% and 70% of $\dot{V}O_{2max}$. $\dot{V}O_{2max}$ and workloads at each stage were estimated with a linear regression equation utilizing gender, BMI, age, and a self-reported physical activity rating.[7] The GXT with verification bout consisted of a series of 1-minute stages progressively increasing in difficulty until the subject was no longer able to maintain the established cadence. The estimated W_{peak} was used to prescribe the custom GXT for each subject using the following: W_{peak}/10 min = 1 minute stages ($W \cdot min^{-1}$).[8] A 3-min active recovery was administered at 50 W, followed by a square wave exhaustive bout performed at two stages below W_{peak} to verify $\dot{V}O_{2max}$.

"True" $\dot{V}O_{2max}$ was defined as the highest measured $\dot{V}O_2$ from either the GXT or exhaustive bout. Measurement agreement between each submaximal estimate and the "true" $\dot{V}O_{2max}$ was determined using intraclass correlation coefficient (ICCα), typical error (TE), and coefficient of variation (CV).[9] Estimates from the submaximal protocols and the "true" $\dot{V}O_{2max}$ were compared using a one-way ANOVA with repeated measures. Descriptive statistics are reported as mean ± SD.

Results

The estimated $\dot{V}O_{2max}$ of the two testers was highly correlated (ICC = 0.98, TE = 2.74, CV = 1.15%) (Table 1). The CSET was moderately correlated with "true $\dot{V}O_{2max}$ (ICC = .84, TE = 5.52, CV = 12.91). There was a significant main effect for estimating $\dot{V}O_{2max}$ (F = 0.033, $p < 0.05$). Neither tester 1 (42.57 ± 8.34 $ml \cdot kg^{-1} \cdot min^{-1}$) not tester 2 (41.29 ± 8.20 $ml \cdot kg^{-1} \cdot min^{-1}$) differed significantly from "true" $\dot{V}O_{2max}$ (41.70 ± 12.10 $ml \cdot kg^{-1} \cdot min^{-1}$) (Table 2). The power output selected for the CSET was 1.5 W greater than GET (p = .085) (Table 3). $\dot{V}O_2$ data from stage 1 of the CSET depicts a steady state beginning at 1.5-min with a relatively flat gain (tester 1: slope =1.13 ± 1.17, tester 2: slope = 1.11 ± 0.85) (Fig 1). The $\dot{V}O_2$ slow component can be seen in stage 2, with a delayed steady state beginning shortly after minute 5 (tester 1: slope = 2.05 ± 1.23, tester 2: slope = 2.03 ± 1.15) (Fig. 1).

Table1. Measurement agreement between two testers of CSET and between CSET and GXT

$\dot{V}O_{2max}$ (ml·kg^{-1}·min^{-1})	ICC (α)	Typical Error (ml·kg^{-1}·min^{-1})	CV (%)
Tester 1 vs. Tester 2	0.98	2.74	1.15
CSET vs. GXT	0.71	5.62	12.91

Table 2. Measured and estimated $\dot{V}O_{2max}$ (ml·kg^{-1}·min^{-1}) measured from the CSET, nonexercising equation, and graded exercise test (*N* = 7)

$\dot{V}O_{2max}$ (ml·kg^{-1}·min^{-1})	Mean	SD
CSET Rater 1	42.57	8.34
CSET Rater 2	41.29	8.20
Nonexercising	41.69	6.98

Table 3. Gas exchange threshold (W) and second stage power output (W) measured from the graded exercise test and CSET (*N* = 7)

Power Output (W)	Mean	SD
GET	166.93	57.91
Stage 2 CSET	168.43	41.36

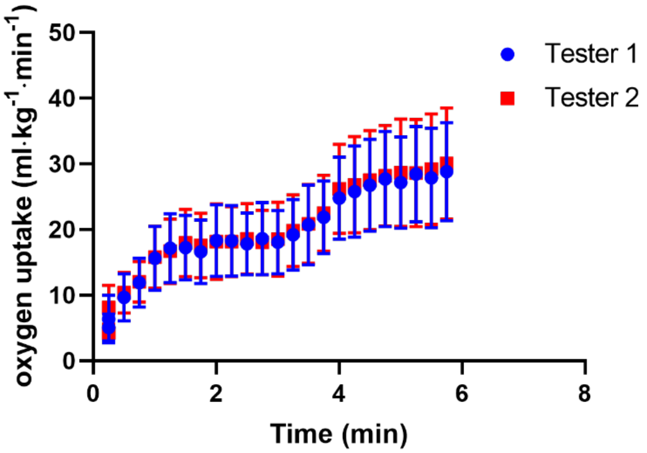

Fig. 1. $\dot{V}O_2$ responses (mean ± SD) from the CSET protocol. Note the steady state in the first stage (tester 1: slope =1.13 ± 1.17, tester 2: slope = 1.11 ± 0.85) and the $\dot{V}O_2$ slow component in the second stage (tester 1: slope = 2.05 ± 1.23, tester 2: slope = 2.03 ± 1.15)

Discussion

To our knowledge, this is the first study to investigate the interrater reliability of the CSET. Our results demonstrate the CSET yields a reliable and valid estimate of $\dot{V}O_{2max}$ (ICC = 0.98, TE = 2.74, CV = 1.15%; F = 0.033, $p < 0.05$). Estimates from both researchers as a whole did not differ from 'true' $\dot{V}O_{2max}$ (ICC = .84, TE = 5.52, CV = 12.91). We believe these results are partially due to the fact that the CSET uses demographic data and the nonlinear oxygen uptake-power output relationship. The non-exercising equation has previously been shown not to differ from 'true' $\dot{V}O_{2max}$.[7] Previous research has also demonstrated the CSET yields a more valid estimate of $\dot{V}O_{2max}$ compared to the YMCA test.[7] The 6-minute CSET includes a stage below and above GET, enabling the test to capture the non-linearity of the $\dot{V}O_2$-power relationship (Fig 1). The CSET eliminates the need to pre-select a protocol since the stages are based on demographic information and a self-reported PA-R. Future research should focus on using this protocol for other modes of exercise and with a more diverse population. The CSET may also be well suited for clinical populations due to the non-invasive and low-moderate intensity of the protocol.

Conclusions

This is the first study to demonstrate the interrater reliability of the CSET. The CSET, which consisted of two 3-min stages at 35 and 70% of the estimated W_{peak}, was highly reliable between the two testers (ICC = 0.98, TE = 2.74, CV = 1.15%). The CSET had a 'verge large" measurement agreement with 'true' $\dot{V}O_{2max}$, similar to previous published data.[6,7] The practical convenience of the CSET distinguishes the protocol from other, more popular tests. As a result, we recommend future research explore the efficacy for use with medically eligible patient populations.

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2. High Intensity Intervals Expands Plasma and Improves Cycling Performance in Acute Hypoxia

Gorini Pereira, Felipe, Berkemeier, Ariana, Venegas, Javier, Avery, Summer, Wilson, Carey, and Gillum, Trevor Ph.D.
California Baptist University, Riverside, CA

Military, firefighters, and athletic populations are often required to perform strenuous exercise in different altitudes, without the resources needed to properly acclimate. Often, acclimation is not feasible due to lack of time, finances, planning, and even location. Multiple studies have directly observed a degree of commonality between heat and hypoxia, by utilizing short-term heat acclimation to better equip subjects for hypoxic stress (4,5,6); this phenomenon is known as cross-tolerance. One of the common adaptations observed within both cross-tolerance (5,6) and heat acclimated (8,9) subjects is a hemodynamic improvement (increased stroke volume, lowered heart rate) that seems to be associated with hypervolemia, due to an expansion of plasma volume (PVE) (7).

Considered to be one of the initial responses to heat exposure, heat acclimation-derived PVE has been proposed as a fundamental mechanism to improve physiological responses and exercise performance at altitude (12). This desirable adaptation has been suggested to improve O_2 delivery to the metabolically active tissue, thus lowering physiological strain during moderate exercise at altitude (2). Further, the propagation of PVE is not only demonstrated by environmental stressors, but PVE can result from increased exercise intensity. A PVE of 10% ± 1.2% has been evidenced following a single bout of high intensity exercise in the heat (8x4 minutes of running bouts at 85% VO_{2max}), underscoring the role of exercise intensity in PVE(3).

Taken together, these data suggest that high intensity exercise is capable of inducing hypervolemia within a short period of time. Best practices suggest that two weeks are needed to acclimate to exercise in hypoxia (10), however the cardiovascular adaptations associated with intensity-derived PVE, could help unacclimated individuals sustain exercise capacity in hypoxia. Thus, the purpose of this study was to determine whether the hypervolemic response generated by a single bout of high intensity (HI) intervals was sufficient to mitigate the hypoxia associated declines in exercise performance.

Methods

Participants

7 healthy and active males (Table 1) participated in this study.

***Table 1:** Participant's Characteristics. Data are mean ± SD.*

Age (years)	Height (cm)	Weight (kg)	Body Fat (%)	$VO2_{max}$ (ml kg^{-1} min^{-1})
24.4 ± 1.5	182.1 ± 7.1	81 ± 10.2	12.8 ± 4.4	46.9 ± 5.8

Experimental Design

As highlighted on Figure 1, two normobaric hypoxic (15% FiO_2) 15 km cycling time trials (TTs) were performed per condition: one before (HYP1) any high intensity (HI) or control exercise bout (CON), and one 48 hours following the respective condition (HYP2).

The HI condition consisted of 8 intervals of 4 minutes at 85% VO_{2max} with 4-minutes rest periods at 25W. This protocol has evidenced PVE of 10% 48 hours post exercise (Gillen et al., 1991). The CON bout consisted of equal kJ production as the HI bout. As energy output was matched, the CON bout averaged 84 minutes at 50% VO_{2max}. Hydration was assessed through specific gravity of urine before each exercise trial. All participants performed both conditions in a counterbalanced order.

***Figure 1:** Experimental protocol.*

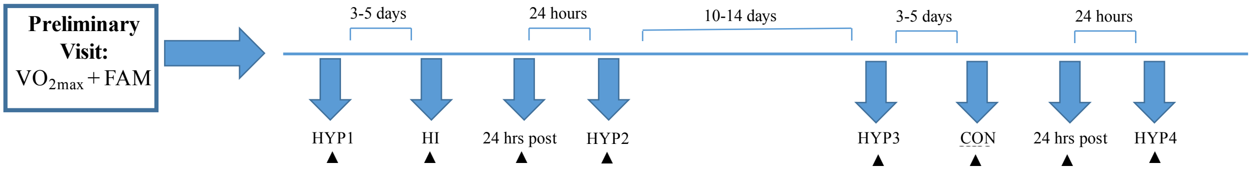

Fig. 1: Shaded triangles (▲) portray bouts in which venous blood draws were performed.

Hypoxic Time Trials

Three days following VO_{2max} assessment, participants reported to the lab for HYP1, which served as a baseline measurement of performance in hypoxia. Participants were asked to abstain from intense exercise 24 hours prior to all subsequent TTs. Cycling TTs included a 10-minute submaximal (50% VO_{2max}) exercise period, in which cardiovascular response (HR, SV, and Q) was analyzed (PhysioFlow,Nanatec Biomedical, France). Then, participants performed a 15km TT. During the TT, participants were aware of distance covered and were instructed to complete the distance as quickly as possible, but were blinded to speed, cadence, and power (Monark LC7 TT). During the TT, HR, RPE and O_2 saturation (SaO_2) (Nellcor, Minneapolis, MN) were recorded every 3 km. The hypoxic environment was created through nitrogen dilution (creating normobaric hypoxia) and monitored through two independent O2 sensors (BioSpherix P360, Parish, NY). The O_2 sensors were set to maintain FiO_2 levels of 15% (simulating ~7,500 ft elevation).

PVE Analysis

Hematocrit (Hct) levels were analyzed in order to quantify plasma volume expansion. Changes in Hct were utilized to determine the relative change in plasma volume as described by Van Beaumont et al (11).

Statistics

Results were obtained via paired sample t-tests and a two-way (condition x trial) Repeated Measures ANOVA; statistical significance was accepted at $p < 0.05$.

Results

Plasma Volume Expansion Analysis

Data indicated a significant PVE 24 hours (6.96% ± 4.84%) and 48 hours (9.77% ± 4.26%) ($p<0.05$) following the HI bout (Figure 2) while the CON condition decreased plasma volume 48 hours post ($p<0.05$).

Figure 2: Plasma Volume Expansion Analysis

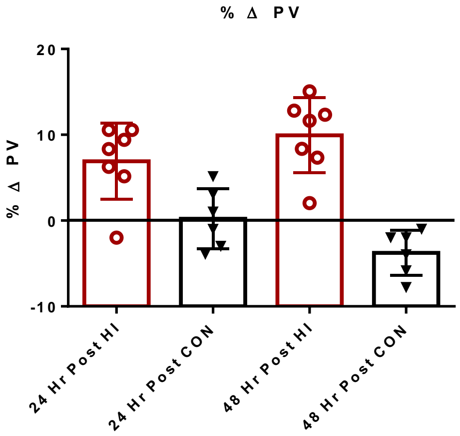

*Fig. 2: Data obtained from venous blood draws before exercise trials, n=7. *p<0.05 24 and 48 hrs after HI.*

Performance and Hemodynamic Responses

Under the HI condition, participants showed an improvement in TT performance (Time: 1880 ± 215s to 1840 ± 203s, Power: 164.8 ± 41.2W to 171 ± 39.5W, HR: 164.5 ± 9.5 bpm to 161.9 ± 8.8bpms) (Tables 2 and 3) ($p < 0.05$). There was no difference in performance in the CON condition (Table 2). Hydration, RPE, SaO_2, blood lactate, SV, and Q were similar in both TTs in hypoxia (Tables 2 and 3).

Table. 2 Physiological and Perceptual Measurements

Variable	*HI*		*CON*	
	TT1	**TT2**	**TT1**	**TT2**
Time (s)	1880 ± 215	1840 ± 203*	1874 ± 161	1866 ± 177
Power (W)	164.8 ± 41.2	171 ± 39.5*	161.4 ± 38.8	165.2 ± 32.8
Post-Blood Lactate (mmol/L)	13.8 ± 2.9	14.5 ± 3.9	13.5 ± 2.6	14.9 ± 2.8
Urine Specific Gravity (SG)	1.010 ± 0.006	1.009 ± 0.006	1.007 ± 0.004	1.008 ± 0.003
RPE	15.5 ± 1.8	15.2 ± 1.5	15.4 ± 1.5	15.8 ± 1.3

*denotes a significant difference between trials ($p<0.05$).

Table. 3 Hemodynamic Measurements

Variable	*HI*		*CON*	
	TT1	**TT2**	**TT1**	**TT2**
HR (bpm)	164.5 ± 9.5	161.9 ± 8.8*	166.3 ± 13.2	163.2 ± 10.5
SV (ml)	112.5 ± 46.6	122.3 ± 36.6	104.4 ± 41.6	109.5 ± 21.2
Q (L/min)	18.6 ± 6.7	19.5 ± 4.9	17.1 ± 6.2	17.5 ± 3.7
SaO_2 (%)	87.8 ± 1.5	86.7 ± 1.5	86.4 ± 2.6	87.3 ± 1.1

*denotes a significant difference between trials ($p<0.05$).

Discussion

The main finding of this study was a single HI bout induced a significant hypervolemic response 24 and 48 hrs post exercise. Further, subjects within the HI condition improved performance measurements in their subsequent TT, but this did not happen in the CON condition.

This study sought to isolate the intensity derived PVE in order to both better understand the degree of commonality between high intensity exercise and hypoxia, as well as examine cardiovascular adaptations that derivate from this hypervolemic response alone. Indeed, these data demonstrated that a significant PVE was accompanied by a significant improvement in TT performance in hypoxia, characterized by a reduction in time to completion and increased average power, while subsequently showcasing an attenuation in HR and trend towards increased Q. These findings are consistent with previous studies, as Periard et al. (7) noted that the acute expansion of plasma assists in the attenuation of HR and positive changes in Q, thus decreasing cardiovascular drift during strenuous exercise only within a few days of heat acclimation (8). Further, it is important to highlight that our results were achieved following a single bout high intensity intervals, significantly mitigating the hypoxia associated declines in exercise performance within an expedited period of time when compared to other altitude acclimation protocols.

In conclusion, a single bout of HI intervals resulted in increased cycling performance in acute hypoxia, accompanied by an enhanced PVE both 24 and 48 hours following exercise. This observed enhancement in cardiac efficiency following intensity exercise may be desirable in military populations or individual desiring to complete physical tasks at moderate altitude f without the means or time to fully acclimatize.

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3. Kinematic Analysis and Neuromuscular Performance in Shooting and Fleeing Scenarios Against Law Enforcement Officers

Kantor, Michael, M.S., Garg, Hina, Ph.D., Lau, Jeff, Ph.D., Tenbrink, Joel, Ph.D., and Pettitt, Robert, Ph.D., FACSM
Rocky Mountain University of Health Professions, Provo, UT

Background

Ambushes against law enforcement are classified in two ways, premeditated or spontaneous, and on average law enforcement officers nation-wide wide experience 215 ambushes a year since 2000 (International Association of Chief Police, 2014).These encounters are often “ambush” in nature because they contain an element of surprise, concealment, or suddenness (International Association of Chief Police, 2014). Ambush attacks accounted for 115 officer deaths, and another 267 officer injuries between 2003 to 2012, where 36% of the attacks were with a firearm (International Association of Chief Police, 2014). Such situations impose rapid decision-making and neuromuscular performance (e.g., the typical response has been found to take 0.46 to 0.70 seconds to begin a physical response) (Lewinski, Hudson, & Dysterheft, 2014; Rippoll, Kerlirzin, Stein, & Reine 1995; Vickers, 2007). To draw and fire a weapon requires 1.68 to 1.94 s, dependent upon whether or not the officer’s holster is snapped, respectively (Campell, Roelofs, & Davey, 2013; Lewinski, Dysterhelp, Bushey, & Dicks, 2015).There is minimal understanding of how much time it takes for assailants to draw and fire their weapon at officers and flee in response, with specific interest in how long it takes for an assailant’s back to be presented to the officer.

Purpose

We examined 3 assailant-involved shooting and fleeing firearm threats (motions) to determine: 1) the time to complete each motion upon initiation, 2) the fastest and most lethal of the 3 motions, 3) the variability/consistency of each motion, and 4) any common kinematic profiles of faster vs. slower shooting performances.

Methods

A total of 20 male subjects (19-34 years old; Mean: Height 182.07 cm; Weight 81.67 kg) who were naïve shooters completed 3 trials of 3 motions shooting a training pistol (SIRT; Ferndale, Washington) at a stationary target of a Police Officer silhouette. Upon viewing a stock video of a person demonstrate each technique, the subject practiced each motion prior to completing three trials with a training pistol. Joint kinematic data relative to time were captured at a rate of 128 Hz using 15 wearable motion inertia sensors (ADPM wearable technologies; Portland, Oregon). We determined the time for initiation of lethal force, shot fired, and time to the back facing the target (officer). All procedures were pre-approved by our Institution Review Board and all subjects completed an informed consent.

The three motions included: 1) 90° turn (simulating a boot leg holster, the shot fired, and a 90° followed by fleeing from the target), 2) 180° turn (simulating a boot leg holster, the shot fired, and a 90° followed by fleeing from the target), and 3) a Strong side turn (whereby the assailant's back is to the target, the turn to shoot the target and turn back to flee). For each motion, the time to threat of lethal force was determined by motion of the right extremity toward the target, the shot fired corresponded with joint kinematics reversing direction, and turned back was confirm when peak extension right hip was achieved. Within-trial analyses of the timed performances were evaluated using interclass correlation coefficient (ICC), typical error (TE), coefficient of variation percentage (CV%). A repeated measured ANOVA was use to evaluate statistical difference between motions. Descriptive statistics were reported as mean with standard deviation.

Results

Despite being naïve shooters, extremely fast shooting and turning times were observed, under one half to one full second, respectively (Table 1). The time to fire the weapon upon initiation of lethal force differed significantly between the three motions ($F=13.6$, $p<0.001$, $N_p^2=0.60$) (Figure 1, left panel); whereas, conversely, no differences in the time for the subject to turn their back to the target was observed (Figure 1, right panel). Reliability for the three trials of the 90 and 180° turn condition were high; yet, the Strong side turn condition was quite variable (Table 1). A large effect size was examined between 180° turn and Strong side turn ($d=0.97$), and medium effect size between 90° turn and Strong side turn we observed ($d=0.53$) (Figure 1). For all three motions, faster times were observed subjects who abducted and externally rotated their shoulder following achievement of peak shoulder flexion, kinematically indicated by the start of right shoulder abduction (Figure 2, right panel), and back turn was kinematically indicated when right hip extension was at its peak (Figure 3). Table 1. also demonstrates the reliability analysis of the 3 motions collected.

Table 1. Summary statistics and reliability analysis (intraclass correlation coefficient (ICC), typical error (TE) and coefficient of variation (CV) for the times to shoot and turn (N = 20).

	Time (sec) SD	ICC (α)	TE (Seconds)	CV (%)
Time to Shoot				
90 Degree Turn	0.422 ± 0.12	0.88	0.04	9.9
180 Degree Turn	0.375 ± 0.11	0.85	0.04	13.3
Strong Side Turn	0.486 ± 0.12	0.44	0.11	24.4
All	0.427 ± 0.12			
Time to Back Turn				
90 Degree Turn	0.830 ± 0.26	0.883	0.09	13.67
180 Degree Turn	0.811 ± 0.28	0.891	0.09	12.3
Strong Side Turn	0.903 ± 0.27	0.693	0.17	19.36
All	0.848 ± 0.27			

Figure 1. Times for shooting and turning a way from the target. P values denote the results of the LSD comparison for the ANOVA and d values represent the effect size of the differences in shooting times

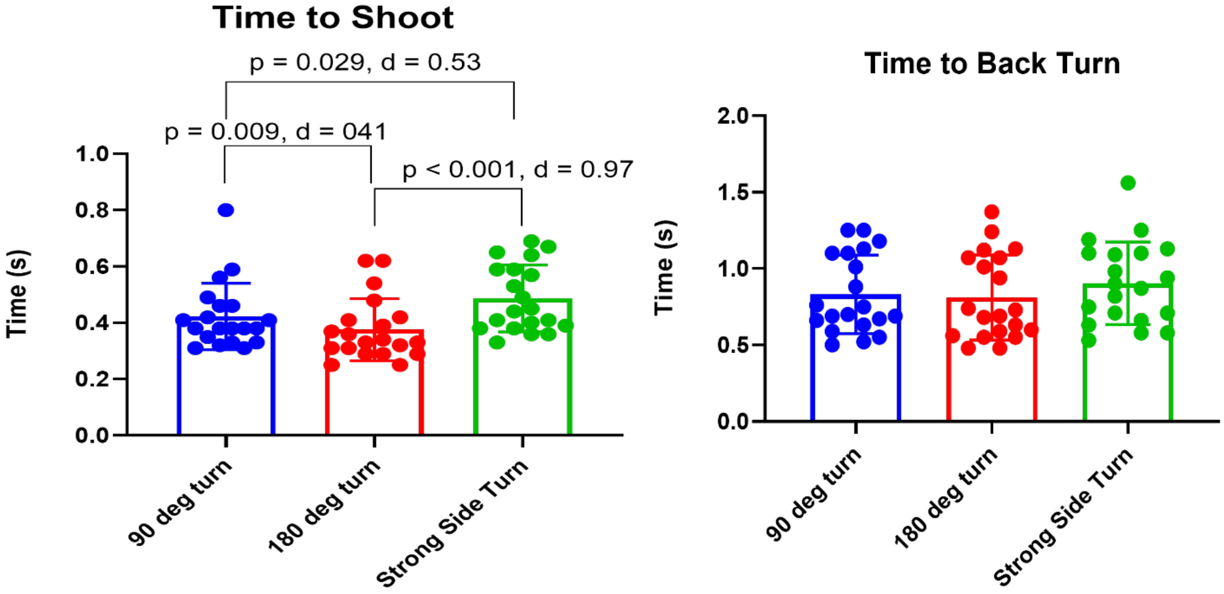
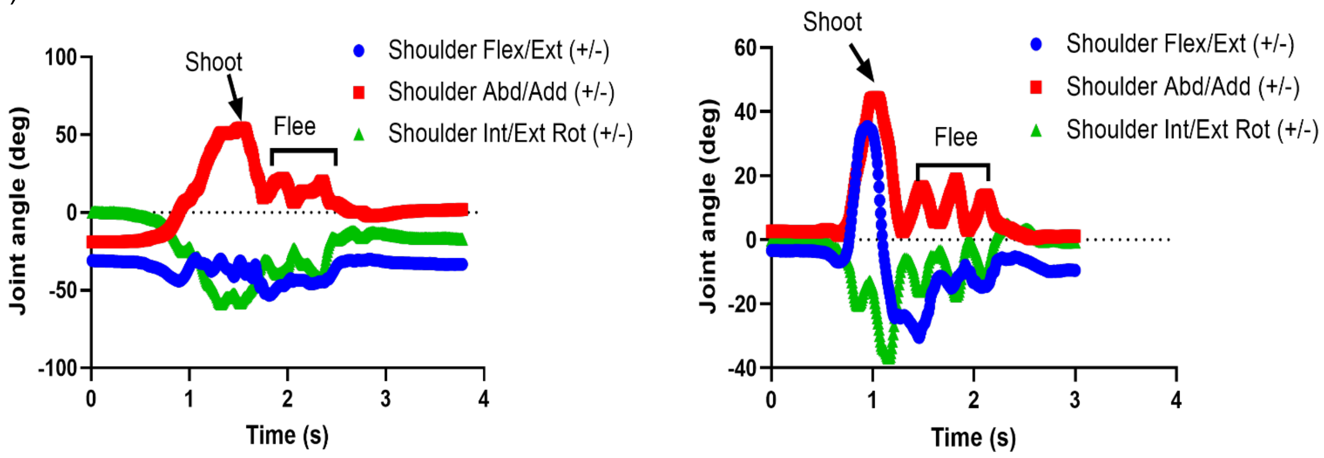


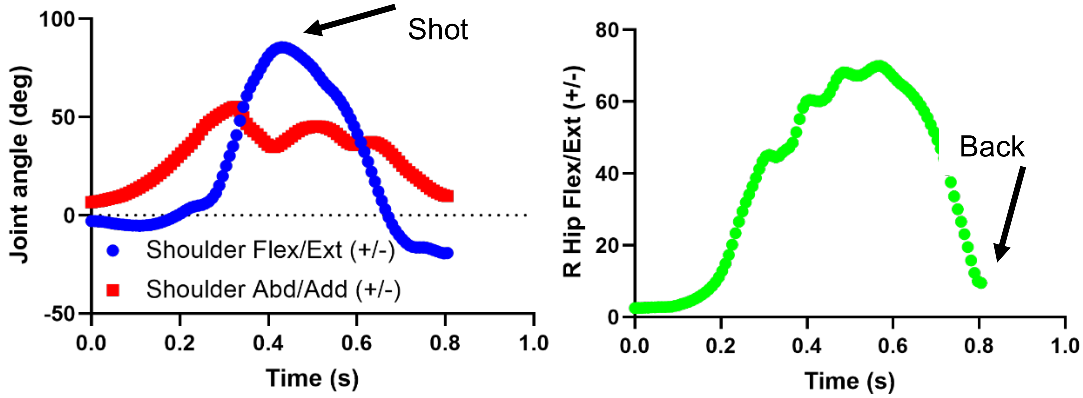
Figure 2. Kinematic breakdown of the shoulder and arm trends in all three shooting motions slow (left) vs. fast (right)



Discussion

The most variability in completing the motions was seen in the strong side turn (See Table 2.) with a 24.4% variation in time trial to trial within each subject, which is a 0.11 seconds human error in the shooting the strong side turn motion. The most lethal motion was the 90° turn due to the low time variability and highest ICC in time to shoot the gun (Table 1) which for all the subjects there was only a 0.04 second error in shooting the gun, which is extremely consist across 20 un-trained subjects, which is almost three times less human error compared to the strong side turn. However, all three motions were completed faster than the mean time is takes for an officer to response to the movement and draw and fire their gun (Lewinski et al., 2014; Rippoll et al., 1995; Vickers, 2007; Campellet al., 2013; Lewinski et al., 2015). Preparing officers to respond to certain kinematic movements is vital in improving officer protocol in dealing with and surviving ambush situations, with a neuromuscular reaction disadvantage. Kinematic tracking from the subjects who performed faster shooting times demonstrated the ability to abduction and externally rotate their shoulder, along with flexion and extension of the shoulder (Figure 2, right panel), which created more speed, which decreased the time to shoot. What attributed to a slower time to shoot was minimal use of other motions, such as just using mostly shoulder abduction (Figure 2, left panel) to move the entire arm to shoot compared to using the shoulder to extended, externally rotate and use elbow to flex and extend while lifting to arm was seen be more kinematically efficient.

Figure 3. Kinematic breakdown of the hip and shoulder to indicated back turned to the officer



Conclusion

All three motions were completed in under 1 seconds beginning to end (Table 1), which is faster than the average time for a train police officer to response and draw their gun in response to the assailant's initiation of the threat. The most lethal shooting motion was the 90° turn, followed by the 180° turn, and lastly was the Strong side turn when comparing the times to shot and reliability between trials and subjects (90-degree turn:

ICC=0.88, TE=0.04 seconds, and CV%=9.9%, 180-degree turn: ICC=0.85, TE=0.04 seconds, and CV%= 13.3, strong side turn, ICC=0.44, TE=0.11 seconds, and CV%=24.4%). Those who incorporated higher use of shoulder abduction and external rotation in the arm and shoulder had faster times compared to those who only using mostly shoulder abduction. This study provides kinematic data of what to look for in a lethal threat, how long it takes for an assailant to fire and flee a scene, help further prepare police officers in these situations, and help to legally walk through police involved shootings in the future.

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4. Kinematic and Real-World Performance Implications of Acquiring a Novel Dart-Throwing Skill in Virtual Reality

Lachica, Isaiah J., Drew, Stefanie A., Ph.D., Awad, Madelyn F., Armendariz, Jazlyn A., Gabay, Bar, and Hinkel-Lipsker, Jacob W., Ph.D.
California State University Northridge, Northridge, CA

Introduction: Virtual reality (VR) has recently advanced to a level where it can provide high resolution and highly immersive environments at a price that is accessible to the masses (Arnaldi, Guitton, & Moreau, 2018; Slater & Sanchez-Vives, 2016). Due to these developments, VR systems are now being used to train motor skills across multiple fields such as sport (Düking, Holmberg, & Sperlich, 2018) and medicine (Aïm, Lonjon, Hannouche, & Nizard, 2016; Li et al., 2017). Use of these systems continues to expand as it has the ability to provide virtual environments where individuals can learn a skill in a safer, more convenient, and more cost-efficient manner (Carruth, 2017; Champney, Carroll, Surpris, & Cohn, 2014). As of right now, the available literature on the transfer of skills learned from a virtual environment to the real world remains relatively new. As such, additional research and a more thorough exploration into the basic science involved in the transfer of skills from virtual to real-world environments is warranted (Düking et al., 2018).

Previous reports have shown that the use of VR head-mounted display systems produce a dissociation between the vergence and accomodation systems of the oculomotor system (Kramida, 2015; Wilson & Soranzo, 2015). This inconsistency can change the perceptual strategies of a person in a virtual environment which, in turn, can affect motor skill acquisition and transfer. From the perspective of Newell's Model of Constraints, a comprehensive framework used to understand human skill acquisition, the interaction between perception and action during execution of a motor skill impact the way that skill is ultimately performed (Newell, 1986). This perceptual-motor interaction is influenced by constraints related to the individual performing the skill, environmental factors, and rules or guidelines imposed by the task. Therefore, if the constraints afforded by a virtual learning environment differ from those in the real world, then how the environment is perceived may ultimately affect the task outcome.

According to Newell's Model of Constraints, the way a virtual environment is perceived ultimately will affect how movement is coordinated. While many studies have reported improvements in performance of various tasks after VR training (Adamovich, Fluet, Tunik, & Merians, 2009), only a few studies to date have assessed the kinematic and coordinative strategies that indivduals adopt while acquiring a skill in a virtual environment. Such information may help to detail whether the movement strategies learned in VR differ from that in the real world. In conjunction with the reported effects on perceptual systems, a deeper understanding of how motor systems are also affected by VR systems is critical in determining the ability to transfer a skill learned in a virtual environment to the real-world. Combined, such information will provide insight into whether the current generation of VR technology is sufficient for transfer of learned kinematics and coordination strategies of acquired motor skills to the real world.

Purpose: The purpose of the study was to determine the effects of a single session of VR training on motor and task performance as compared to a single session of real world training. We hypothesized that, after training, (1) VR-trained participants will have different throwing arm joint angles at the point of dart release and (2) will utilize coordination patterns that are detrimental to the successful performance of the task. We also hypothesized that (3) participants trained in VR will perform worse, in terms of task outcomes, on a real-world follow up test compared to those trained in the real world.

Methods: Fifty participants were recruited and signed consent forms approved by a California State University, Institutional Review Board. Participants were eligible if they were 18 years old or older with normal or corrected vision. They must also be able to use contacts to correct their vision during the study. Due to not meeting additional specific visual criteria, data from nine participants were removed, ultimately leaving 41 participants. The participants were randomly assigned to a VR training group (n=22) or a real-world (RW) training group (n=19).

After being consented into the study, eleven retro-reflective markers were placed on the participants' trunk and throwing arm. All participants were then asked to complete a baseline test consisting of two sets of five dart throws at a dartboard set at regulation height and distance. Following this, participants began training in their assigned groups, with the VR group using an HTC Vive (HTC, Taoyuan, Taiwan) preloaded with the VR darts game, VR Darts Zone (Reality Busters Co., 2017), while the RW group trained in the real world. Training for the VR group began with 5 minutes of familiarization where the participants were provided with instructions on how to navigate the VR environment and acclimate to the virtual space. Participants in the RW group also began their training with familiarization and acclimation except in the real-world space. Then, all participants were instructed to begin throwing ten sets of ten darts in their respective environments for 25 minutes. A 1-minute break was provided in between each dart throw to minimize fatigue. After training, all participants were asked to complete a post-training test consisting of two sets of five dart throws similar to the baseline test. Three-dimensional marker coordinate data were recorded continuously at 150 Hz in both the baseline and post-training tests as well as during the first five throws of each of the 10 training sets using an 8-camera motion capture system (Motion Analysis Corp., Santa Rosa, CA). Accuracy, measured as the radial distance of each dart from the bullseye, was recorded at the end of each of the two baseline and post-training sets.

Marker coordinate data were used to create a 4-segment model in Visual 3D (C-Motion, Germantown, MD) from which shoulder, elbow, and wrist joint angles were extracted for each of the throws. Shoulder, elbow, and wrist joint angles were time-normalized from 0-100% of the throw to create ensemble curves used for visual inspection of throwing motion utilized by both groups. Additionally, the shoulder, elbow, and wrist joint angles at the point of dart release were also compared between groups as a way to observe differences that could have emerged due to the difference in training environments. In addition, the Index of Motor Abundance (IMA), computed using an Uncontrolled Manifold approach, was used to determine how participants from both groups utilized variability in their throwing motions to stabilize a task-related variable—a three-dimensional vector from the shoulder joint center on the throwing arm to the 3rd metacaral of the throwing hand (for details on this calculation, see Scholz & Schöner, 1999). An IMA closer to 1 indicates that the participants used the variability in their joint configurations to explore movement solutions that did not affect the position of the hand at the time of dart release (which would theoretically not affect throwing accuracy). On the contrary, an IMA closer to -1 indicates that the participants used the variability in their joint configurations to explore movement solutions that did affect the position of the hand during dart release—a strategy that would likely be detrimental to throwing accuracy. An IMA of 0 indicates that the participants did not utilize any joint coordination strategies. IMA was computed at five different time points: at 0%, 25%, 50%, 75%, and 100% of the dart throw.

Three repeated-measures, two-factor analyses of variance (rANOVAs; α = 0.05) were performed to test for the main effects of practice group and time on the shoulder, elbow, and wrist joint angles of the throwing arm. Five rANOVAS (α = 0.05) were also used to test for the main effects of practice group and time on the five IMA time points (0%, 25%, 50%, 75%, and 100%). Additionally, a two-factor rANOVA (α = 0.05) was used to test for the main effects of practice group and time on accuracy.

Results: A qualitative visual examination of the shoulder, elbow, and wrist joint ensemble curves demonstrate that there were no differences in the throwing kinematics between the two training groups before and after training (Figure 1a, 1b, 1c). The results of the statistical analyses provide evidence to support these observations.

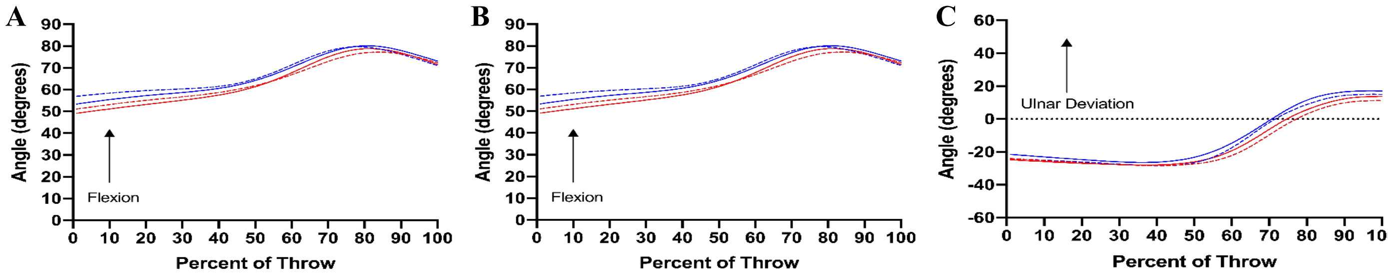


Figure 1. Ensemble curves of the (A) shoulder, (B) elbow, (C) wrist joint angles from 0% to 100% of the dart throw

No significant effect of time was found for the end shoulder joint angles (p=.131) and end wrist joint angles (p=0.057). No significant time x group interaction was found for the end shoulder joint angles (p=.08, Figure 2a) and end wrist joint angles (p=0.304, Figure 2c) as well. However, a significant effect of time (p<0.001) and a significant time x group interaction (p<0.001) was found for the end elbow joint angles. Using Bonferroni-corrected follow-up comparisons, these differences were found to be during training as the VR group had a significantly greater elbow flexion at the point of dart release compared to the control group for training sets 1-5 and 7-10 (p<0.05, Figure 2b).

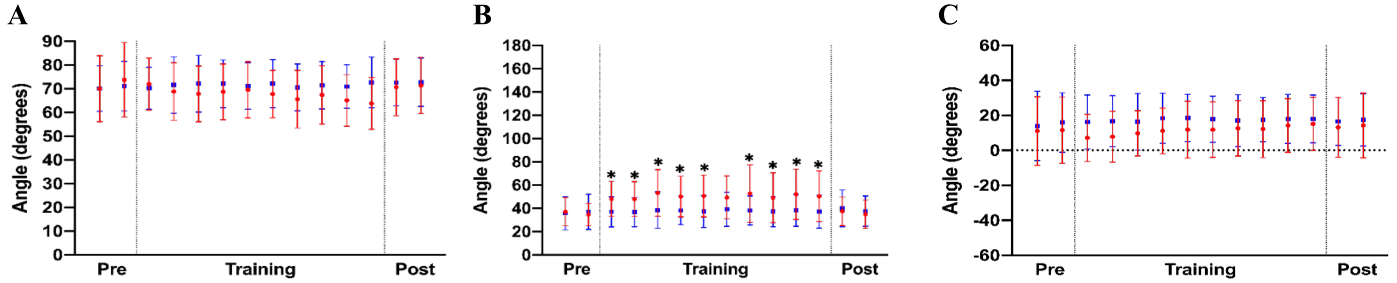
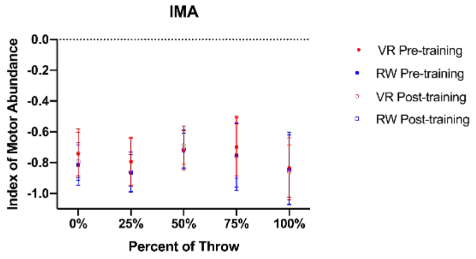
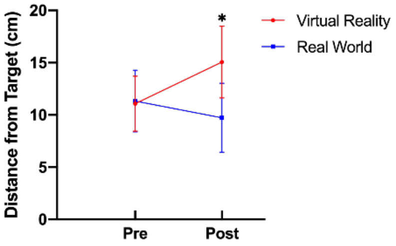


Figure 2. Discrete (A) shoulder, (B) elbow, and (C) wrist joint angles at the point of dart release

No significant effect of time was found for the IMA values at the 0% (p=.197), 25% (p =.764), 50% (p=.191), 75% (p=.850), and 100% (p =.242) time points. Additionally, no significant time x group interaction was found for the IMA values at the 0% (p=.401), 25% (p=.731), 50% (p=.572), 75% (p=.880), and 100% (p=.109) time points as well (Figure 3).





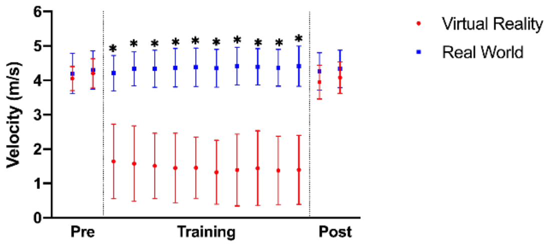


Figure 3. Index of Motor Abundance **Figure 4.** Dart-throwing accuracy **Figure 5.** Peak dart-throwing velocity

A significant time x group interaction was found on dart throw accuracy (p<.001). Using post-hoc analyses, dart throw accuracy was found to be significantly worse for the VR group than the RW group (p<.001). A significant effect of time was found for both groups. Specifically, the accuracy of the VR group was significantly worse after training (p<.001) while the accuracy of the RW group was significantly better after training (p=.029, Figure 4).

An additional post hoc analysis was performed to discover what caused the differences in task performance between the groups after they trained in their respective environments. Previous studies have reported that expert dart throwers perform the task at higher velocities compared to novices (Schorer, Jaitner, Wollny, Fath, & Baker, 2012). As such, we computed the peak resultant linear velocity of the 3rd metacarpal marker of the throwing hand for both groups where signficant main effect of time (p<.001) and a significant time x group interaction (p<.001) was found (Figure 5).

Discussion: The results of the study does not support our first hypothesis as no significant differences were found for the throwing arm joint angles of the VR group and the RW group after training. However, significant differences were found for the elbow joint angles at point of dart release during VR training. This greater elbow flexion exhibited by the VR group during training could be caused by the utilization of a controller instead of an actual dart. Since the physical characteristics of objects can affect a person's reaching and grasping behavior (Johansson & Cole, 1992), the use of a controller could have potentially introduced a different task constraint that is different compared to when using an actual dart. Despite this difference during training, the VR group was able to adapt their movement to the real-world, as indicated by the lack of significant differences found when compared to the control group. As such, the different throwing pattern that emerged during training was not utilized on the real-world follow-up test.

Futhermore, the results of the study does not support our second hypothesis as no significant differences were found between the two groups in post-training tests at any of the IMA time points. Additionally, both groups demonstrated IMA values closer to -1, which indicates that all participants were exploring movement variabilities that worked to destabilize the position of the hand. There are two reasons why this result may have occurred. First, because the participants were only trained for a single session, they were unable to learn the skill to a degree where they could take advantage of the different kinematic strategies to stabilize the hand position during the throw. Second, the position of the hand relative to the shoulder at the time of dart release may not be an important variable to control in order to perform an accurate throw.

However, even with kinematic and coordinative similarities between groups, the VR group still performed significantly worse in accuracy during the post-training tests. Surprisingly, they also performed worse compared to their initial results before training. Despite the lack of post-training differences in motor behavior, these findings support our third hypothesis. It is possible that the measures included in this study were not enough to capture the perceptual and motor differences that could have reduced the accuracy of the VR group.

Conclusion: As our results indicate, VR training had a detrimental effect on task performance in the real-world. In addition, unique kinematic patterns were observed during VR training that were not utilized on the real-world follow-up test. As such, while the differences in unique motor patterns found during VR training do not transfer to the real world, there is still evidence to suggest that VR training does not transfer to the real world due to the decrease in task performance observed. More research is needed to further clarify how the unique constraints imposed by a virtual learning environment impact the perceptual and motor strategies that lead to successful real-world performance.

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5. Effect of Gas Compression Artifact on Expiratory Flow Limitation Assessment in Children with and without Obesity

Strozza, Danielle[1], Wilhite, Daniel P, Ph.D.[2], Babb, Tony G, Ph.D.[2], and Bhammar, Dharini M, Ph.D., M.D.[2-3]
School of Medicine, University of Nevada Las Vegas, Las Vegas, NV[1]
Institute for Exercise and Environmental Medicine, Texas Health Presbyterian Hospital Dallas and UT Southwestern Medical Center, Dallas, TX[2]
Department of Kinesiology and Nutrition Sciences, University of Nevada Las Vegas, Las Vegas, NV[3]

Background: Expiratory flow limitation (EFL) occurs when tidal expiratory flow reaches maximal expiratory flow and compensatory respiratory muscle effort cannot increase expiratory flow causing mechanical ventilatory constraint (1). When individuals experience EFL during exercise, time for expiration is prolonged and complete expiration can be limited (2), which can increase end-expiratory lung volume (EELV) leading to dynamic hyperinflation (2). This phenomenon adds an elastic load on inspiratory muscles and increases the work of breathing. EFL and dynamic hyperinflation could provoke dyspnea, respiratory muscle fatigue, and exercise intolerance (3, 4).

To determine EFL, tidal exercise flow volume loops are plotted in the maximal expiratory flow volume (MEFV) envelope and overlap between the loops is expressed as a percent of tidal volume (5). The MEFV curve is typically constructed from expiratory flow measured at the mouth (MEFVm), however, this can pose a limitation in the assessment of EFL because MEFVm does not account for gas compression artifact (6). Gas compression artifact is the reduction in lung volume due to pressures applied by static elastic recoil, airway resistance, and respiratory muscle exertion (6, 7). When gas compression artifact is not accounted for, measurements by MEFVm underestimate the flow rates measured at 25 and 50% of forced vital capacity (FVC) (6). As a result, when tidal exercise flow volume loops are plotted within the MEFVm, there could be an overestimation of EFL (8)(Figure 1A). Gas compression artifact can be corrected for by measuring MEFV with a volume displacement plethysmograph, where volumes are measured at the lung (MEFVp) instead of the mouth, thus adjusting for gas compression at the thorax (6, 8, 9).

Compared to adults, children have lower lung volumes, less elastic recoil (10), and less maximum expiratory pressure (11). These differences suggest that less pressure is being applied to the gas in the lungs, potentially leading to less gas compression artifact and less overestimation of EFL by MEFVm in children. Although the link between overestimated EFL with MEFVm has been shown in adults (8, 9, 12), it has never been investigated in children who experience high rates of EFL (13). Furthermore, since children with obesity breathe at lower lung volumes and are more likely to experience EFL (14), it is important to examine the effect of gas compression artifact on estimation of EFL in children with *and* without obesity.

Purpose: The purpose of this study was to compare EFL at peak exercise from exercise tidal exercise flow volume loops plotted within MEFVm (i.e., not corrected for gas compression artifact) versus MEFVp (i.e., corrected for gas compression artifact) in children with *and* without obesity. We hypothesized that MEFVm, which does not correct for gas compression artifact, would overestimate EFL at peak exercise compared with MEFVp in children with and without obesity. **Design/Methods:** The child's parent or guardian provided written, informed consent, and children provided written assent (IRB approval #052012-076). 28 children with obesity ([BMI] >95th percentile) and 13 without obesity (BMI between 16th and 84th percentile), all 8-12 yr. old, completed screening procedures, pulmonary function testing, and maximal graded exercise test. Pulmonary Function: All participants had standard spirometry and lung volume determinations according to the guidelines of the American Thoracic Society (15). Maximal flow-volume loops (MEFVm and MEFVp) were measured in a pressure-corrected volume-displacement body plethysmograph to eliminate gas compression artifact (SensorMedics model 6200, Yorba Linda, CA). Volume of gas compressed was assessed by measuring the difference in volume at peak expiratory flow between MEFVm and MEFVp. Percent difference in isovolume (iso) $FEF_{50\%}$ was also assessed at 50% of FVC between MEFVm and MEFVp (Figure 1A).

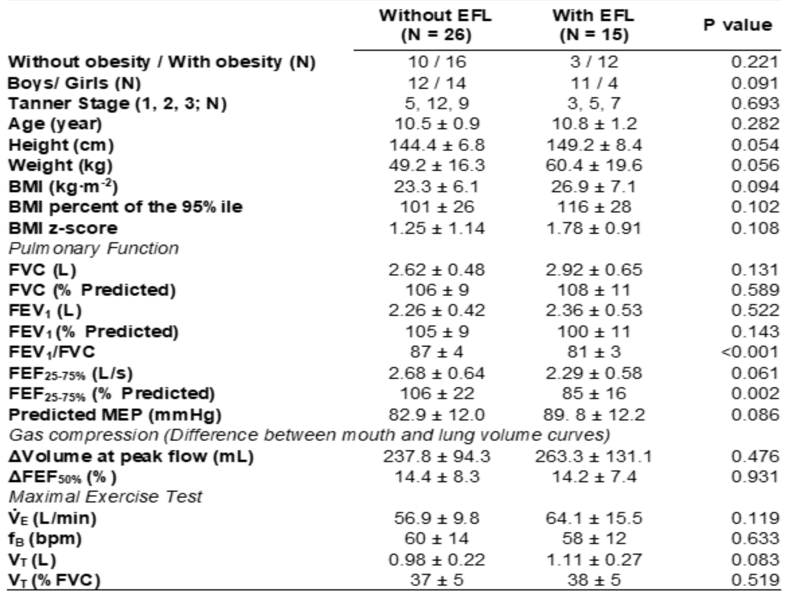
Maximal Incremental Exercise Test: The maximal incremental exercise test was performed on a cycle ergometer (Lode Corival, The Netherlands). The initial work rate was 20W, and the work rate was increased by 10 or 15W every minute until volitional exhaustion. Measurements of minute ventilation and gas exchange were made with the Douglas bag method as described previously (16). Expiratory and inspiratory flows were measured at rest and continuously during exercise to obtain tidal volume (V_T), breathing frequency, and exercise tidal flow-volume loops as described previously (17, 18). IC was measured during the last 20s of each exercise increment by having participants inhale maximally to total lung capacity on cue from the investigator. A typical maximal tidal flow-volume was chosen from the breaths at peak exercise and it was positioned within the MEFV loops using the measured IC for EFL estimation.

Expiratory flow limitation: Expiratory airflow limitation was defined as the % of V_T where peak exercise tidal expiratory flow impinged on maximal expiratory flow (Figure 1A). Two MEFV curves were compared with peak exercise tidal flow volume loops:

1. MEFVp: lung volume obtained from plethysmography; corrected for gas compression artifact
2. MEFVm: mouth volume obtained from spirometry; not corrected for gas compression artifact Statistical analysis: Differences between children with and without obesity were compared with independent t tests. Differences in EFL between methods (MEFVp and MEFVm) and groups (with and without obesity) were determined by mixed ANOVA. Bland-Altman plots examined the agreement between MEFVp and MEFVm in determining EFL (19). Pearson correlations were used to examine associations. A P value of 0.05, two tailed, was considered significant.

Results: After correcting for gas compression artifact (MEFVp), 15 children experienced EFL (true positives) and 26 children experienced no EFL (Table 1). The volume of gas compressed during the MEFV maneuver (7.2 ± 2.5%TLC) and the difference in isoFEF$_{50\%}$ between MEFVm and MEFVp (14 ± 3%) did not statistically differ between children with and without EFL. The difference in EFL between MEFVm and MEFVp was associated with volume of gas compression (r = 0.416; p = 0.039; N=25). Of the 26 children who experienced no EFL, 10 would have been *misdiagnosed* with EFL (i.e., false positives) with the MEFVm loop (i.e., not corrected for gas compression artifact).

Table 1: Participant characteristics presented for children with and witho expiratory flow limitation (EFL)



	Without EFL (N = 26)	With EFL (N = 15)	P value
Without obesity / With obesity (N)	10 / 16	3 / 12	0.221
Boys/ Girls (N)	12 / 14	11 / 4	0.091
Tanner Stage (1, 2, 3; N)	5, 12, 9	3, 5, 7	0.693
Age (year)	10.5 ± 0.9	10.8 ± 1.2	0.282
Height (cm)	144.4 ± 6.8	149.2 ± 8.4	0.054
Weight (kg)	49.2 ± 16.3	60.4 ± 19.6	0.056
BMI ($kg \cdot m^{-2}$)	23.3 ± 6.1	26.9 ± 7.1	0.094
BMI percent of the 95% ile	101 ± 26	116 ± 28	0.102
BMI z-score	1.25 ± 1.14	1.78 ± 0.91	0.108
Pulmonary Function			
FVC (L)	2.62 ± 0.48	2.92 ± 0.65	0.131
FVC (% Predicted)	106 ± 9	108 ± 11	0.589
FEV_1 (L)	2.26 ± 0.42	2.36 ± 0.53	0.522
FEV_1 (% Predicted)	105 ± 9	100 ± 11	0.143
FEV_1/FVC	87 ± 4	81 ± 3	<0.001
$FEF_{25-75\%}$ (L/s)	2.68 ± 0.64	2.29 ± 0.58	0.061
$FEF_{25-75\%}$ (% Predicted)	106 ± 22	85 ± 16	0.002
Predicted MEP (mmHg)	82.9 ± 12.0	89. 8 ± 12.2	0.086
Gas compression (Difference between mouth and lung volume curves)			
ΔVolume at peak flow (mL)	237.8 ± 94.3	263.3 ± 131.1	0.476
$\Delta FEF_{50\%}$ (%)	14.4 ± 8.3	14.2 ± 7.4	0.931
Maximal Exercise Test			
$\dot{V}_E$ (L/min)	56.9 ± 9.8	64.1 ± 15.5	0.119
f_B (bpm)	60 ± 14	58 ± 12	0.633
V_T (L)	0.98 ± 0.22	1.11 ± 0.27	0.083
V_T (% FVC)	37 ± 5	38 ± 5	0.519

BMI: body mass index, FVC: forced vital capacity, FEV_1: forced expirato volume in 1s, FEF: forced expiratory flow, MEP: maximum expirato pressure, $\dot{V}_E$: minute ventilation, f_B: breathing frequency, V_T: tidal volume.

There was no significant main effect of group, thus children with and without obesity were pooled to analyze the effect of method of measurement on EFL estimation. 61% of participants experienced EFL as measured by MEFVm (38 ± 27) and 37% as measured by MEFVp (15 ± 22). MEFVm overestimated the degree of EFL by 26% in children when compared with MEFVp (26 ± 15), which corrects for gas compression artifact (p<0.001, Figure 1B).

Bland-Altman analysis showed wide-limits of agreement and an overestimation bias of 26% for MEFVm compared with MEFVp (p<0.001, Figure 1C). MEFVm was highly sensitive in diagnosing EFL with a value of 1.00. However, specificity for MEFVm was much lower at a value of 0.62.

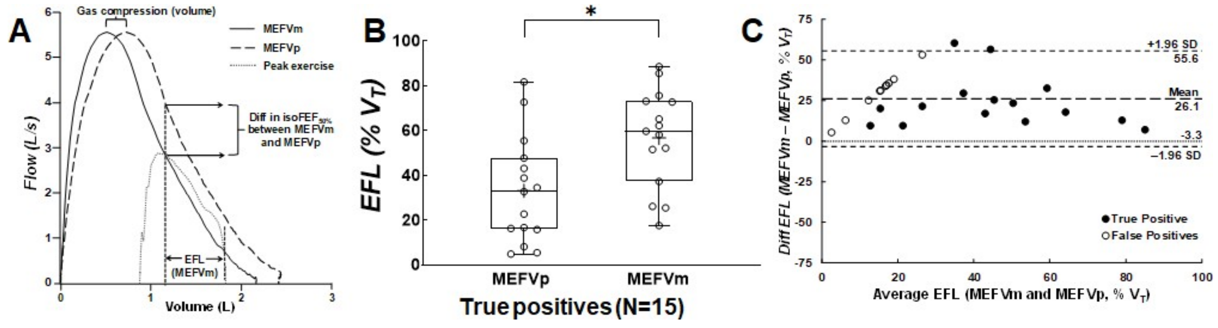


Figure 1: A. Expiratory flow limitation (EFL) was calculated as the overlap of the tidal volume loop with the maximal expiratory flow volume envelope (MEFVm and MEFVp) and expressed as a percentage of tidal volume.
B. Comparison of MEFVp and MEFVm in "true positive" children with EFL showed that MEFVm significantly overestimated EFL (P<0.001). There were no differences by obesity status.

Discussion: Although it has been established that gas compression artifact can affect the measurement of EFL in adults (9), previous studies examining EFL in children have not corrected for gas compression artifact (13, 20-23). We show that EFL can be overestimated by 26% in children when the MEFV curve is not corrected for gas compression. This magnitude of overestimation can significantly affect the interpretation of clinical exercise tests. Furthermore, the volume of gas compression was moderately associated with the overestimation of EFL. Therefore, individuals at risk for increased gas compression artifact are more likely to be over diagnosed with EFL when correction for gas compression is performed.

This study noted that the effect of gas compression artifact on EFL in children (26%) was greater than previously reported in adults (19%) (12). This could be due to methodological differences in correction for gas compression artifact between the studies. Future studies need to use similar methodology to assess if gas compression is truly greater in children vs. adults.

This study noted that the effect of gas compression artifact on EFL in children (i.e., 26% overestimation of EFL) was of greater magnitude than previously reported in adults (i.e., 19% overestimation of EFL) (12). This could be due to methodological differences in correction for gas compression artifact between the study in adults vs. the current study. Future studies need to use similar methodology to assess if gas compression is truly greater in children vs. adults.

Gibson et. al (20) showed a higher prevalence of EFL in children with obesity (38%) compared with children without obesity (8%) (20). The current study showed no group effect (with versus without obesity) on EFL and thus data from all children were pooled in the analyses. However, of the 13 children without obesity, only three (23%) experienced “true” EFL as measured by MEFVp. In comparison, of the 28 children with obesity, 12 (43%) experienced “true” EFL as measured by MEFVp, which is almost at twice the rate of children without obesity, suggesting the EFL is a concern for children with obesity.

Conclusions:

This study showed that not correcting the MEFV curve for gas compression artifact leads to significant overdiagnosis and overestimation of EFL. Therefore, clinicians must exercise caution while interpreting EFL when the MEFV curve is not corrected for gas compression artifact.

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6. The Effects of 4 Weeks of Time Restrictive Feeding on Exercise Performance, Metabolism, and Recovery in Competitive Male Runners

Tovar, Ashley, M.S. R.D.[1], Richardson, Christine, M.S.[1], Casazza, Gretchen, Ph.D.[2], and Keim, Nancy, Ph.D. R.D.[1]
Department of Nutritional Biology, University of California Davis, Davis, CA[1]
Department of Neurobiology, Physiology and Behavior, College of Biological Sciences, University of California Davis, Davis, CA[2]

Background: Nutritional needs for competitive athletes are different compared to sedentary individuals due to the athletes' increased physical activity and the physiological stress associated with exercise. As a result, athletes rely on nutritional strategies to optimize their performance and recovery.[1] Their quest for performance enhancement through nutrition often causes athletes to follow dietary trends based on the perceived performance benefit associated with these diets.[2] One example of this is the increased popularity of time restrictive feeding (TRF) dietary patterns, which have shown favorable effects on metabolism in various groups including obese populations,[3, 4] individuals of a healthy weight,[5] and male resistance trained athletes.[6]

A TRF pattern is a form of intermittent fasting, where individuals undergo longer periods without the consumption of food. Fasting periods may last 10-21 hours and are traditionally defined by restricting the dietary intake to avoid energy consumption in the form of calories while allowing for water intake.[6] The proposed physiological benefits of spending more time in a fasted state are based on findings indicating that feeding and fasting affect signals related to the circadian rhythm.[7] A recent investigation focused on a form of TRF called the 16/8 diet, which requires 16 hours of fasting and 8 hours of feeding in a 24 hour period, in resistance trained male athletes.[6] After 8 weeks of adhering to a 16/8 TRF pattern, subjects experienced a significant decrease in serum glucose, insulin, total testosterone, IGF-1, leptin, free triiodothyronine (T3), IL-1β, and TNF in the TRF condition compared to the normal diet (ND), which has a 12 hour feeding window. Reduced windows of caloric intake have been shown to prioritize physiological functions necessary for survival while suppressing metabolic processes, growth, and reproduction.[8] Low insulin, leptin, testosterone and an increase in cortisol, as seen in these resistance trained athletes, suggests that not all effects may be beneficial as these alterations to the hormones are seen in athletes who have difficulty recovering from exercise.[9] Resistance training requires reliance on different cellular adaptations such as the stimulation of mTORC1 to stimulate muscle hypertrophy.[10] Longer duration endurance training utilizes oxidative pathways and adaptations such as mitochondrial biogenesis through the stimulation of AMP-activated protein kinase (AMPK), an inhibitory signal to mTORC1 that is also increased from fasting alone. The variance in adaptive mechanisms and metabolic needs to fuel activity leads to a gap in our understanding of how TRF would affect endurance athletes' metabolism and performance.

Purpose: The purpose of this ongoing study is to investigate the effects of a TRF dietary pattern on performance, metabolism, and recovery in trained male athletes.

Methods: The study utilized a randomized cross-over intervention in healthy, competitive male runners between 20-40 years of age. Sixteen subjects are needed based on power analysis (power = 0.8, significance p=0.05, mean difference (MD) = 0.77 ng/ml and SD = 0.9 for leptin).[11] The results presented here are for the 9 subjects who have completed all phases of the study to date. The participants complete two trials, a typical eating pattern (12 fast/12 feed) or a time restrictive (16 fast /8 feed) eating pattern. Each feeding trial continued for 4 weeks and the participants were instructed to follow the same calorie and macronutrient patterns for each arm, with at least a 2-week washout in-between each arm. Subjects arrived at the research center for a familiarization visit and 4 test days, for 5 visits in total. At the familiarization visit, informed consent was obtained, health history questionnaires were administered, an ECG was reviewed by the study physician, and a maximal running test to confirm a VO_2max of 40-70 ml/kg/min, and a practice 10km time trial were completed. Each participant then completed 4 total days of testing, one at the beginning and end of each 4-week trial. Participants arrived at the research center in the early morning following an overnight fast, at these four time points of the study.

Wrist worn Polar A370 activity monitors (Polar Electro Oy, Kempele, Finland) with built-in accelerometer and photoplethsmography (heart rate) capabilities were worn by all participants during the study to assess physical activity for each day of the 4-week arms. The monitor provided training heart rate data and distance to verify consistency across study arms to limit influence from a training effect on study outcomes. Food and beverage consumption were documented by the participant to determine consistency of caloric and macronutrient intake during the 4 weeks of each arm.

Test Visits Completed at the Research Center: During in-person testing visits subjects completed validated questionnaires assessing mood and recovery from sport. The Profile of Mood State (POMS) questionnaire was used as certain alterations in responses to this questionnaire has been associated with alterations to recovery.[12] Substrate utilization testing utilized a graded exercise test with increases in speed after each 3-4 minute stage. Each stage utilizes the running speed at 60%, 70%, 80%, and 90% of the subject's VO_2max. A ParvoMedics TrueOne 2400 metabolic cart was used for collection and analysis of the expired gases. At the end of each stage, subjects briefly straddled the treadmill for ~30 seconds to draw 1-2 drops of blood from an earstick to measure blood glucose and lactate. During each stage respiratory exchange ratio (RER), heart rate, and rate of perceived exertion (0-10 scale) were also collected. Following the exercise test, a recovery period and an additional 10 minutes of rest were provided. Subjects then were instructed to complete a 10km running time trial on the treadmill as fast as possible. They were blinded all variables except distance, but able to manually adjust their speed.

Assessment of Dietary Intake: Participants logged all food and beverage intake and documented feeding times using the food logging application/website MyFitnessPal, Inc. This measure was collected and analyzed for the subject's high, medium, and low days of activity each week (3 days/week) during each trial.

Results: Characteristics for the nine participants who have completed all phases of the study are described in mean values ± SD as follows: age 29.4 ± 4.7 years, height 177.0 ± 6.6 cm, weight 74.3 ± 8.0 kg, body fat 18.5 ± 5.8 %, VO_2max 50.2 ± 67.0 ml/kg/min. Participants showed great adherence to the intervention protocol as seen in Table 1. However, subjects did have a variance in the caloric intake on high intensity exercise days.

As a result of adhering to the TRF diet, participants experienced a decrease in lactate of 0.4 mmol/L at a running intensity of 60% VO_2max and a 0.8 mmol/L decrease at 90% VO_2max, compared to smaller observable changes from the ND, which saw a 0.0 mmol/L increase at 60% VO_2max and a 0.2 mmol/L increase at 90% VO_2max (Table 2). Performance in the 10km time trial post-TRF (50:14 ± 10:40 min:sec) was decreased by 31.3 seconds compared with the pre-TRF running time of 50:44 ± 9:47 min:sec, indicating a faster running speed compared to the ND (pre-ND 51:11 ± 12:06 min:sec, post-ND 51:12 ± 11:37 min:sec), which was a 1.6 second longer after the trial. Subjects reported changes to their mood as assessed through POMS responses. Despite the faster running time in the TRF, there was an observed decrease in the vigor score when on the TRF treatment (-9.0% change) compared to the ND (+7.0% change) and an increase in fatigue score on the TRF treatment (+34.2% change) compared to the ND (-14.4% change).

Mean Treatment Differences

	Normal Diet	TRF Diet
	Mean ± SD	Mean ± SD
Caloric Intake	2459.3 ± 455.0	2442.0 ± 208.9
Caloric Intake - High Intensity Days	2534.4 ± 435.0	2245.0 ± 526.6
Carbohydrate Intake - g	283.1 ± 118.8	274.8 ± 75.7
Protein Intake - g	112.3 ± 26.5	110.8 ± 13.9
Fat Intake - g	94.2 ± 18.4	102.4 ± 17.7
Weekly Running - miles	21.5 ± 4.7	22.9 ± 5.8
Feeding Window - hours	11.6 ± 1.0	7.6 ± 0.4

Table 1

Mean Values by Treatment

	Normal Diet Week 1 Mean ± SD	Normal Diet Week 4 Mean ± SD	Normal Diet Change	TRF Diet Week 1 Mean ± SD	TRF Diet Week 4 Mean ± SD	TRF Diet Change
60% VO$_2$ intensity - HR (BPM)	143.5 ± 9.5	140.1 ± 9.8	-3.4	143.5 ± 9.5	144.1 ± 10.9	+0.6
90% VO$_2$ intensity - HR (BPM)	178.9 ± 12.1	178.5 ± 12.4	-0.4	179.3 ± 8.8	177.7 ± 8.2	-1.5
60% VO$_2$ intensity - RER	0.85 ± 0.05	0.83 ± 0.05	-0.02	0.85 ± 0.06	0.83 ± 0.06	-0.02
90% VO$_2$ intensity - RER	1.01 ± 0.07	1.00 ± 0.08	-0.01	1.01 ± 0.07	0.97 ± 0.07	-0.04
60% VO$_2$ intensity - Lactate mmol/L	1.2 ± 0.4	1.2 ± 0.7	0.0	1.4 ± 0.5	1.0 ± 0.27	-0.4
90% VO$_2$ intensity - Lactate mmol/L	4.2 ± 2.1	4.4 ± 1.9	+0.2	4.7 ± 1.5	3.9 ± 1.0	-0.8
60% VO$_2$ intensity - Glucose mg/dL	101.2 ± 5.8	99.6 ± 6.8	-1.6	103.9 ± 9.1	102.9 ± 10.5	-1.0
90% VO$_2$ intensity - Glucose mg/dL	110.3 ± 15.2	109.6 ± 23.1	-0.7	110.6 ± 6.8	105.9 ± 15.0	-4.7
60% VO$_2$ intensity - RPE	1.8 ± 0.8	1.8 ± 0.7	0.0	2.2 ± 0.9	2.0 ± 0.9	-0.2
90% VO$_2$ intensity - RPE	6.7 ± 2.3	6.3 ± 2.0	-0.4	6.5 ± 2.1	7.3 ± 1.9	+0.8

Table 2

Discussion: Athletes may incorporate specific dietary practices into their training plan in the weeks leading into their event. Adhering to a TRF protocol of 8 hours of feeding for 4 weeks may provide a performance benefit for a medium distance 10km race, potentially related to increased fat oxidation and lactate metabolism. However, subjective increases in fatigue and reductions in vigor and increased RPE at higher intensity exercise may indicate difficulty with long term adherence to the diet affecting recovery. Difficulty maintaining caloric intake on days of a perceived high training load while adhering to a TRF diet may suggest an impaired ability to maintain adequate nutrition strategies on days with longer duration training. Future investigations should examine cellular adaptations from following a TRF diet in both men and women to determine if increased AMPK activity as a result of the diet may contribute to increased mitochondrial biogenesis and fat oxidation. Longer term interventions to determine the practical application of adherence and its effects on recovery may be warranted as well.

Conclusion: Preliminary results indicate that 4 weeks of TRF may provide a performance benefit as seen by faster 10km time trial times and increased capacity to metabolize lactate during endurance exercise, but increased fatigue and decreased vigor could indicate signs of impaired recovery compared to a ND eating pattern.

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