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Effects and Comparison of Eccentric Cycling Trainings Versus Concentric Cycling Training on Muscular and Functional Capacities in Sedentary People

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I. Introduction

Physical deconditioning is a prevalent issue among individuals aged 55 years and older, often resulting from age-related inactivity or underlying pathological conditions. It is characterized by a progressive decline in aerobic capacity (i.e., maximal oxygen consumption and maximal aerobic power – VO_2max and MAP) (Vanhees et al., 2005) and is frequently accompanied by increased adiposity, fatigue, reduced muscle mass, strength, and function —collectively termed sarcopenia (Cruz-Jentoft & Sayer, 2019). These changes elevate the risk of falls and the development of chronic diseases. Globally, approximately 31% of adults fail to meet the World Health Organization's recommended levels of physical activity, thereby exacerbating the burden of noncommunicable diseases and contributing to an estimated economic cost of US$27 billion annually (Bull et al., 2020). It is therefore of paramount interest to develop strategies to tackle this phenomenon.

Physical activity is widely recognized as an effective intervention to improve muscular strength and functional capacities.(Bull et al., 2020; Miles, 2007) Traditional training modalities such as resistance (strength) training and aerobic conditioning have been extensively utilized (Grgic et al., 2019; Knuttgen, 2007). However, these methods may be perceived as physically demanding or inaccessible to older populations due to their intensity or cardiovascular demands (Falck et al., 2017; Lambert & Evans, 2005). More recently eccentric training has emerged as a new effective method presenting various interesting characteristics for rehabilitation (Isner-Horobeti et al., 2013; P. LaStayo et al., 2014; Lewis et al., 2018).

Eccentric contractions involve muscle lengthening under tension, typically occurring during deceleration movements, such as descending stairs or sitting down. Compared to concentric or isometric contractions, eccentric contractions can generate higher force outputs while eliciting a significantly lower metabolic cost—characterized by reduced heart rate and oxygen consumption (Hody et al., 2019; Isner-Horobeti et al., 2013; P. LaStayo et al., 2014; Lewis et al., 2018). These effects are attributed to biomechanical and physiological mechanisms including the contribution of elastic elements (e.g., storage and restitution of potential energy) and the engagement of sarcomeric structural proteins such as titin working as a molecular spring enhancing force production independent of ATP hydrolysis (Hody et al., 2019). Additionally, eccentric contractions require lower motor unit activation and reduced recruitment of both agonist and antagonist muscles, contributing further to their metabolic efficiency (Duchateau & Baudry, 2014; Duchateau & Enoka, 2016; Enoka, 1996).

Given these advantages, eccentric-based exercise modalities have been successfully implemented in rehabilitation settings for patients with cardiopulmonary diseases (Besson et al., 2013; Chasland et al., 2017; Inostroza et al., 2022; Peñailillo et al., 2022), obesity (Julian et al., 2019), and age-related deconditioning (Chen et al., 2017; P. C. LaStayo et al., 2003; Mueller et al., 2009). More recently eccentric cycling has emerged as a particularly promising intervention. This technique utilizes a motor-driven ergocycle to produce backward pedal motion that the user resists, thereby inducing repeated eccentric contractions in the lower limbs (Abbott et al., 1952; Abbott & Bigland, 1953; Barreto, De Lima, et al., 2023; Barreto et al., 2021; Barreto, Lima, et al., 2023). Such devices allow for the generation of high mechanical loads within relatively short durations and at a low rating of perceived exertion (RPE) (Lastayo et al., 1999).

Recent studies have explored the metabolic and functional benefits of high-intensity interval training (HIIT), which alternates short bursts of high-intensity effort with recovery periods (Coates et al., 2023). Compared to continuous moderate-intensity training, HIIT has been shown to improve maximal oxygen uptake and induce muscular adaptations more rapidly and with lower total training volume (Oliveira et al., 2024; Ramos et al., 2015; Rohmansyah et al., 2023). Moreover, HIIT is often perceived as more enjoyable than continuous training, despite similar RPE (Thum et al., 2017).

While eccentric HIIT, a novel combination of eccentric exercise and interval training, has shown promise, especially in terms of eliciting greater mechanical stimuli with lower cardiovascular strain, it may initially provoke muscle soreness, decrements in muscle function and longer recovery times compared to a work matched continuous training (Green et al., 2022; Lipski et al., 2018a). Nonetheless, evidence suggests that gradual exposure to eccentric loading fosters neuromuscular adaptations that attenuate the adverse effects (delayed onset muscle soreness (DOMS), decreased muscular function and range of motion, inflammatory episodes, swelling) over time (Hody et al., 2019; Nosaka et al., 2001). Eccentric HIIT thus represents a potential compromise between the high metabolic demands of concentric HIIT and the limited cardiovascular stimulus of continuous eccentric training (Peñailillo et al., 2023).

Given that eccentric cycling at a fixed workload elicits 40–80% lower oxygen consumption compared to concentric cycling (Barreto et al., 2021; P. C. LaStayo et al., 2003), combining eccentric loading with the interval format may provide a unique stimulus to enhance both aerobic and neuromuscular adaptations. Furthermore, this modality may confer these benefits with lower perceived effort and cardiovascular strain, making it particularly relevant for elderly or clinical populations.

However, despite its theoretical advantages, comparative studies examining the acute and chronic effects of eccentric HIIT versus other training modalities remain scarce. In particular, no previous study has comprehensively assessed the physiological and perceptual responses to eccentric interval cycling relative to both continuous eccentric training and concentric HIIT under matched workload conditions.

The present study aims to compare the acute and training responses of (1) eccentric high intensity interval training, (2)work-matched continuous eccentric training, and (3) concentric high intensity interval training, all performed on cycle ergometers. The variables of interest include ratings of perceived exertion (RPE), cognitive demand (Fat), heart rate (HR), maximal oxygen consumption (VO_2max), maximal aerobic power (MAP), and various functional and health-related parameters.

It is hypothesized that eccentric HIIT will produce comparable or superior improvements in functional outcomes relative to concentric HIIT, but at a lower metabolic and perceptual cost. Furthermore, eccentric HIIT is expected to yield greater physiological benefits than continuous eccentric training for a similar perceived and metabolic load.

II. Population

A. Recruitment

The study was conducted on sedentary individuals aged 50–75, engaging in no more than 3 hours of light-to-moderate activity per week.

Participants were recruited through:

- Notices in the Movement Sciences Department (ULiège, Blanc-Gravier),
- Social media,
- Professional/personal networks.

All participants are legal adults, volunteers, and signed an informed consent form, previously approved by the University Hospital Ethics Committee of Liège (ref 2023/072).

B. Sample Size Estimation

Given the study design (three groups, two time points), a repeated-measures ANOVA was selected to assess within-group changes, between-group differences, and potential group × time interactions. The primary outcomes were changes in isometric maximal strength and maximal aerobic power. The significance level (α) was set at 2.5% to account for multiple primary comparisons.

Assuming a moderate to large effect size (f = 0.3–0.5) and a statistical power of 80%, the required total sample size was estimated to range from *n* = 18 to *n* = 36. Accounting for an anticipated dropout rate of 20%, the recommended sample size ranged from 8 to 15 participants per group. Sample size calculations were performed using *G*Power* software.

Inclusion criteria:

- Aged 55 to 75 yo;
- Sedentary or engaging in <3h of regular physical activity/week.

Exclusion criteria:

- Smoking;
- Recent lower limb injury or pain (past 6 months) interfering with ergocycle tests;
- Uncontrolled acute or chronic disease;
- Cardiovascular disorders.

III. Experimental Protocol

This is a **prospective interventional longitudinal study**, conducted during a single period (year 2024 - 2025).

The experimental study will compare the effects of:

- Two **eccentric training protocols** (continuous or interval training),
- One **concentric training protocol**, all using ergometric bikes.

Random assignment will place subjects into one of three experimental groups. They will follow a 14-week training program with 2 sessions/week (total 28 sessions). Participants must abstain from physical activity the week before and during the entire protocol.

Symptomatic management techniques are prohibited. Various parameters will be assessed before, during, and after the program to compare the protocols.

A. Experimental Design

Participants in the EI and EC groups trained using an eccentric ergometer, while the CI group trained on a concentric ergometer. Baseline and post-intervention assessments were conducted during weeks 1 and 14, respectively. These included a maximal incremental cycling test to determine maximal oxygen consumption and maximal aerobic power, followed by six functional performance assessments.

The training protocol consisted of three consecutive 4-week phases:

1. Familiarization Phase (Weeks 2–5)
2. Initial Training Phase (Weeks 6–9)
3. Progressive Training Phase (Weeks 10–13) with increased training intensity.

B. Incremental Cycling Test

At the first and final visits, participants underwent a concentric incremental cycling test to determine maximal oxygen consumption and maximal aerobic power. The test began with a standardized 2-minute warm-up at 30 watts (W) and a cadence of 60 revolutions per minute (rpm). The workload was then increased every minute by 15 W for women and 20 W for men until volitional exhaustion.

Participants were instructed to maintain a cadence above 60 rpm and were verbally encouraged throughout the test. Respiratory gas exchange, heart rate and blood lactate concentration (sampled every 2 minutes) were continuously monitored. The test was considered maximal if one or more of the following criteria were met:

- Plateau in VO_2 despite increasing workload,
- Respiratory quotient (RQ) > 1.1,
- HR > 85% of age-predicted maximum,
- Blood lactate concentration > 4 mmol/L,
- Inability to maintain the target cadence.

C. Training Protocol

The 14-week training intervention was structured into three consecutive phases: (1) familiarization, (2) initial training, and (3) progressive training. All participants completed two supervised sessions per week, either on a recumbent eccentric ergometer (*Cyclus 2*, RBM Elektronik-Automation GmbH, Germany) or a seated concentric cycle ergometer (*Technogym*, Italy), depending on group allocation.

1. Phase 1 (T1) – Familiarization (Weeks 2–5)

During the familiarization phase, all groups completed work-matched sessions adapted to their respective contraction modality (eccentric or concentric cycling). Based on the findings of Lipski et al., a conversion ratio of 1.5 was used to estimate eccentric MAP (eMAP) from concentric MAP (cMAP), such that 100% eMAP was considered equivalent to 150% of cMAP.

Training intensity and duration were progressively increased across the four weeks. Participants began with 5 minutes of cycling at 30% of their cMAP and progressed to 30 minutes by the end of the phase. Final familiarization sessions were as follows:

- **Eccentric Continuous Group (EC)**: 30 minutes (min) at 60% of cMAP
- **Concentric Interval Group (CI)**: 9 x 2 min training/1 min rest at 65% of cMAP
- **Eccentric Interval Group (EI)**: 9 x 2 min training/1 min rest at 100% of cMAP

This phase aimed to ensure adequate neuromuscular adaptation to the modality-specific demands and minimize potential DOMS, particularly in the eccentric groups.

2. Phase 2 (T2) – Initial Training (Weeks 6–9)

In the second phase, all groups trained at an intensity equivalent to 80% of their modality-specific MAP for 30 minutes per session:

- **EI Group**: 10 x 2 min training/1 min rest at 120% of cMAP
- **EC Group**: 30 min at 80% of cMAP
- **CI Group**: 10 x 2 min training/1 min rest at 80% of cMAP

3. Phase 3 (T3) – Progressive Training (Weeks 10–13)

Training intensity was further increased to 90% of each group's modality-specific MAP:

- **EI Group**: 10 x 2 min training/1 min rest at 135% of cMAP
- **EC Group**: 30 min at 90% of cMAP
- **CI Group**: 10 x 2 min training/1 min rest at 90% of cMAP

This progressive overload aimed to enhance aerobic capacity and muscular adaptations in a contraction-specific manner. All sessions remained isocaloric and time-matched across groups to allow for valid comparisons.

D. Training Parameters

1. Heart Rate Monitoring

Throughout each training session, HR was continuously monitored using a *Polar Verity Sense optical heart rate sensor* (*Polar Electro Oy, Finland*), worn on the upper arm and connected to the *Polar Flow* application via an *Apple iPad*. Both mean and maximal HR (mean HR and max HR) values were recorded per session. They are expressed in percentage of the maximal HR measured during the incremental cycling test (% max HR). For analysis, mean and max HR values were averaged for each of the three training phases.

2. Rating of Perceived Exertion

At the end of each training session, participants reported their RPE using the Borg RPE scale, ranging from 6 (no exertion) to 20 (maximal exertion). Average RPE values were calculated for each training phase and used for subsequent analysis.

3. Cognitive Demand

Perceived Fat was assessed following each session using a modified Borg scale ranging from 0 (no cognitive effort) to 10 (maximal cognitive effort). Participants were asked to evaluate the mental demand specifically related to the cognitive focus required during training. Phase-wise averages were computed for analysis.

4. Perceived Muscle Soreness

Prior to each training session, participants rated their perceived muscle soreness in the lower limbs using a visual analog scale (VAS) ranging from 0 millimeters (mm) (no soreness) to 200 mm (unbearable soreness). These ratings were intended to reflect residual soreness from the previous session. Means of each training phase were computed for statistical analysis.

E. Functional Parameters

A battery of six functional tests was performed pre- and post-intervention to evaluate intra-group improvements and inter-group differences. All tests were administered by the same trained evaluator to minimize inter-rater variability. Standardized instructions and verbal encouragement were provided to ensure consistency across participants.

1. Maximal Isometric Force (MIF)

Maximal isometric knee extensors strength of the dominant leg was assessed using a *MicroFET2* handheld dynamometer (*Hoggan Scientific, USA*) secured to an immovable frame. Participants were seated with hips at 85° and knees at 90° flexion. After a warm-up involving five minutes of low-intensity cycling and three submaximal isometric contractions (50–90 % maximal effort), participants completed five maximal voluntary contractions, each lasting five seconds with 30 seconds of rest between efforts. The highest recorded value was retained for analysis and expressed in newton-meters (Nm).

2. Handgrip Strength

Handgrip strength of the dominant hand was measured using a handheld isometric dynamometer (*Takei Hand Grip Dynamometer, Japan*). Participants performed three maximal grip trials, with 30 seconds of rest between each trial. During testing, the arm was kept extended along the body without any auxiliary movements. The best value was retained and expressed in kilograms (kg).

3. Balance Error Scoring System (BESS)

Static balance was assessed using the BESS protocol, which includes three stance positions (double-leg, single-leg, and tandem) performed on both firm and foam surfaces. Each position was held for 20 seconds with eyes closed and hands on hips. Errors, such as opening eyes, lifting hands or losing balance were counted, with a maximum of 10 errors per trial.

4. Ten Times Sit-to-Stand Test (TTSST)

Functional lower limb strength and mobility were assessed via the TTSST. Participants began seated with arms crossed over their chest and were instructed to stand up and sit down 10 times as quickly as possible. The test started with a countdown and was timed using a stopwatch. Participants performed 3 trials and the best values was retained for analysis and expressed in seconds.

5. Timed Up and Go (TUAG) Test

Mobility and dynamic balance were assessed using the TUAG test. Participants rose from a seated position, walked three meters, turned 180°, returned to the chair, and sat down, performing a second 180° turn. The time to complete the sequence was recorded with a stopwatch. Participants performed 3 trials and the best values was retained for analysis and expressed in seconds.

6. Six-Minute Walking Test (6MWT)

Aerobic endurance was evaluated via the 6MWT. Participants were instructed to walk as far as possible in six minutes along a 30-meter indoor track, turning around two cones at either end. HR and RPE were monitored throughout the test. The total distance covered was expressed in meters.

F. Statistical Analyses

All statistical analyses were conducted using R Commander (R version 4.4.2; R Foundation for Statistical Computing, Vienna, Austria). Data were initially assessed for normality using the Shapiro–Wilk test and for homogeneity of variances using Levene's test. For normally distributed variables with equal variances, repeated-measures analysis of variance (ANOVA) was used to examine the effects of time (pre- vs. post-intervention), group (EI, EC, CI), and their interaction. When significant main effects or interactions were found, post hoc comparisons were performed using Tukey's Honestly Significant Difference (HSD) test to control for Type I error.

For outcome variables related to participants characteristics and functional performance that did not meet the assumptions of normality, non-parametric tests were applied. Specifically, within-group comparisons across time were conducted using the Wilcoxon signed-rank test, and between-group comparisons were evaluated using the Kruskal–Wallis test,.

All results were considered statistically significant at $p < 0.05$. Data are presented as mean ± standard deviation (SD) for parametric variables and as median with interquartile range (IQR) for non-parametric variables, unless otherwise stated.

Summary

Phase 0 – Testing	Week –1 (2 sessions)	Evaluation
Phase 1 – Familiarization	Week 2-3 (2x/wk)	5' 20% MAP - 10' 30% MAP 15' 30% MAP - 20' 40% MAP
		5' 20% - 10' 20% 15' 30% - 20' 30%
	Week 4-5 (EC, 2x/wk)	20' 40 et 50 % MAP, 60 rpm 30' 50 et 60% MAP, 60 rpm
	Week 4-5 (EI, 2x/wk)	6 x 2'-1' à 60 et 80% MAP, 60 rpm 9 x 2'-1' à 80 et 100% MAP, 60 rpm
	Week 4-5 (CI, 2x/wk)	6 x 2'-1' à 40 et 50% MAP, 60 rpm 9 x 2'-1' à 50 et 65% MAP, 60 rpm
Phase 2 – Training	Week 6-9 (EC, 3x/wk)	30' 80% MAP, 60 rpm
	Week 6-9 (EI, 3x/wk)	10 x 2'-1' 120% MAP, 60 rpm
	Week 6-9 (CI, 3x/wk)	10 x 2'-1' 80% MAP, 60 rpm
Phase 3 – Training	Week 10 – 13 (EC, 3x/wk)	30' 90% MAP, 60 rpm
	Week 10 – 13 (EI, 3x/wk)	10 x 2'-1' 135% MAP, 60 rpm
	Week 10 – 13 (CI, 3x/wk)	10 x 2'-1' 90% MAP, 60 rpm
Phase 4 – Retesting	Week 14	Evaluation

EI = eccentric interval ; EC = eccentric continuous ; CI = concentric interval ; x/wk = time per week ; ' = minute ; MAP = maximal aerobic power ; rpm = revolution per minute ; % = percent

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