Handcycling: Training effects of a specific dose of upper body endurance training in females

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Short title: Upper body endurance training in females

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Abstract

Purpose: This study aims to evaluate a handcycling training protocol based on ACSM-guidelines in a well-controlled laboratory setting. Training responses of a specific dose of handcycling training were quantified in a homogeneous female subject population to obtain a more in depth understanding of physiological mechanisms underlying adaptations in upper body training. **Methods:** 22 female able-bodied participants were randomly divided in a training (T) and control group (C). T received 7-weeks of handcycling training, 3 x 30 minutes/week at 65% heart rate reserve (HRR). An incremental handcycling test was used to determine local, exercise specific adaptations. An incremental cycling test was performed to determine non exercise specific central/cardiovascular adaptations. Peak oxygen uptake (peakVO_2), heart rate (peakHR) and power output (peakPO) were compared between T and C before and after training. **Results:** T completed the training sessions at 65%±3%HRR, at increasing power output (59.4±8.2W to 69.5±8.9W) over the training program. T improved on handcycling peakVO_2 (+18.1%), peakPO (+31.9%), and peakHR (+4.0%) No improvements were found in cycling parameters. **Conclusion:** Handcycling training led to local, exercise-specific improvements in upper bodyparameters. Results could provide input for the design of effective evidence-based training programs specifically aimed at upper body endurance exercise in females.

Keywords: *arm exercise; upper body physiology; training program; exercise specificity; fitness; health and mobility*

Abbreviation List:

C = control group.
HR = Heart Rate
T = training group
PO = power output
VO_2 = Oxygen Uptake
%HRR = % of the heart rate reserve

Introduction

Being largely dependent of their upper body, wheelchair users have limited muscle mass available for daily functioning and ambulation, impacting on their engagement in an active lifestyle (World Health Organization, 2011). Adequate training programs for the upper body have the potential to optimize rehabilitation and increase functional status and participation of wheelchair users (Haisma et al 2006). Handcycling and/or arm cranking have been suggested as promising training modalities to impose upper body endurance training in this context (Arnet et al 2012; Dallmeier et al 2004a; Dallmeier et al 2004b; Franklin 1989; Glaser 1989; Hettinga et al 2013; Hettinga et al 2010; Jacobs 2009; Valent et al 2010; Valent et al 2008; Valent et al 2009; Valent et al 2007; Van Der Woude et al 2001, Van Drongelen et al 2006). It has also been suggested that exercise guidelines as defined by the American College of Sports Medicine (ACSM) can be used as a basis to prescribe training for the upper body (Garber et al 2011; Hettinga et al 2013). However, based on comparisons between one-legged and two-legged cycling, it was found that exercise regimens involving less active muscle mass resulted in different physiological responses to endurance exercise at bodily level than exercise regimens involving more active muscle mass (Kjaer et al., 1991; Vianna et al., 2010; Neary and Wenger, 1986; Abbiss et al., 2011). Therefore, more knowledge on training adaptations to specific doses of upper body training is required to use as input to prescribe adequate upper body endurance training regimens. In addition, most training studies have only included male subjects so not much is known on upper body endurance training in females in particular. As it is well-known that gender differences in endurance capacity are evident and recently gender differences in fatigability that impact on exercise and training have been identified (Hunter 2014), it is clear that it is important to collect more data on training effects in females. To provide input for the design of evidence-based upper body endurance training programs that are applicable to females, effects of various training programs should first be evaluated under standardized conditions, and origins of training adaptations need to be explored. Therefore, the present study will evaluate the effects of a 7-week handcycling endurance training program based on ACSM-guidelines in a homogeneous able-bodied untrained group of females. It is hypothesized that upper body endurance training conform to the ACSM-guidelines will improve important training parameters such as peak oxygen consumption (VO_{2peak}) and peak power output (PO_{peak}), but not necessarily in similar way as in lower body exercise. A secondary aim of the present study will be to determine if the occurring adaptations to the presented upper body endurance training are exercise specific and merely local, or if transfer effects of handcycling training towards leg cycling could be determined indicating more central systemic adaptations.

Method

Participants

Twenty-two able-bodied women participated voluntarily in this study. After a screening using the Physical Activity Readiness Questionnaire (Cardinal et al 1996), participants were randomly assigned to two groups; a training group (T: n = 11) and a control group (C: n = 11). Participants gave written informed consent. Criteria for inclusion of this study were; female, no experience in handcycling, no recent activity in (upper body) endurance sports, no change in activity level during the study and no medical contra-indications. The study protocol was approved by the local ethics committee.

At their first visit to the laboratory, subjects familiarized to the experimental set-up with three 6-minute familiarization trials in the handcycle on a cycletrainer (Sirius T1435, Tacx BV, The Netherlands). Thus, subjects could become acquainted to the hand cycle propulsion technique. Subsequently, a fourth trial was presented on a handcycle on the motor-driven treadmill to get used to the propulsion and steering mechanism.

Design

An incremental exercise test was performed to obtain peak cardiovascular variables for handcycling (to evaluate local, exercise specific adaptations) as well as for cycling (to evaluate transfer effects of central adaptations) before and after a 7-week training or no training program. The training group (T) received a 7-week hand cycling training program with a frequency of three times a week with a duration of 30 minutes conform to the ACSM-guidelines (Garber et al 2011). The average training intensity was 65% heart rate reserve (HRR) using three different training patterns, which will be described further in *training*. The control group (C) did not receive any training and was asked to maintain their activity level similar during the experimental period. Before and after the training, an incremental handcycling test was performed to evaluate exercise specific training effects on peak physiological handcycling capacity.

Training

The training sessions were performed in an attach-unit handcycle, consisting of a handrim wheelchair (Double Performance, RGKWheelchair Inc., England) connected with a mounted handcycling unit (Tracker Challanger, Alois Praschberger, Austria). The training sessions were executed 3 times per week for half an hour on a motor-driven treadmill (Enraf Nonius, Delft, Netherlands) at an average power output corresponding with 65%HRR, as is conform to the ACSM-guidelines (13). Resting heart rate (HR) and peak heart rate (HR_{peak}) were measured before training (Polar Accurex Plus; Polar Electro, OY, Finland) to calculate HRR.

To measure resting HR, subjects sat quietly in the handcycle for 10 minutes in a quiet laboratory, before commencement of the warm-up preceding the incremental test. The final minute was used as resting HR. HR_{peak} was measured during the final stage of the incremental handcycle pre-test as described in *Training evaluation: pre- and post-test*.

The first four training sessions were used to increase the training intensity gradually towards 65%HRR, determined conform (Karvonen et al 1957). The first training session was performed at 50%HRR. Exercise intensity was increased every next training session with 5%HHR to meet a stable 65%HRR in the fifth training session. To increase exercise intensity, a pulley system was used to add workload as described in Dallmeijer et al. (2004b). The training was monitored by a heart rate monitor (Polar Accurex Plus; Polar Electro, OY, Finland) and RPE-scores were obtained after each training session (Borg 1982). To offer variation within the training sessions, three different temporal training patterns (see figure 1) were imposed in two different types of training: resistance training and velocity training. This training variation has been previously used with successful results in wheelchair exercise (van der Woude et al 1999). The training types were varied by changing the resistance (in the resistance training sessions) or velocity (in the velocity training session) every three minutes during the training sessions using 3 different temporal patterns as depicted in figure 1. In the resistance training, the work load was varied using these 3 temporal patterns around a mean exercise intensity of 65%HRR by adding or reducing work load through the pulley system every three minutes, while the velocity was kept constant at $1.39 m \cdot s^{-1}$ as done in (van der Woude et al 1999). Power output was monitored using a power meter (PowerTap SL, CycleOps, Saris Sycling Group inc., United States). During the velocity training, the resistance was kept constant at a workload corresponding to the workload required to handcycle at 65%HRR only now the velocity was varied every three minutes using the three different temporal patterns.

Please insert figure 1

Training evaluation: pre- and post-test

Before the training commenced, but after the intitial handbike familiarization sessions and a resting period, an incremental handcycling test was performed on the handcycle on the motor-driven treadmill. The test started with a 5-min submaximal steady state warm-up at 30W. On a different day, the leg cycling incremental test was performed on a bicycle ergometer (Excalibur, Lode BV, The Netherlands), also preceded by a 5-min submaximal steady state warm-up. The incremental exercise tests were performed on the same time of the day. After 7 weeks of training or no training, both incremental tests were repeated at the same time of day on the same day of the week. The training parameters VO_2, PO, HR minute ventilation (V_E) and RPE were obtained for both handcycling and leg cycling, and differences between post-test and pre-test were analyzed.

The protocol of the handcycling stepwise (1min) incremental test was based on a handcycling protocol designed for males (Dallmeier et al 2004a, Dallmeier et al 2004b). This protocol was modified for females based on pilot testing, so that the incremental exercise test would last about 8-12 minutes (Buchfuhrer et al 1983). The initial PO of the test was set at 20W, and increased with 7W every minute until voluntary exhaustion. The PO was increased every minute by adding load through a pulley system attached to the rear end of the handcycle (van der Woude et al 1999). Power output (PO) was increased by adding weight to the pulley system (see figure 2), and could be determined by the additional force (Fadd), the drag force (Fdrag) and the velocity (v), as described by equation 1:

Power output (PO) = (Fadd + Fdrag) * v Equation 1.

Please insert figure 2

The velocity of the treadmill was kept at the same speed at 1.39m·s^{-1} which in combination with the gear setting, coincided with an rpm of 70. Respiratory and metabolic parameters during the incremental test were measured breath by breath, using open circuit spirometry (Oxycon Delta, Jaeger, Hoechberg, Germany). The gas analyzers were calibrated using room air, a Jaeger 3l-syringe and a calibration gas (16.0% O_2, 5.0% CO_2). The following parameters were obtained continuously: VO_2, VCO_2, RER, V_E and HR. Every minute, mean values of all parameters between 20s and 50s were calculated. RPE scores were obtained using a 15-point (6-20) Borg scale (Borg 1982). Before commencement of the first stage of the test as well as in the last 10s of each stage, the experimenter moved his finger along an enlarged, printed RPE list. Participants were informed to nod when the experimenter was pointing to their RPE, so that speech would not interfere with the collected respiratory data.

The incremental protocol on the bicycle ergometer was matched to the handcycling protocol. Increments were based on pilot testing aiming to develop an incremental exercise test that would last about 8-12 minutes (Buchfuhrer et al 1983). The initial PO and the increments per minute were set at a starting intensity of 60W with increments of 20W per minute. The participants were instructed to maintain 90rpm during the test. When voluntary exhaustion was reached, or the rpm dropped below 70, the test was ended.

Statistics

Data were analyzed with SPSS version 16.0. An independent t-test was used to determine baseline differences in personal characteristics (age, length, body mass) and the pre-test peak values (VO_2, V_E, HR, RER, PO) between the experimental and control group. The effect of the training on physiological capacity between the two groups was evaluated with a 2 factor repeated measures ANOVA (p<0.05). The difference between pre- and post-test was used as within-subject factor and group as between-subjects factor. The interaction term 'test x group' was considered to be most important to identify training effects.

Results

Participants

Participant characteristics age, length and body mass are presented in Table 1. No differences were found at baseline between T and C. Peak physiological handcycling and cycling capacity at the pre-test also did not differ between groups (Table 2-3).

Table 1: Participant characteristics for age, length and body mass for the training (T) and control (C) group.

	Training (n = 11)	Control (n = 11)
Age (year)	21.6 (3.7)	21.1 (3.6)
Length (cm)	171.6 (7.3)	173.9 (5.6)
Body mass (kg)	67.9 (7.8)	64.7 (6.7)

Values are presented as mean (SD) and significant differences (p>0.05) are marked with *

Training

All participants in T completed the entire 7-weeks training program of 3 times/week. The training intensity over the fifth until the last training session was 65±3%HRR and included eleven resistance- and six velocity-training sessions. Some subjects could not perform the required three training sessions every week. They were then allowed to perform extra sessions in other weeks, so all subjects have performed a total of 21 sessions. Between the fifth and 21st session, the average PO in the training sessions increased by 17.3±8.1% from 59.4±8.2W to 69.5±8.9W.

Training evaluation: handcycling pre- and post-test

All peak physiological capacity parameters, except RER, increased significantly for T compared to C after the 7-week handcycling training program (see table 2). VO_{2peak} increased by 18.1%, V_{Epeak} by 31.4% and HR_{peak} by 4.0%. PO_{peak} increased by 31.9% (table 2). No training improvements were found in maximal physiological capacity in leg cycling (Table 3) when comparing the pre and post-tests.

Table 2: Peak physiological capacity values in handcycling before (pre) and after (post) the experimental period for both groups.

		Training	Control	p-value (pre-post x group)
VO_2 ($ml \cdot min^{-1}$)	pre	1897 (251)	2041 (387)	
	post	2240 (240)	1923 (343)	<0.01*
VO_2 ($ml \cdot kg^{-1} \cdot min^{-1}$)	pre	28.3 (5.1)	31.7 (5.6)	
	post	33.2 (4.0)	29.8 (4.2)	<0.01*
V_E ($l \cdot min^{-1}$)	pre	70.8 (13.3)	79.4 (18.8)	
	post	93.0 (15.4)	71.8 (18.7)	<0.01*
HR (bpm)	pre	174 (13)	174 (10)	
	post	181 (8)	171 (15)	0.02*

RER	pre	1.18 (0.09)	1.20 (0.06)	
	post	1.20 (0.10)	1.26 (0.09)	0.42
PO (W)	pre	89.0 (11.8)	91.2 (17.6)	
	post	117.4 (11.9)	92.5 (19.3)	<0.01*

Values are presented as mean (SD). Differences between pre- and post-tests x group ($p < .01$) are marked with *.

No significant differences were found in baseline values between the training and control group on pre-tests.

Table 3: Peak physiological capacity values in cycling before (pre) and after (post) the experimental period for both groups.

		Training	Control	p-value
VO_2 ($ml\cdot min^{-1}$)	pre	3171 (366)	3184 (350)	
	post	3135 (455)	3024 (364)	0.11
VO_2 ($ml\cdot kg^{-1}\cdot min^{-1}$)	pre	47.1 (6.1)	49.4 (5.2)	
	post	46.7 (7.8)	46.9 (3.4)	0.09
V_E ($l\cdot min^{-1}$)	pre	104.8 (11.0)	101.6 (18.2)	
	post	112.4 (19.7)	103.4 (21.7)	0.19
HR (bpm)	pre	189 (7)	189 (9)	
	post	188 (7)	188 (8)	>0.99
RER	pre	1.20 (0.06)	1.19 (0.06)	
	post	1.21 (0.06)	1.25 (0.03)	0.28
PO (W)	pre	274.5 (25.4)	269.1 (30.2)	
	post	278.2 (28.9)	267.3 (27.2)	0.22

Values are presented as mean (SD). Differences between pre- and post-tests x group ($p < .01$) are marked with *.

No significant differences were found in baseline values between the training and control group on pre-tests.

Handcycling vs Cycling performance

To underline the differences in physiology in upper body exercise compared to lower body exercise, we also descriptively presented the ratio between peak variables attained in handcycling (table 2) related to those attained in cycling (table 3), expressed as a %. Before training, VO_{2peak} attained in handcycling was only 59.8% of the VO_{2peak} attained in cycling. After training, the VO_{2peak} in handcycling was as high as 71.5% of the VO_{2peak} attained in cycling (see table 4). Values for HR_{peak}, VE_{peak} and PO_{peak} are presented in table 4 as well.

Table 4: Peak variables of the training group (T) attained in handcycling related to those attained in cycling, for both the pre- and post-test. For cycling, peak values of the pre-test were used.

	Pre-test peak value of handcycling expressed as % of peak cycling variable	Post-test peak value of handcycling expressed as % of peak cycling variable
VO_2 (%peakcycling)	59.8	71.5
HR (%peakcycling)	92.1	96.3
V_E (%peakcycling)	67.6	82.7
PO (%peakcycling)	32.4	42.4

Discussion

To provide input for the design of evidence-based upper body endurance training programs in the context of rehabilitation, it is important to study effects of various specific training doses on training responses. Most training studies have been conducted in males exercising the large muscle groups of the lower body while at the same time, active muscle mass seems to impact on physiological responses to exercise (Kjaer et al., 1991; Vianna et al., 2010; Neary and Wenger, 1986; Abbiss et al., 2011) and differences in fatigability between genders have been identified (Hunter 2014). Therefore, more knowledge on upper body training in females is very welcome. In addition, physiological differences between upper and lower body exercise exist in relation to exercise, as HR is higher in arm vs leg exercise of equal metabolic intensity due to the fact that preload is lower and systolic blood pressure higher, causing stroke volume to be reduced. As a result, the elevation of HR allows the conservation of cardiac output (Miles et al., 1989). When using %HRR as a guideline to set training intensities in upper body exercise, this might affect resulting training adaptations and effects, also underlining the need for studies exploring handcycling training effects.

The present study showed that a well-controlled handcycling endurance training dose of 7 weeks, 3x30 min per week of handcycling at an average of 65%HRR, with an increasing training power output (59.4±8.2W to 69.5±8.9W) over the training program, resulted in improvements in incremental handcycling performance of healthy females on the training parameters VO_{2peak} (+18.1%), PO_{peak} (+31.9%), HR_{peak} (+4.0%) and V_{Epeak} (+31.4%). Interestingly, the magnitude of increase in VO_{2peak} (18.1%) in the present study seems comparable to the 18% increase that was found in endurance capacity after a 6 week cycling endurance training program in males, measured by time to exhaustion at exercise at 85% of VO_{2peak} (Hardman et al 1986). It has to be acknowledged though that underlying physiological mechanisms responsible for evoking changes in time to exhaustion might differ from those responsible for evoking changes in $VO_{2peak.}$ Nevertheless, both parameters are reflecting changes relevant for endurance capacity, which is the main interest of the current study. It thus seems that even though ACSM-guidelines are mainly oriented towards exercising a large active muscle mass, they can be used as a basis to design upper body endurance handcycling training programs for females with limited active muscle mass recruited and relative dose-response relations seem of similar magnitude. A recent study that focused on sub-maximal results demonstrated no differences on gross-efficiency between cycling and handcycling (Simmelink et al 2015), indicating that dose-response relations are also not expected to differ due to differences in gross-efficiency between exercise modalities.

Compared to the exercise modality wheelchair propulsion, handcycling provides the possibility to reach a higher cardiovascular strain while evoking lower biomechanical peak forces and torques on the shoulder region (Arnet et al 2012; Dallmeier et al 2004b; Hettinga et al 2010). A higher cardiovascular strain, is expected to result in higher training responses. The conducted handcycling training resulted in an improvement in VO_{2peak} of almost twice the magnitude of the improvements demonstrated for wheelchair training in literature in able-bodied males using a similar program (De Groot et al 2013; van der Woude et al 2001). Nevertheless, results of wheelchair training on PO_{peak} were very large compared to our handcycling results, underlining the potential effects and importance of motor learning in wheelchair testing (Vegter et al 2014).

Also in a rehabilitation setting in persons with a spinal cord injury, aerobic capacity has been shown to improve with handcycling training (Valent et al 2009; Valent et al 2008). A 12-week arm crank training program of 3 x 30 minutes at exercise intensities of 70-85%HR_{peak} has been imposed to persons with a complete paraplegia (Jacobs 2009). This led to an increase in VO_{2peak} of 11.8%, somewhat smaller than the 18.1% increase evidenced in the present study. Baseline levels of VO_{2peak} in the individuals with a complete paraplegia ($1.27 \pm 0.54 l \cdot min^{-1}$) were somewhat lower than values of the able-bodied subjects ($1.90 \pm 0.25 l \cdot min^{-1}$), which might be an explanation for the lower increase. In addition, a unique physiology is associated with each specific disability (Glaser 1989). For example, the cardiac response to training and exercise can be altered due to a spinal cord injury above T4, resulting in a heart rate restricted to a maximum of 130bpm (Freychuss et al 1969; Hettinga et al 2014). Comparing our data on able-bodied individuals to data collected in individuals with a disability could lead to an improved understanding of the impact of a variety of disabilities on training and exercise. However, if we are interested in using the results as input for evidence-based training guidelines in a rehabilitation context it will always remain important to take the impact of specific disabilities into account.

A secondary aim of the present study was to determine if the occurring adaptations to the presented upper body endurance training were exercise specific and local, or if transfer effects to cycling could be determined, indicating more central systemic adaptations. The present set-up allows us to determine transfer effects of handcycling training on cycling performance, providing information about mechanisms underlying the training adaptations, impossible to acquire in a spinal cord injured population. It thereby contributes to knowledge and understanding of upper body training, additive to data that have been collected in practice. In literature, not only local adaptations (an increase in oxygen utilization in the trained muscles), but also central adaptations (an increase in cardiac output and oxygen delivery to the muscles) were found after upper body endurance training in elderly participants (~70 yrs) with a low physiological capacity (Pogliaghi et al 2006). Due to these central adaptations, the physiological capacity in leg exercise increased after upper body endurance training without training the leg muscles. Also in older patients with intermittent claudification (~70 yrs) and patients with peripheral arterial disease, it was shown that walking performance improved after upper body endurance training, at least partly due to lower limb O_2 delivery (Tew et al 2009; Zwierska et al 2005). However, transfer effects of handcycling training did not occur in cycling performance of our young (~20yrs), healthy able-bodied females, suggesting that training adaptations in handcycling are mainly local and exercise specific and not so much attributable to central adaptations. This is conform to the interpretations and results of Bhambani et al (1991), who studied transfer effects of arm as well as leg cycling in middle-aged subjects (35-40yrs) with high aerobic powers and also concluded that training adaptations were primarily of peripheral origin. It seems that transfer effects only occur in low intensity exercise tasks such as walking, or in older male subjects with a relatively lower fitness level compared to the younger populations, so differences compared to these groups are most likely associated with the difference in baseline physiological conditions of the populations. In addition, differences in individual's responses to training and their capacity to adapt have been reported to vary (Borreson et al 2009) and recent literature review has explored gender differences in fatigability and their relevance for exercise, training and rehabilitation (Hunter 2014). It was found that females are usually less fatigable than males and have different muscle properties such as a generally lower percentage of type II muscle fibers. It was suggested that neuromuscular adaptations and thereby optimal training programs between males and females differ which could explain that our findings in a group of young females regarding transferability differ from several studies in males found in literature. Though relative dose-response relations in upper body endurance exercise in females seem comparable in magnitude to those found in lower body exercise in males, interpretation of our results seems less straightforward regarding the origins of training adaptations. More research into gender differences, effects of baseline fitness levels and individual variability in adaptive responses to training and exercise is required to further understand these findings.

Conclusion

The evaluation of training programs in a well-controlled laboratory setting can contribute to quantify the training responses of a specific dose of upper body training in a homogeneous female subject population. It can also contribute to a more in depth understanding of physiological mechanisms underlying adaptations in upper body training. The present study showed that a training schedule based on the general training guidelines as prescribed by the ACSM has led to local, exercise specific adaptations improving handcycling performance in young, able-bodied female subjects. It could thereby provide input for the design of evidence-based training programs specifically aimed at upper body endurance exercise in females, as is relevant in the context of rehabilitation, health and mobility.

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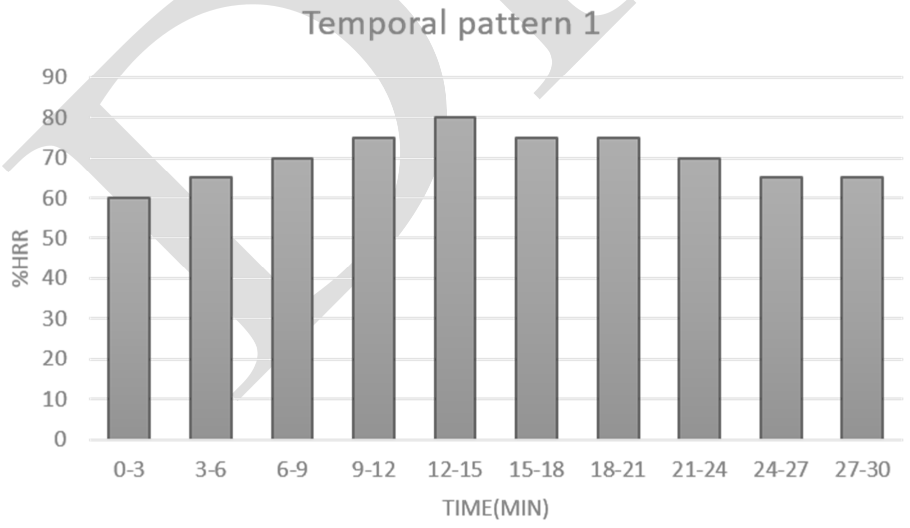
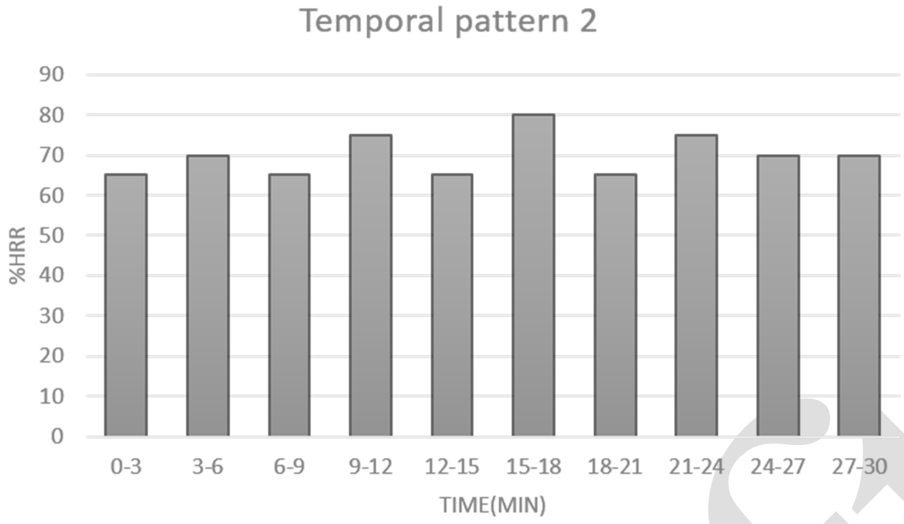
Figure 1a,1b,1c: 3 different temporal patterns that were imposed by varying either velocity or resistance.




Temporal pattern 2
%HRR
90
80
70
60
50
40
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20
10
0
0-3
3-6
6-9
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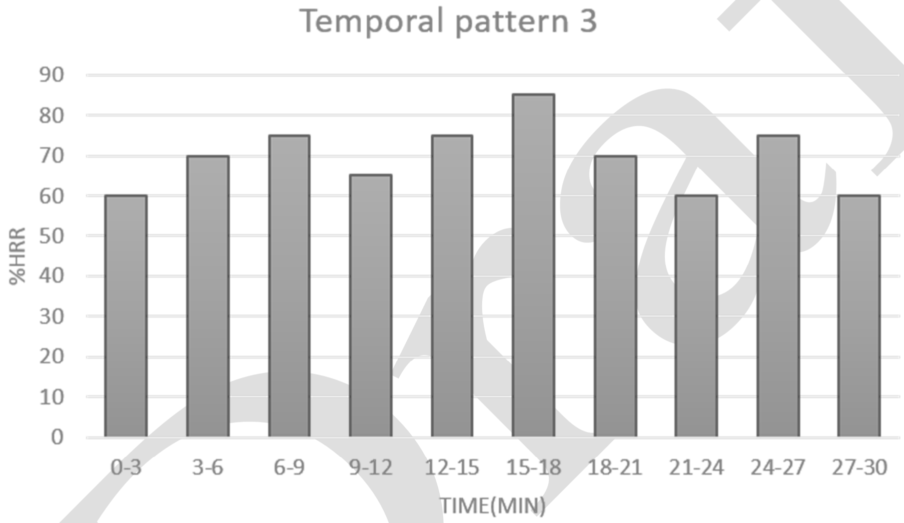
12-15
15-18
18-21
21-24
24-27
27-30
TIME(MIN)


Temporal pattern 3
%HRR
90
80
70
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50
40
30
20
10
0
0-3
3-6
6-9
9-12
12-15
15-18
18-21
21-24
24-27
27-30
TIME(MIN)

Figure 2: Pulley system that was attached to the handcycle set-up on the treadmill. Exercise load could be increased or decreased by adding or removing known loads.