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FROM GROUND TO SPACE—UTILIZATION OF A FLYWHEEL DEVICE ACROSS TACTICAL POPULATIONS

During spaceflight missions, exposure to microgravity (virtual absense of gravity) results in deconditioning of several physiological systems, potentially leading to impaired physical condition and performance in astronauts (5,12,18,28). Physical exercise is the cornerstone of strategies to mitigate physical deconditioning during spaceflight (5,6). Decades of research and operational experience have enabled the development of optimized exercise strategies and equipment onboard the International Space Station (ISS); however, the effects of microgravity cannot be completely eliminated (5,18).

In 2017, National Aeronautics and Space Administration (NASA) launched the Artemis Program with the aim of returning to the moon and beyond (22). Deep space exploration will place further operational, technical, and logistical constraints upon the use of exercise as a countermeasure to partial gravity and microgravity. For example, the spacecrafts will have much less volumetric space for exercise and equipment compared to the ISS. Longer duration missions (e.g., up to three years for a Martian mission) will impose a longer exposure to microgravity than low Earth orbit missions, such as traveling to the ISS, highlighting the need for continued research and development of physical deconditioning countermeasures.

The Orion spacecraft is the vehicle designed for early Artemis missions. Orion has a habitable volume of 330 cubic feet (comparable to the habitable volume of a large sport utility vehicle [SUV]) and can support four crewmembers (23). Thus, a small, lightweight device, requiring no power yet providing high resistance is required for exercise countermeasures. An inertial flywheel was identified as the most suitable option to meet this need.

Inertial training using a flywheel dates back to the early 1990s (2,8,11,18). The utilization of flywheel exercises was initially proposed as a countermeasure to mitigate the known effects of microgravity during long-duration space travel; however a flywheel was not adopted as a nominal exercise device for the ISS (6,13,24). Despite the growing terrestrial use of flywheels in the last few years, especially in the performance and rehabilitation settings, there is still a gap in the literature. More research is needed to provide precise recommendations on how to design exercise sessions and prescribe volume and intensity in flywheel exercises using a systematic approach, especially among tactical populations (3,13,16).

The first crewed Artemis mission (Artemis II) will evaluate the operational feasibility of using a flywheel device for exercise in this confined environment. Exercise prescriptions are bound by the following requirements: 1) 30 min of exercise per day per crewmember, 2) the flywheel device is the only exercise device and can be used for resistance and aerobic sessions, and 3) there is a limited number of approved exercises. In preparation for supporting the crew on this mission, which includes a Canadian astronaut, the authors have been developing methods to prescribe exercise on a flywheel. This article will present insights on the methodology used to develop exercise prescription and observations following these exercise prescription constraints. This methodology is relevant to other settings that different tactical populations may face during operations.

HOW DOES FLYWHEEL TRAINING WORK

The law of inertia, as described by Newton's First Law, is the concept that an object will continue its current motion until some external force causes its speed or direction to change. The flywheel device utilizes inertial disc(s) (resistance) which rotate and store energy during the concentric portion according to the achieved rotational speed, inertial load, and machine characteristics. When the rope rewinds in the eccentric phase, the user is required to resist the rotating disc(s). This is the reason why it is often compared to a yo-yo.

The intensity of the exercise on a flywheel is primarily determined by the force and speed that the user puts into it. The harder and/or faster the user pulls, the more resistance they will experience in both the acceleration and deceleration, for any given inertial load. This differs from traditional weight training, where resistance (intensity) is determined by the load. During flywheel training, the inertial load (discs) selected is not the only factor of intensity. For example, using a lighter inertial load and pulling fast might create higher resistance than using a heavier inertial load at a lower speed. The flywheel paradigm is characterized by unlimited resistance available during the entire range of motion with optimal muscle loading at any given joint angle (7,14,25). Another important factor of flywheel device training is the constant movement (no pauses) during the execution of a set. For this reason, the user may experience muscle fatigue faster than with regular weight training.

INERTIAL LOAD AND FORCE-TIME CURVE

Following the principle of inertia, a higher inertial load will require more force to increase the speed of the flywheel, while a lower inertial load will require less force to increase the speed of the flywheel. By changing the inertial load (by using different discs) and manipulating the speed of the movement, the user can achieve the desired training adaptations. Table 1 identifies the targeted training stimulus, depending on the inertial load and movement speed.

From the literature, the ideal inertial load recommended to induce chronic adaptations and enhance human performance lays between 0.05 – 0.11 kg·m^2 (4,9,15,17,20,25,27). As with traditional weight training, higher loads may be preferable to develop force, while lower loads could be used for power purposes (19). However, there is a lack of evidence about the optimal inertial load in the space context required to maximize chronic effects (e.g., development and maintenance of muscle function, mass, and capacity) across medium and long training periods, as well as the inertial load required to obtain an aerobic stimulus to maintain cardiovascular fitness.

LOAD MANAGEMENT AND INDIVIDUALIZATION

To optimize training outcomes, it is recommended that tactical facilitators individualize flywheel training by developing inertia-power or inertia-velocity profiles and periodizing flywheel training based on the results of those profiles. Flywheel training allows for monitoring and periodizing the load. By controlling the speed of the movement, cueing cadence with a metronome, and using a constant inertial load and rope length, it is possible to estimate the power and force that a user produces.

To allow precise monitoring and periodization, it is recommended to plot power (watt) and/or force (newton) over cadence (beats per minute [bpm]) for different inertial loads for each exercise. It is important to account for rope length (which is influenced by the height of the user, limb length, and exercise depth preferences) due to its implication on cadence and speed development. As an example, Figure 1 outlines the average concentric power over any given cadence for three different inertial loads (low: 0.01 kg·m^2, medium: 0.06 kg·m^2, and high: 0.11 kg·m^2) for deadlifts performed by a 174-cm tall user. The user performed 10 repetitions and the average power for the set was recorded. This step was repeated for every five-bpm increment. This method helped characterize the user's power curve. In a similar fashion, to prescribe an aerobic training session using heart rate, it is possible to plot heart rate (or heart rate reserve) with a cadence and inertial load. The user should perform continuous repetitions of an exercise for 2 – 3 min (suggested time) at a constant cadence and by taking the mean stable heart rate from the last 30 – 60 s of that set.

TABLE 1. TRAINING STIMULUS ASSOCIATED WITH DIFFERENT INERTIAL LOADS

SPEED	INERTIA		
	LOW	MEDIUM	HIGH
Low	Warm-up	Technique	Strength
Medium	Warm-up	Strength	Overload*
High	Power	Overload*	

*Overload represents a feature of the flywheel device where the user creates very high concentric inertia and focuses on controlling the eccentric portion of the movement, thus maximizing the eccentric stimulus.

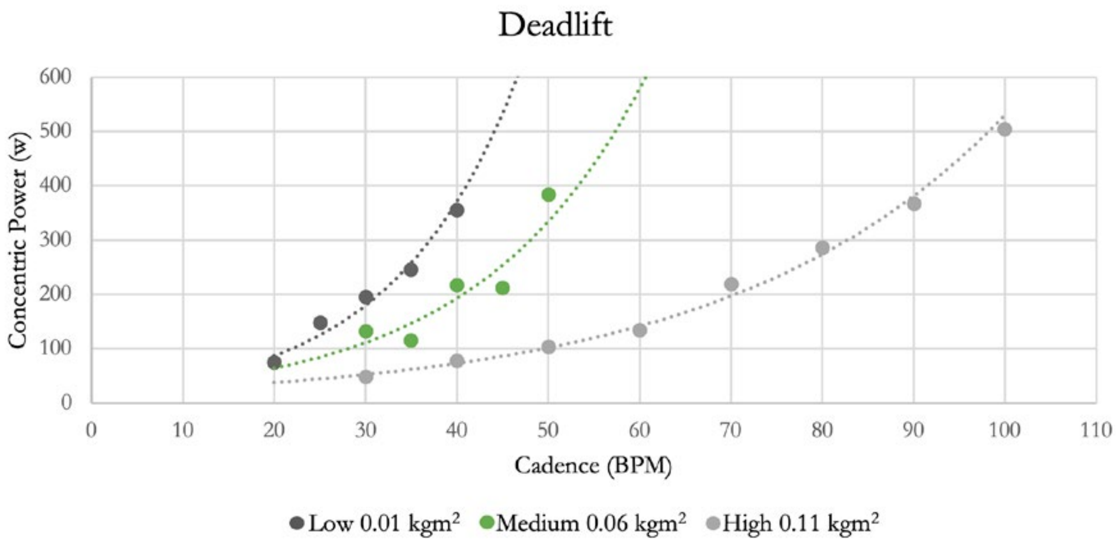

FIGURE 1. RELATIONSHIP BETWEEN CONCENTRIC POWER (W) AND CADENCE (BPM) FOR THREE DIFFERENT INERTIAL LOADS (LOW 0.01 KGM^2, MEDIUM 0.06 KGM^2, AND HIGH 0.11 KGM^2)

As discussed previously, there are better combinations of inertial loads and speeds of execution to achieve the desired stimulus. However, it is important to note that a very slow cadence with a low inertial load is hard to maintain due to a lack of kinetic energy (resistance) created. Similarly, it is hard to maintain a high cadence with a high inertial load due to the immense resistance it creates.

Tactical facilitators generally determine the inertia–power profile of a given flywheel exercise, which allows the selection of the optimal inertia load for the user (e.g., power output maximization) and it can be used as a feasible and reliable method for assessing training adaptations and progress.

TYPE OF SESSION

Flywheel training is known to have many benefits with regards to strength, power, and overload stimulus (2,7,10,13). However, little to no research is reported about aerobic training. It remains to be determined whether the appropriate aerobic stimulus (and potential aerobic improvements), as well as the best prescription methodologies for aerobic sessions using a flywheel device, can be achieved. The authors developed different protocol with a commercially off the shelves (COTS) flywheel device to investigate this.

Table 2 provides a template of an eight-day sample microcycle describing exercise selection, gear, volume (sets times repetitions), and movement speed for targeted stimulus. The template follows these criteria: 1) only bent-over row, deadlift, deadlift high pull, biceps curls, and harness squat allowed as exercises; 2) low (0.01 $kg{\cdot}m^2$), medium (0.06 $kg{\cdot}m^2$), and high gear (0.11 $kg{\cdot}m^2$); 3) 30-min timeframe; 4) need to be able to create both a strength and aerobic stimulus; and 5) alternating strength and aerobic.

From these trials and experiences, flywheel device training provides a variable load modality to target power, strength, and likely aerobic outcomes. Thus, this modality is a practical tool for deployed environments where space is limited (e.g., space, military ships, police departments, fire departments, aircraft hangars, military operational forward operating bases). To the authors' knowledge, no studies have investigated the effects of using the flywheel device as the main exercise apparatus across tactical populations. In this article, the authors followed many constraints to reflect the space context with Artemis program; however, many other exercises can be done with flywheel devices (70+) and other training methodologies. The Orion capsule was developed for missions of up to 30 days (21). Future research should investigate the effects of using only the flywheel device over that duration on muscle function and cardiovascular fitness.

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TABLE 2. SAMPLE 8-DAY MICROCYCLE IN THE CONTEXT OF SPACEFLIGHT PREPARATION

	EXERCISE	GEAR	SETS	REPETITIONS	SPEED	STIMULUS
DAY 1 – STRENGTH						
	1A) Bent-over row	Low	4	25	Moderate-high	Endurance
	2A) Deadlift	Low	4	10	High (max)	Power
	3A) Deadlift high pull	Medium	4	10	Moderate	Strength
	4A) Squat	High	4	4 – 6	High (max)	Max strength
DAY 2 – AEROBIC						
	1A) Graded deadlift high pull	Low	X	40 per stages completed	Starting at 40 bpm +5 every stage	Max aerobic capacity
	2A) Biceps curls	Low	4	25	High (max)	Endurance
DAY 3 – STRENGTH						
	1A) Squat	Low	4	25	Moderate-high	Endurance
	2A) Bent-over row	Low	4	10	High (max)	Power
	3A) Deadlift	Medium	4	10	Moderate	Strength
	4A) Deadlift high pull	High	4	4 – 6	High (max)	Max strength
DAY 4 – AEROBIC						
	1A) Squat	Low	8	20 s on/ 10 s off	High (max)	
	2A) Bent-over row	Low	8	20 s on/ 10 s off	High (max)	
	3A) Deadlift	Low	8	20 s on/ 10 s off	High (max)	
	4A) Deadlift high pull	Low	8	20 s on/ 10 s off	High (max)	
DAY 5 – STRENGTH						
	1A) Squat	Low	4	10	High (max)	Power
	2A) Deadlift high pull	Low	4	25	Moderate-high	Endurance
	3A) Bent-over row	Medium	4	10	Moderate	Strength
	4A) Deadlift	High	4	4 – 6	High (max)	Max strength
DAY 6 – AEROBIC						
	1A) Graded squat	Low	X	40 per stages completed	Starting at 40 bpm +5 every stage	Aerobic Max capacity
	2A) Biceps curls	Low	4	25	High (max)	Endurance
DAY 7 – STRENGTH						
	1A) Deadlift	Low	4	25	Moderate-high	Endurance
	2A) Deadlift high pull	Low	4	10	High (max)	Power
	3A) Bent-over row	High	4	4 – 6	High (max)	Max strength
	4A) Squat	Medium	4	10	Moderate	Strength
DAY 8 – AEROBIC						
	1A) Deadlift high pull	Medium	6	25	Moderate-high	Aerobic
	2A) Biceps curls	Low	4	25	High (max)	Endurance

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