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Inertial training: from the oldest devices to the newest Cyklotren technology

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Abstract
Introduction. **Inertial training is a little known strength training method. Very few research papers describing the effectiveness of inertial training have been published. Many questions regarding inertial training still remain unanswered. What do we know about the methodology of inertial training? What is the efficacy of inertial training? What are advantages and disadvantages of different inertial devices? The present study attempts to explain the concept of inertial training and recapitulate the state of current knowledge about this training method.** Methods. **Material for this study consisted of publications retrieved from the PubMed, Springer, SPORTDiscus, and MEDLINE databases.** Results. **There has been only one scientific study concerned with the optimal methodology of inertial training. In the present paper the authors discuss a method for optimal muscle loading during inertial training. However, most articles reveal a high efficacy of inertial training for strength and power improvement in a relatively short time. Inertial training can evoke functional changes and can be useful in sport practice. There have been a few types of inertial devices, and in the last five years two devices have been designed which enable the development of inertial training methodology: ITMS and Cyklotren. However, since inertial training methodology still remains insufficiently examined, further research is needed in the area.** Conclusions. **Considering its high effectiveness, inertial training appears to be a highly promising strength training method. However, the methodology of inertial training must be further developed. The application of the new Cyklotren inertial device can greatly facilitate this objective.**

KEYWORDS: inertial, device, training, strength, power.

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What is already known on this topic?
It is commonly known that strength training improves the quality of life and is necessary for athletes to achieve a high sport performance level. Among the multiple strength training methods one little known method is inertial training. The precise methodology of this type of strength training still requires a great deal of research.

Introduction

Inertial training is a type of strength training performed with a specialized device that utilizes inertial resistance. Although, the concept of inertial training is not new (the first inertial device was developed by Hill in 1922 [1]), it is still little known.
What is the idea of inertial training and what are differences between inertial and weight training methods? Traditional resistance training uses Earth's gravity, and therefore the weight of barbells, dumbbells, etc. depends on their mass. Thus, in the relatively constant Earth's gravity weight is proportional to the mass of the physical body loading the muscles during exercise. In inertial training the role of gravity is strongly reduced

(for that reason devices used in inertial training are called „gravity-independent devices"). During inertial training Earth's gravity is replaced by acceleration generated by muscles (thanks to which inertial training can be performed even in space to counteract muscle loss experienced by astronauts exposed to reduced gravity) [2, 3]. During concentric contractions the inertial load of, for example, a flywheel is accelerated. When the accelerated mass crosses the zero point, strong eccentric contractions begin, e.g. a training individual tries to flex his/her arm in the elbow joint while the mass of inertia causes an extension in this joint. Norrbrand et al. [4] states that muscle loading in the eccentric phase is greater in inertial training than in traditional weight training as reflected by the EMG image.

Aim of Study

The present study is a review of the state of current knowledge of inertial training. The authors attempt to find answers to three questions: What are the advantages and disadvantages of different inertial devices? What is the efficacy of inertial training using different types of devices? What do we know about inertial training methodology?

Material and Methods

The material for this study consisted of publications retrieved from the PubMed, Springer, SPORTDiscus, and MEDLINE databases. The publications were searched using keywords: inertial, training, eccentric, flywheel, strength, power, sport. To compare the effectiveness of training carried out by different researchers, percent changes (means or medians) and their significance (calculated by the authors of cited publications) were given. If the authors did not present these percentage changes, then relative changes were calculated using the formula:

$$RI\,[\%] = \frac{x_{post} - x_{pre}}{x_{pre}} \cdot 100$$

Where RI is the relative increase and x is the measured value before (pre) and after (post) training.

Results and Discussion

Inertial training devices and methodology

The authors of the analyzed papers used different types of inertial devices: Impulse Training System (ITS), Yo-Yo technology, Inertial Kinetic Exercise (IKE), and Versa Pulley. These devices are user-friendly but due to their construction each of them has some limitations: a small range of motion, impossibility or limited possibility of determination of varied movement models, lack of on-line observation and registration of training parameters, e.g. force, work, power, time and distance covered during each repetition and each set. In our opinion these limitations have not permitted the development of proper methodology of inertial training. Although, the authors of the studies always describe training methodology, they never argue why they used particular loads, number of sets, number of repetitions in each set, etc. Sometimes the authors used a methodology recommended by the manufacturers.

To develop the methodology of inertial training a new inertial device called the Inertial Training Measurement System (ITMS) was constructed [5]. It appears that it does not possess any of the aforementioned limitations. The ITMS allows on-line control and registration of training parameters such as peak force, mean force, power, work, time, and number of cycles. ITMS measurements exhibit very high reproducibility (ICC consistency and agreement > 0.92). The absolute error of the measurement system, consisting of the tensometer and DAQ module, is smaller than 0.5 N. Training loads used on the ITMS can be regulated by increasing the speed of movement or by adding weights, depending on the training objectives (improvement of muscle power or muscle strength), and exercises can be performed within a range of motion at various speeds. The ITMS makes it possible to establish many different movement models which can engage different muscle groups, and its also allows performing specific movements that are typical of various sports or professional activities.

Considering the aforementioned advantages of inertial training the authors have tried to develop the methodology of inertial training. The main problem in inertial training is the choice of the training load. The optimal load for inertial training cannot be determined using the traditional method, i.e., determining the percent value of 1RM, because estimating 1RM during inertial training is simply impossible. Choosing loads in relation to body mass or muscle mass is not a good solution either, because even if participants have similar body/muscle mass their muscle strength can still vary. Naczk et al. [6] revealed an alternative solution for estimating training loads during inertial training: the independent variable – maximal movement velocity. In one group of subjects, loads were adjusted individually for each participant to achieve maximal movement velocity at approximately 7.50 rad $\cdot$ s^{-1}, and in the other group the loads were adjusted individually for each participant to achieve maximal movement velocity at approximately 5.76 rad · s^{-1}. Therefore, each participant trained with different loads but the same maximal movement velocity. The authors stated that using this methodology the relative load for each participant in one group was the same. To the best of our knowledge that study has been the only one so far attempting to find a universal solution for muscle loading during inertial training. It was possible thanks to the measurement system of the ITMS, which allows registering physical parameters directly from the device. Optimal estimation of training parameters depending on training objective (e.g. number of sets, repetitions in each set, periods between the sets, etc.) may be similar to estimation used in traditional strength training methods, but it should be tested in the future.

Unfortunately, it is now impossible to purchase the ITMS, as its mechanical construction was not attractive for potential buyers. Moreover, various parts of the ITMS tend to wear out quickly, making the device rather faulty and awkward to use. For these reasons the ITMS designers decided to construct another inertial device called the Cyklotren, which will hopefully solve the basic problems of usability and dissemination of inertial training. For this purpose, the following design ideas were considered:

- a wide range of selection of interacting masses;
- ease of precise selection of any weight values from the assumed range;
- possibility to establish many different movement models during training that can involve different muscle groups, and allow the possibility of performing specific movements typical of various sports or professional activities;
- possibility of mapping the properties of the majority of other inertial devices on the market;
- possibility of mapping the properties of some training devices of non-inertial nature of interaction (e.g. isokinetic, isodynamic);
- possibility of recording digital signals of force, position, and phase of movement;
- cooperation with other measuring instruments in performing concurrent measurements;
- possibility of using inertial properties of exercises for the analysis and development of coordination abilities;
- a wide range of applications: from scientific (developing physical strength and fitness) to physiotherapeutic;
- easy accessibility to the equipment and services provided by means of the device;
- ease of use and affordability.

To accomplish these objectives, a solution was adopted in which the force interacting with the mass was replaced by the force generated by an electric engine by winding a rope on the drum, controlled by an automatic control system reproducing inertial properties of training by emulating the behavior of the mass of a given value, moved by the force of the exercising person. In this way, a compact device was designed in which the mass value was set in the software, allowing entering values from the graphical user interface. Using a single-phase motor with the power of 3 kW a practical ability to emulate mass values between 0.01 and 200 kg was attained.

The signals of forces of rope tension and rope position, representing the course of the training, are both used in the feedback loop of the automatic control system and in the diagnostic information about the conducted training. These data are stored in an ASCII text file containing a string of instantaneous values of force of tension and rope position, sampled at a frequency of 1000 Hz. This file format is suitable for numerical processing using mathematical software to extract features constituting the basis of assessment of the exercise.

The software emulation of mechanical phenomena makes it possible to map specific (resulting from mechanical features) properties of some commercially available inertial training devices as well as to provide other, non-inertial, interaction models. As a result, it is possible to accurately reproduce previous experiments of many researchers who used other devices, and to refer to these experiences in a precise manner. The graphical user interface enable participants to see feedback in the form of a bar graph and digital indication of the value of one or two selected parameters describing the course of the training. These quantities include:

- time of the acceleration or deceleration phase of the cycle, or the time of the entire cycle;
- the mean value of the force for the deceleration or acceleration phase or the entire cycle;
- range of motion;
- concentration ratio of the force (the Gini coefficient).

For each of the two bar graphs mapping the value of selected parameters, a tolerance window can be specified in which the value should be maintained by the exercising person.

Considering the fact that in inertial interaction the mass is associated with time, force and range of motion, controlling the values of any two of them is linked to the controlling of a third one. It, therefore, engages the senses of control of motion, time and proprioception, providing an opportunity to train, and analyzing the properties of coordination and sensory integration.

This range of its functionality expands renders the device extremely useful in physiotherapy and physical recreation.
With the intention to make full use of the specificity of the construction and functionality of the Cyklotren device, its authors decided to solve one of the fundamental problems of training and physiotherapeutic treatment: access to training devices and specialist consultations. For this purpose they developed the concept of a central system of services based on remote care provided by a specialist – a personal trainer or a physiotherapist – through a computerized system of automatic data acquisition from training devices using feedback about the progress of training or physiotherapeutic treatment as well as about the changes in a current configuration of the training (Figure 1).
Altogether, the aforementioned properties of Cyclotren enable the functioning of the system in different market

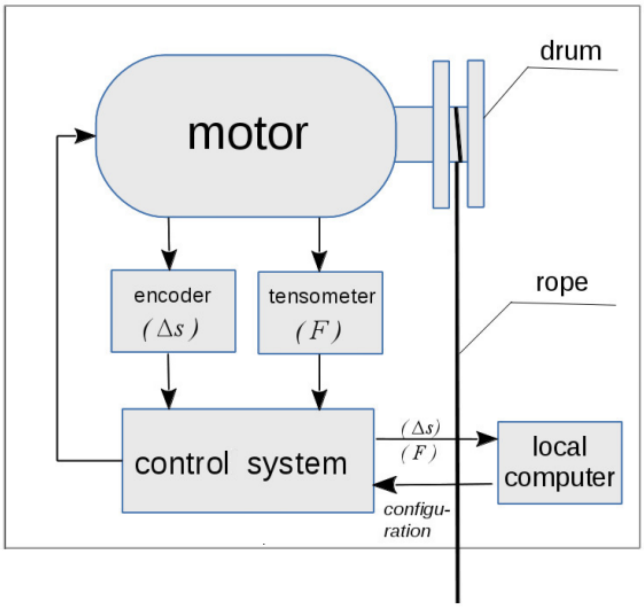

Figure 1. Schematic representation of the Cyklotren. The force (F) signal from the tensometer and the rope position (Δs) signal from the encoder are used by the system controlling the motor, operating following a model of interaction adequate to the type of exercise. These same signals are transmitted to a local computer registering the course of exercise, saved on removable media, and sent to a central system of services. Also a graphic representation of the exercise course is generated to monitor and interact with the exercising person, using the biofeedback principle. The local computer also allows users to configure the exercises from the graphical user interface (GUI).

niches and areas of specialist services, limited merely by the availability of the Internet.

Inertial training efficacy

Despite lack of information concerning optimal methodology of inertial training most studied articles revealed a high efficacy of inertial training for strength and power improvement in a relatively short time (usually within 5 weeks of training; Table 1).
So far inertial training has been performed by young, middle-aged and elderly, untrained subjects. There is no data concerning the efficacy of inertial training in physiotherapy and fitness training. However, physiological changes due to inertial training suggest that it can also be used in these areas. Inertial training causes a large hypertrophy of trained muscles in a relatively short time. Seynnes et al. [12] observed a 9% ($p \leq 0.05$) and a 13.8% ($p \leq 0.01$) increase in the cross-section area of the vastus lateralis muscle, after 20 and 35 days of inertial training, respectively. Moreover, a study by Tesch et al. [3] showed a 6% increase in quadriceps volume as a result of five weeks of inertial training. Muscle hypertrophy was also observed in young trained subjects by Naczk et al. [6] and Naczk et al. [9]. This effect is probably caused by a strong eccentric phase during inertial training. According to Norrbrand et al. [4] the eccentric phase during inertial training is stronger and muscle activation is greater in comparison to standard weight training. Moreover, a great number of studies indicate that eccentric contractions elicit greater muscle hypertrophy than concentric contractions [14, 15, 16]. Thus, the strong eccentric phase characteristic of inertial training can elicit great muscle hypertrophy (Figure 2).
Strength and power changes observed after inertial training may also result from neural adaptations. Several studies have indicated that short-term inertial training causes a significant increase in the EMG amplitude and median frequency of trained muscles [5, 6, 9, 10, 12]. These changes suggest that inertial training leads to recruitment of higher-threshold motor units or/and to increased motor unit firing rates. However, studies by McLoda et al. [17], Onambele et al. [11] and Tesch, et al. [3] show that an increase in EMG activity following inertial training does not always occur.
Inertial training can also evoke functional changes. Naczk et al. [9] obvserved that 5 weeks of training caused a significant increase in countermovement jump, squat jump, and anaerobic power in young untrained subjects. This suggests that inertial training can be useful in sport practice. However, so far, the effectiveness of inertial

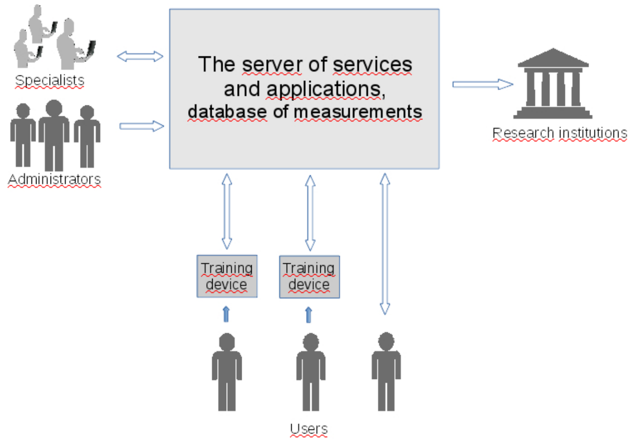

Figure 2. The central system of services. The measurement data are automatically transmitted to the central server from training devices after each exercise. Administrators manage services and assign users to professionals (trainers and physiotherapists). Users working on their own, leased or rented training devices, use the remote support of specialists or graphical or textual presentations of training results generated automatically. Research institutions can benefit from the archived resources of measurement data without revealing users' personal data of users for research purposes.

training in different sports has been subject to limited research. To the best of our knowledge, only two studies have been published [17, 18] on the influence of inertial training on ball throwing efficacy in baseball. Davison et al. [18] found that baseball pitch velocity significantly increased after inertial training in adolescent baseball players, but the results by McLoda et al. [17] were conflicting.

Conclusions

Inertial training still remains a little known training method. Considering the physical, physiological, and functional changes induced by inertial training, it can be concluded that it is a highly promising strength training method, which still deserves some elaboration. It is worth noting that effective methodology of inertial training must be developed. The use of a new inertial device called the Cyklotren can facilitate this objective. Prospective implementation of different training protocols (isokinetic and isodynamic) with the Cyclotren will allow wider applications of this device in rehabilitation and fitness training practice.

Table 1. Strength and power changes following inertial training

Reference	Type of device	Trained muscles	Training duration (weeks)	Training days per week	Number of sets	% increase in muscle strength	% increase in muscle power
Albert et al. [7]	ITS	elbow flexors	5	3	3	13.8 – 26.9*	NT
Brzenczek- -Owczarzak et al. [8]	ITMS	shoulder adductors	5	3	3	3.5 – 21.9*	9.8 – 34.3*
Naczk et al. [9]	ITMS	knee extensors	5	3	3	23.3 – 25.2*	27.0 – 33.2*
Naczk et al. [5]	ITMS	shoulder adductors	4	3	3	13.0 – 15.5*	15.5 – 19.5*
Naczk et al. [6]	ITMS	elbow flexors	5	3	3	13.7 – 28.4*	12.4 – 37.7*
Naczk et al. [6]	ITMS	elbow extensors	5	3	3	8.5 – 12.5*	11.0 – 21.1*
Norrbrand et al. [4]	Yo – Yo	knee extensors	5	2-3	3	4.4 – 6.0	8.9 – 12.0
Norrbrand et al. [10]	Yo – Yo	knee extensors	5	2-3	3	15.0 – 19.0*	10.0 – 17.0*
Onambele et al. [11]	Yo – Yo	knee extensors	12	3	1-4	8.0	28.0*
Seynnes et al. [12]	Yo – Yo	knee extensors	5	3	3	38.9*	NT
Tesch et al. [13]	Yo – Yo	knee extensors	5	2-3	4	10.8 – 11.1*	NT
Tesch et al. [3]	Yo – Yo	knee extensors	5	2-3	4	11.0 – 12.0*	SI

* – statistically significant increase; NT – not tested; SI – significant increase (detailed data were not presented)

What this study adds?
This is the first study which summarizes the state of current knowledge of inertial training. The paper discusses the advantages and disadvantages of inertial training. The main disadvantage is the lack of optimal methodology, whereas the main advantage is the high efficiency of inertial training for muscle strength and power enhancement in a relatively short time. Moreover, some developmental directions are also discussed concerning inertial training equipment, which can contribute to the popularization of this training method.

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