Force, power and physiological load during kettlebell swings

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Abstract

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Introduction:
To determine intensities during complex exercise it is necessary to quantify physical loads and physiological values. For kettlebell exercises, especially for the popular swing, exist only a few studies for physiological and physical loads. Furthermore, we found no research for the use of kettlebell swing in the practical setting of performing cumulative sets until exhaustion with a combined measurement of power, force and cardiopulmonary parameters. This study is the first one which combines the investigation of physical and physiological research in functional kettlebell exercises, especially during the kettlebell swing.

Material and Method:
The study included 9 subjects (4 men, 5 women) which are experienced in kettlebell exercises. The participants had to perform two test sessions in randomized order separated by 5 days: test A: a ergometrical test to determine the maximum values of oxygen consumption and heart frequency; test B: 5 sets of kettlebell swing until exhaustion. For Test B the subjects were randomized assigned to perform with either 10 or 16 kg (women) respectively 16 or 24 kg (men). Every kettlebell weight (10, 16 and 24 kg) was exercised by three individuals. Oxygen consumption (K4B[2,] Cosmed, Italy) and heart frequency (PhysioFlow Enduro, Manatec, France) were recorded continuous during both tests. Power and force were additionally recorded during the kettlebell exercise (Beast Sensor, Beast Technology, Italy).

Results:
Power and force during the swings significantly increases with higher kettlebell weights in a proportional relationship. The kettlebell swing produces homogeneous physical loads by regarding the chosen weight. The subjects reach higher set durations with lighter kettlebell weights. The heart rates tended to be a little bit lower during swings with higher weights, but all kettlebell weights produce maximal or submaximal heart frequencies. The oxygen consumption was higher in the heavier weights, but not in a proportional manner.

Conclusion:
Power and force displayed homogeneous values during the kettlebell swing. So it is possible to predict maximum and average loads during the swing from the kettlebell weight. Oxygen consumption and heart rate reactions seemed to be regulated in a different manner. Whereas the heart frequency reaches maximum values in every kettlebell weight while the oxygen consumption depends on the chosen weight and reaches only submaximal intensities.
In conclusion the kettlebell swing is a safe exercise with homogeneous physical and physiological stress. Additional research is necessary to fully understand the mechanisms of cardiac and metabolic regulations.

Keywords:
kettlebell, power, force, oxygen consumption, heart rate

Introduction

Strength and endurance training should not be seen as fundamentally contradictory types of intervention with regard to intensity, duration and target tissues. Rather it exists a continuum on the physiological training stimuli and adjustments can be selected depending on the desired effect. Load, speed, work and power should be chosen in dependence of the intervention goal. The kettlebell swing got special opportunities and potentials for a broad range of training designs. Complex exercises could apply in strength, endurance and rehabilitation trainings.

But dynamic exercises are difficult to determine in the risk of load and overloading because relatively high power amplitudes are produced within one repetition on the basis of great velocity amplitude and dynamic exercising. As example, on the upper turning point is no force to bear and in the phase of maximum upward acceleration act a multiple of the dumbbell weight.
For the first time this study investigates the kettlebell swing in cumulative sets. In this setting physical load and physiological stress, shown in terms of oxygen uptake and heart rate, could be studied. In our knowledge there

are no studies (searched in PubMed, MEDLINE, SpoLit) who measured the physical performance over many repetitions until exhaustion as swings are often used in various training programs.
Complexes exercise should be investigated in settings which are close to the use in trainings and interventions [2]. Kettlebell exercises are mainly performed in high intensity circuit training or as a ballistic exercise in strengthening. So a cumulative fatigue should be taken in account. So we transfer the use in interventions with exhaustion characters into this study.
This perspective allows the first time a common measurement and presentation of physical and cardiopulmonary variables during kettlebell swing and takes the fact of exhaustion into account.

Method

This study is a randomized, controlled laboratory test. The data collection and the study design are subject to the guidelines of Good Clinical Practice (GCP) and the Declaration of Helsinki 1996 (revised version of 2013).

Study population/study design:
All subjects were recreational athletes who regularly workout in strength or strength endurance training sessions (more than one workouts per week). The participants could perform the kettlebell swing close to the defined technical guidelines with a high accuracy. This ensured that the subjects are claimed only in their ordinary training load and the recorded data are representative for beginners and advanced athletes. Before including the subjects in the study they were informed and enlightened orally and they gave their written consent. The study group (n=9) consists of 5 women and 4 men.

A medical anamnesis excluded any acute and chronic diseases or limitations so that the subjects are complete loadable and no contraindications are given.
The characterization of the included subjects is shown in table 1.

Table 1 basic characteristic of the study participants

	study group (n = 9)
age (years)*	23.44 ± 2.7
height (cm)*	178 ± 8
weight (kg)*	77 ± 8
Men (n)	4
Women (n)	5

* average value and standard deviation in the study population

Study Procedere:
On the first sessions the subjects were interviewed to their medical and training history and the volunteers gave their written consent to participate in the study. Then either there was to perform a bicycle ergometric test for detecting the maximum physiological values (test A) or a kettlebell test (test B) dependent on the randomization.
Test A was a bicycle ergometric test until subjective exhaustion on the Daum medical 8i ergometer. The ergometry began with a power of 50 watt and got an increment of 15 watts per minute.
Test B includes the kettlebell (Reebok, USA) investigation.
The volunteers were instructed in the test design. They completed five sets of a two-hand swing until subjective exhaustion after a short warm up. The resting periods between the sets was standardized to two minutes. In figure 1 the study design is schematically shown.

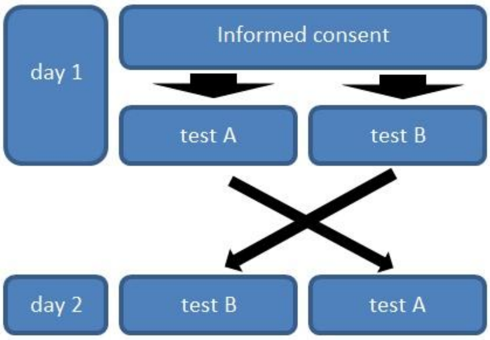

Fig. 1: study design

The subjects were randomly allocated to the kettlebell weight on Test B. So each of the three weight classes (10kg, 16kg, 24kg) in this study was performed by three subjects. They were assigned to either a light or a heavy weight. The light weight was the weight for normal trained beginners and the heavy weight was the recommend weight for advanced athletes. The weight selection is based on the recommendations of the association of Kettlebell USA [1]. For men, the weights accordingly are 16kg for beginners and 24kg for advanced athletes. Women should start with 10kg or with 16kg if they are experienced. This weight difference by men and women also show nearly proportional differences in regard to traditional kettlebell weight which is given in poods (1 pood is around 16 kg).

Kettlebell swing
The volunteers were instructed to swing the kettlebell close to the following additional technical recommendations to obtain a comparable motion within the subjects and to eliminate the risk of overloading:

- The kettlebell should be swung at shoulder level or one kettlebell diameter above
- The handle of the kettlebell is always in straight extension of the arm and wrist
- The initial impulse is homogenous generated as knee and hip
- The swing frequency is between 25-30 swings to produce a constant and homogenous exercise flow

Data Recording

All measured data were recorded continuously.

The physical values power and force are calculated by the given weight of the kettlebell out of the displacement and acceleration measurements of the inertial measurements system *Beast Sensor* (Beast technologies, Italy). Wrong identified repetitions by the software, e.g. a repetition time of a half second, are not considered in data collection.

The average power of Test B is calculated out of the power of every single repetition over the five sets by the software processing of the sensor system. So not only the acceleration of the kettlebell is taken in account but the whole displacement work during the set durations. Also, the maximum forces during the single repetition are averaged over all repetitions of the five sets (force). Despite the good cyclisation of the movement vary the maximum forces within the repetitions. The peak force represents the highest recorded force in the five sets to assess how much the maximum force differs from the peak force. The cardiac stress through different kettlebell weights was quantified by measuring the heart rate. The measuring and storing of the heart rate was done by the bipolar ECG lead of the mobile thoracic impedance *PhysioFlow Enduro* (Manatec, France).

The oxygen consumption was additionally measured to describe exercises in the term of physiological and metabolic load. Thus, a link between the physical load, as power, and the physiological reaction, as heart rate and oxygen consumption, can be created. Oxygen uptake was measured and stored breath by breath by the mobile spiroergometry K4B² (Cosmed, Italy). To compensate the variability of individual breaths the measured dates were averaged over 10 seconds.

Statistics

All statistical analysis and graphs was done by using GraphPad Prism 6.0 (GraphPad Software Inc., California, USA). The descriptive statistics, the arithmetic mean and the standard deviation are described below. Differences of weight classes were examined for significance using the Kruskal-Wallis test.

The following significances were defined as $p \leq 0.05$ significant (*).

Results

Power

The power shows a high depending of the chosen weight. The influence of different subjects was low. The power increases significantly by heavier weights. As shown in figure 2, the three subjects of their respective weight category (graphed for each weight as minimum, maximum value and median) have very unique performance values.

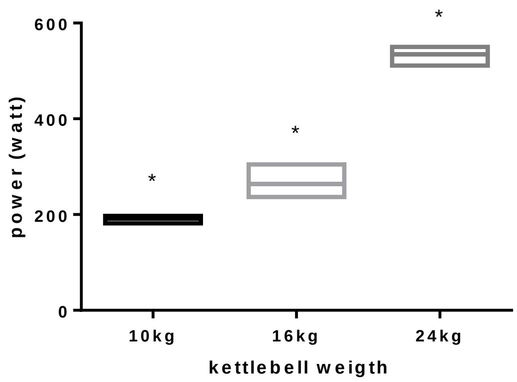

Fig. 2: power in relationship of weight (min, max, median)

Accordingly, the standard deviations are small, so that there are clear differences between the kettlebell weight classes. A nearly proportional increase in the power results by increasing the kettlebell weight. The observed power demonstrate, with 534 watts (24kg) and 264 watts (16kg), high values with a small standard deviation. Also the 10 kg kettlebell produces a power demand of 191,7 watts.

The presented data determines the possibility to predict the power demand with only a small error. Approximately the power for the swing is about the twentyfold of the kettlebell weight.

In conclusion the power values demonstrate that kettlebell swings require a lot of power even with light weights but the power demand could predicted by the weight with a small error.

Table 2 physical values (mean ± SD)

weight [kg]	24	16	10
power [watt]	534,0 ± 20,4	264,3 ± 35,8	191,7 ± 8,6
maximum force [N]	627,9 ± 33,7	442,9 ± 4,1	289,5 ± 3,3
peak force [N]	680,1 ± 58,4	496,0 ± 17,0	357,1 ± 41,2
peak force of average [%]	108,2 ± 3,5	112,0 ± 4,2	123,3 ± 12,8

Maximum force

The 24 kg kettlebell affects a average force of 627,9 N during the swing. The force drops nearly proportional by reducing the weight. The lower weights required 442,9 N for 16kg and 289,5 N for 10 kg.

So the average maximum force of the kettlebell swing is around the threefold of the kettlebell weight (Fig. 2).

All nine subjects demonstrate homogeneously repetitions during the exercises which resulted in small standard deviations of the force. Furthermore, there is not only a uniform performance in comparison of different individuals by the same weight. By taking a look of the repetitions of one set a uniform executed exercise is shown. In fig. 3 an example of one set of one subject with 24 kg shows a average maximum force of 630,9 N and a very small standard deviation (± 2,8 N). This example

demonstrates the typical regularly paced and executed kettlebell swing we found in this study and therefore a constant course of force in a set.
These data example is representative of the entire study cohort and demonstrate the high degree of homogeneity within the sets and the subjects.

Peak Force

The peak force measuring is required for the assessment of the maximum strength by performing the swing close to the technical optimum and without taking a risk of overloading.
Therefore we show the highest recorded forces during test B. The maximum force strongly depends of the chosen weight. As shown in table 2 the peak force is about 8 to 23% higher than the average force. With higher kettlebell weight the peak force approaches the average force and the variation reduces. The relative risk to underestimate the maximum required force or to produce a single overloading repetition reduces by choosing higher weight.
Finally the maximum needed force for performing a safety kettlebell swing is around 3,5fold of the chosen weight.

Physiological Values

Performing kettlebell swings during training sessions lead to a high cardio respiratory exhaustion. We recorded continuous the oxygen consumption and the heart rate to answer the question how to classificate the physiological load during kettlebell swings.
Especially the maximum values are important for describing the physiological load because they cause the highest physiological stress. We determined the maximum physiological load as the recorded average values for the 50 seconds of the highest intensity. For that, we choose in each set the 10 seconds with the highest average value.

Oxygen consumption

Describing the oxygen cost is the most common method to determine the metabolic load during exercises. As shown in Fig. the oxygen consumption raises with higher kettlebell weights but the amount of oxygen is only slightly different between the weights. The subjects consume 3098,7 ml/min oxygen during the 24 kg swing and for less than half of the weight (10kg) they required still 2248,9 ml/min. The 16 kg swing lead to an oxygen demand of 2507,4 ml/min.
So small weight also causes substantial oxygen demands and the efficiency (ml oxygen/ kg kettlebell weight) raises by higher kettlebell weights.

Heart Rate

The comparison of the reached heart frequency shows no difference between the groups. Higher weights tended to lower heart rates, reaching statistical significance between 10 and 24. The 10 kg swing was only performed by girls and they reached their ergometric determined maximum heart rate during the swing. We observed very high to maximal heart rates in all weights.

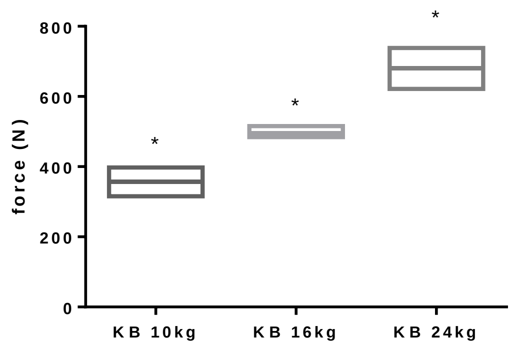

Fig. 2 average maximum force and kettlebell weights

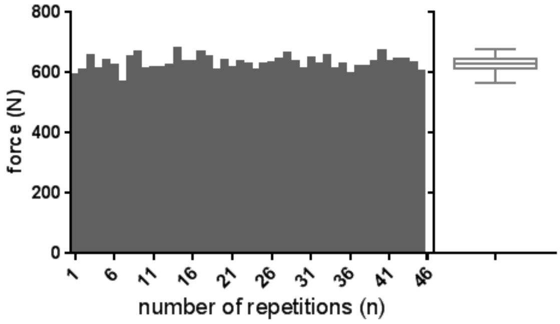

Fig. 3: force for every rep. in a set (left); mean, SD, min, max (right)

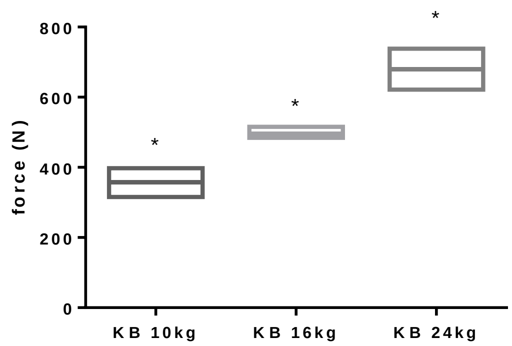

Fig. 4 peak force and kettlebell weight

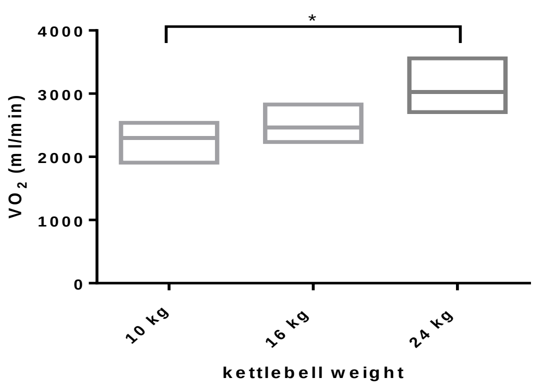

Fig. 5 oxygen consumption (median, min, max) and kettlebell weight

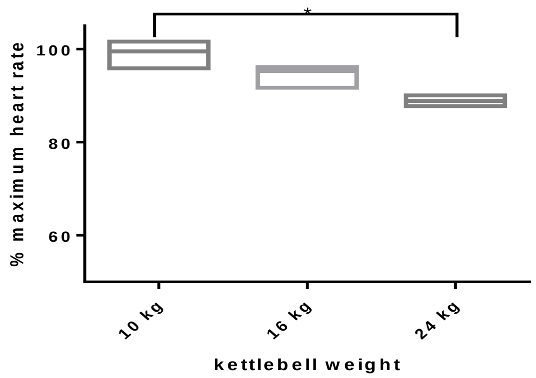

Fig. 6 relative maximum heart rate (median, min, max) and kettlebell weight

Set duration

The reached physiological values are better to interpret by taking the set duration in account. The duration of the exercise depends on the chosen weight. The set duration decreases with higher kettlebell weights as shown in Fig. 7. The group with the heaviest weight performed the swing for 1:08 min (SD ± 0:11 min), the 16 kg group for 1:40 min (SD ± 0:11) and the 10 kg group for 1:51 (SD ± 0:15).

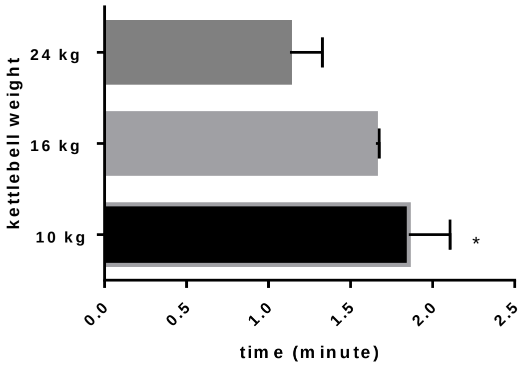

Fig. 7 set duration and kettlebell weight

Discussion

Power and force displayed homogeneous values during the kettlebell swing. So it is possible to predict maximum and average loads during the swing if exercised close to the described swing technic. Moreover, if taken into account that only 9 subjects produced clear and homogenous values for power and force.

The measured power demonstrates that swings with small kettlebell weight resulted in high power outputs. So in other settings, e.g. metabolic rehabilitation, kettlebell weights below 10kg could be used to induce sufficient metabolic loadings.

The force which will be produced during a swing is about the 3.5 fold of the weight and got a proportional manner to the weight. So if the maximum strength in the posterior muscle chain and leg muscles is known, maybe generated from the one repetition maximum of the deadlift or from other complex postural strength tests, a safety swing weight could be select.

To emphasize is that the generated peak forces are only 8 to 23% higher than the average maximum forces. By taking into account that the differences in higher weights are smaller (8% 24kg, 23% 10kg) a safe execution will be generated. A reason therefore could be that with higher weights an effective and economic execution is required to stabilize the kettlebell in the given technical description. Another fact is that by working close to the maximum force in a movement the execution economize to produce homogenous force patterns and to reduce peak forces which may also depend on the sensomotoric feedback.

In the contrast to the physical values the oxygen consumption and heart rate reactions seemed to be regulated in a different manner. The heart frequency reaches maximum and submaximal values, but less frequency load by higher weights. This mainly depends on the shorter set duration because 1:08 minute is maybe too short to reach maximal heart frequencies in a slow performed exercise (25-30 swings/minute) out of resting conditions in comparison to nearly two minutes set time with lighter bells. But the duration of the 24 kg swing is still enough to reaches high and submaximal heart rates. So it is possible to stimulate the cardiac regulation by the central co-innervation with heavier weights or during training with lighter weights and longer durations. The heart stress could increase if swings are combined with other exercises in prestimulated or exhausted cardiac training conditions.

The oxygen consumption showed a trend to a higher demand with higher weights, but this is not proportional to the weight like the physical power. Only between the 24kg swing and the 10kg swing is a statistical significant different. The oxygen consumption during exercise depends on many different factors. The ability to extract and mobilize the oxygen demand in a short duration, the maximum oxygen demand, the sex and other factors influence the result in oxygen measuring. Also shorter set durations with higher kettlebell weight could lower the maximum demand. So further research is needed to understand how the oxygen consumption is influenced by the named factors during swings and other functional exercises. The number of subjects is too small and the cardio pulmonic preconditions are too different to explain regularities and the effect of different influences factors. It could also be possible, that the cardiac regulation may show an increase in the heart rate, but in opposition the stroke volume decrease. Reasons for that could be the high peripheral pressure generated from the muscle tone during high loads.

In conclusion the kettlebell swing is a safe exercise with homogeneous physical and physiological stress. Additional research is necessary to fully understand the mechanisms of cardiac and metabolic regulation. The expected stress depends mainly on the chosen weight. If athletes and patients are loadable in regard to the expected physical, metabolic and cardio pulmonic stress the kettlebell swing is a good exercise to combine various training intentions.

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