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# THE EFFECTS OF WARM-UP DURATION ON CYCLING TIME TRIAL PERFORMANCE IN TRAINED CYCLISTS

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**Abstract** The purpose of this study was to assess the effects of three different warm-up condi-tions on a 5K cycling time trial (TT). Sixteen trained cyclists completed the study. At the first testing session, participants completed a maximal graded exercise test to assess maximal oxygen consumption ($VO_2max$) and a familiarization of the TT. At three subse-quent visits, the participants completed the TT after no warm up, short warm-up of three minutes at 60% $VO_2max$, or long warm-up of ten minutes at 60% $VO_2max$. The warm-up was assigned in randomized order. $VO_2$, heart rate (HR), lactate, power, and speed were assessed after the warm-up, 1K, and completion of the 5K TT. There was no dif-ference between type of warm-up for time, power, cadence, speed, $VO_2$, HR, or lactate levels at the end of the TT. There was no significant difference between type of warm-up for time, $VO_2$ or HR at the end of the 1K split. Warm-up length was not impactful on 5K TT performance or during the first km of the TT in trained cyclists. These results con-flict with previous evidence indicating that a warm-up in endurance events primarily improved $VO_2$ kinetics at the onset of the exercise.

**Key words** Maximal oxygen consumption, endurance training, lactate, oxygen kinetics, aerobic

## Introduction

Completing a warm-up before anaerobic and aerobic exercise may prepare vari-ous physiological mechanisms that athletic performance relies upon including: blood flow, oxygen kinetics and metabolic activity (Hajoglou et al., 2005; Johnson, Gregson, Mills, Gonzalez, Sharpe, 2014; Tomaras, MacIntosh, 2011). Warm-up methods have two broad classifications: passive and active warm-ups (Bishop, 2003a, 2003b). This study focuses on active warm-ups which consist of using exercise (e.g. jogging, cycling, and swimming) that produces the same effect as a passive warm-up (Bishop, 2003a, 2003b). There are numerous studies that have determined the benefits of a passive or active warm-up for short duration, high intensity and resistance exercise (Bishop, 2003a; Gray, Nimmo, 2001); however, there are conflicting studies that contest whether a warm-up will improve (Bishop, 2003b), hinder (Andzel, Busuttil, 1982; Gregson, Drust, Batterham, Cable, 2002), or have no effect (Andzel, 1978; Andzel, Busuttil, 1982; Andzel, Gutin, 1976; Grodjinovsky, Magel, 1970) on long-term endurance exercise. The amount of time between the warm-up and performance is also important. A transition time of less than five minutes appears to be most effective (Andzel, 1978, 1982; Andzel, Gutin, 1976; Genovely, Stamford, 1982; Grodjinovsky, Magel, 1970) as the athlete is able to recover from the warm-up bout, and will likely begin the exercise with an elevat-ed oxygen consumption ($VO_2$) and muscle temperature and therefore be more prepared for the performance.

Studies reporting improvement in endurance performance related to warm up at-tribute the benefit to an increase in $VO_2$ (Andzel, 1978; Andzel, Gutin, 1976; Genovely, Stamford, 1982; Grodjinovsky, Magel, 1970; Martin, Robinson, Wiegman, Aulick, 1975), an increase in heart rate (HR) (Andzel, 1978; Andzel, Gutin, 1976; Martin et al., 1975), a decrease in lactate accumulation (Gerbino, Ward, Whipp, 1996; Kozlowski et al., 1985; Mujika, de Txabarri, Maldonado-Martin, Pyne, 2012), or increased time to exhaus-tion (Ng, Cheng, Fung, Ngai, Wong, Yeung, 2007). Physiologically, the improved performance correlated to warm up may be related to the increased muscle temperature (Bishop, 2003a; Jones, Koppo, Burnley, 2003), improved $VO_2$ kinetics early in the exercise bout (Burnley, Jones, Carter, Doust, 2000; Gerbino et al., 1996; Hajoglou et al., 2005; Johnson et al., 2014), improved exercise tolerance (Carter et al., 2005), improved aerobic abilities (Bishop, 2003a; Carter et al., 2005; Hajoglou et al., 2005; Johnson et al., 2014; Jones et al., 2003), and increased nerve conduction velocity (Johnson et al., 2014). It is hypothesized that the increase in $VO_2$ and increase in HR (Bearden, Moffatt, 2001) would likely decrease the oxygen deficit and increase cardiac output, allowing for greater performance at the onset of ex-ercise. Increased cardiac output would also assist with removal of any lactic acid accu-mulated during the warm-up, resulting in fewer disturbances in blood pH.

These positive changes have been seen with various warm-up methods includ-ing different intensities and durations. For example, increasing the intensity of a warm-up by including sprints, has been shown to be effective in long-term and intermediate performance (Grodjinovsky, Magel, 1970; Hajoglou et al., 2005). Whereas, an active low-intensity warm-up at 40% $VO_2$max demonstrated a greater efficiency of thermoregu-lation in cross-country skiers, resulting in an early sweat response (Chwalbinska-Moneta, Hanninen, 1989). Johnson et al. (2014) found that an active full body warm-up resulted in an improved endurance performance during a 10K cycling time trial, which supported a study by Hajoglou et al. (2005). In these cases, a warm-up was shown to improve exercise performance over no warm-up, and most of the improvements were seen during the first few minutes of the exercise bout, which researchers believed were likely due to accelerated $VO_2$ kinetics (Hajoglou et al., 2005). In addition, cyclists that completed a low-intensity rowing warm-up of 30 minutes produced a higher mean power output compared to those that completed a 60-minute warm-up with various in-tensities (Mujika et al., 2012). Specifically, the higher power output was more promi-nent during the first 7.5 minutes of the 10-minute time trial. This study supports the no-tion that a warm-up should not be too long, as it may result in too much physiological strain.

Intensity and duration of the warm-up should be monitored to avoid significant disruptions in homeostasis such as muscle fatigue, high core temperatures, lactate production, and substrate depletion (Andzel, Busuttil, 1982; Bergstrom, Hermansen, Hultman, Saltin, 1967; Carter et al., 2005; Genovely, Stamford, 1982; Gregson et al., 2002; Kozlowski et al., 1985; Wittekind, Beneke, 2009). Warm-up intensities above lac-tate threshold tend to increase blood lactate response more than low-intensity warm-ups (Genovely, Stamford, 1982; Gray, Nimmo, 2001). These warm-ups have also been shown to hinder work output (Genovely, Stamford, 1982; Tomaras, MacIntosh, 2011), have no effect on exercise time to exhaustion (Wittekind, Beneke, 2009), or improve $VO_2$ kinetics and muscle perfusion (Gerbino et al., 1996). In instances of prolonged warm-ups performed at high intensity, a decline in performance is believed to be due to glycogen depletion. However, when participants completed a prolonged warm-up at an intensity below anaerobic threshold, body temperature was increased and there was no change in lactate accumulation or maximal performance (Genovely, Stamford, 1982).

Manipulation of the warm-up protocols may include alterations in the warm-up duration, intensity, or transition period. Various studies have demonstrated mixed ef-fects of a warm-up on performance due to employing different warm-up routines (inten-sity and duration) that make it difficult for uniform comparison. Furthermore, there is little evidence indicating the ideal duration and intensity of a warm-up and its effect on long-term aerobic performance. Therefore, the purpose of this study was to determine if differing durations of a warm-up completed below lactate threshold affects power out-put, $VO_2$, and lactate during a 5K cycling time trial.

## Material and methods

Sixteen (males, n = 10; females, n = 6) trained cyclists (41.0 ±7.7 years, 76.5 ±13.5 kg, 1.75 ±0.11 m, 16.3 ±5.8% body fat, and 50.5 ±11.7 ml • $kg^{-1}$ • $min^{-1}$) volunteered to participate in the study. Trained cyclists were defined as cycling at least twice a week for the last four months. All subjects were considered low risk as defined by American College of Sports Medicine (ACSM). Exclusionary criteria included: moderate- or high-risk for cardiovascular disease as defined by the ACSM, individuals taking androgenic medications or ergogenic levels of nutritional supplements that could affect muscle mass or anabolic/catabolic hormone levels within one month prior to the start of the study. Prior to beginning the study, participants read and completed university-approved written informed consent document. All testing procedures were conducted at the Health and Human Performance Laboratory at Meredith College.

At baseline testing, participants were measured for height, weight, and body composition using the seven-site skinfold technique. The participants completed a graded exercise test for determination of $VO_2$max and lactate threshold. All testing was completed using a stationary cycle simulator (Computrainer, RacerMate, Seattle, WA) and the participants provided their own bicycle. The baseline testing protocol consisted of a three-minute warm-up at 25 W, followed by gradual increases in workload over three-minute increments until the participant could no longer maintain the pace. During the test, expired respiratory gases were collected and analyzed for oxygen and carbon dioxide concentration (Mini CPX, VacuMed, Ventura, CA). A 25-microliter (1-drop) blood sample was collected from an earlobe puncture at the end of each three-minute stage and analyzed for lactate concentration (Lactate Pro, Arkray, Inc., Kyoto, Japan) to de-termine lactate threshold. HR (Polar Electro, Finland) and blood pressure were moni-tored at the end of each stage. After completion of the GXT, the participant completed a five-minute cool down followed by a familiarization with the 5K time trial (TT).

This study was a randomized cross-over design, with each participant complet-ing all three testing conditions. Following baseline testing, participants completed each of the following warm-up protocols in random order one week apart: Short warm-up of three minutes at 60% $VO_2$max (SW), long warm-up of ten minutes at 60% $VO_2$max (LW), or no warm-up (NW). After the warm-up, participants began a 5K TT at a simulated 3% grade. There was one minute between completion of the warm-up and initiation of the TT. This short time period was necessary to configure the cycle simulator to the proper settings for the TT. Participants were not privy to any performance measures except dis-tance during the TT. No verbal encouragement was provided to participants during the experimental sessions. During each trial, expired gasses and ventilation were meas-ured throughout the warm-up and the TT. HR, blood pressure, rating of perceived exer-tion (RPE), and lactate concentration were measured prior to the warm-up, prior to the TT, and after completion of the TT. $VO_2$ and HR were also measured at the end of the first kilometer. Performance time, absolute power, relative power, cadence, and speed were obtained from the Computrainer at the 1K split and at the end of the TT.

Data were analyzed with a multivariate ANOVA to address differences among type of warm-up at the completion of the TT and after completion of the first kilometer. Tukey HSD was used for post-hoc analyses. The variables that were tested included absolute power, relative power, cadence, speed, HR, $VO_2$ and lactate. An alpha level of 0.05 was used for all analyses. SPSS Statistics 19 (IBM Corporation, Somers, NY) was used for all statistical analyses.

## Results

There was no statistical difference between types of warm-up for any of the per-formance variables, including: completion time ($F_{2.45}$ = 0.231, p = 0.795), absolute power ($F_{2.45}$ = 0.088, p = 0.916), relative power ($F_{2.45}$ = 0.105, p = 0.900), cadence ($F_{2.45}$ = 0.607, p = 0.549), speed ($F_{2.45}$ = 0.226, p = 0.798), heart rate ($F_{2.45}$ = 0.269, p = 0.766), lactate ($F_{2.45}$ = 0.556, p = 0.577), and $VO_2$ ($F_{2.45}$ = 0.029, p = 0.971) at the completion of the 5K TT. There was also no significant difference between the warm-up types for any of these variables at the end of the first kilometer (completion time: $F_{2.45}$ = 0.928, p = 0.403; absolute power: $F_{2.45}$ = 0.501, p = 0.609; relative power: $F_{2.45}$ = 0.605, p = 0.509; cadence; $F_{2.45}$ = 0.250, p = 780; speed: $F_{2.45}$ = 0.952, p = 0.394; heart rate: $F_{2.45}$ = 1.99, p = 0.149; and $VO_2$: $F_{2.45}$ = 2.34, p = 0.121).

Figure 1 shows the completion time for both the 1K split and the TT completion. While there was no significant difference between type of warm-up in the 1K split, the NW trial was on average 10–11 s slower than the other two warm-up conditions. Fur-ther, the NW trial completion time was on average 28 seconds and 34 seconds slower than the SW and LW trials respectively.

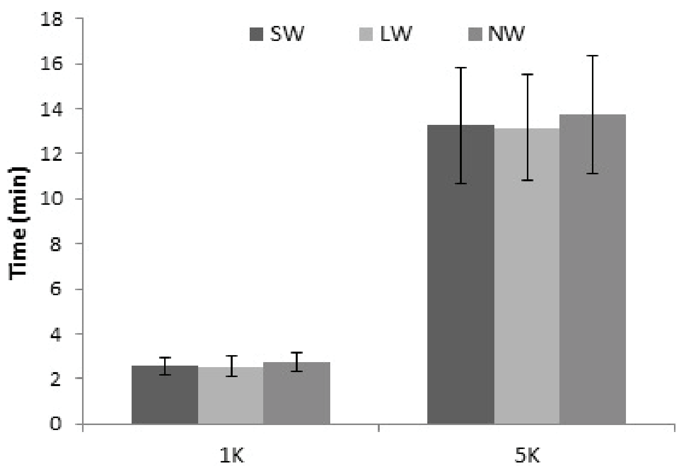


**Figure 1.** Mean times for the first kilometer (1K) and at the end of the 5K TT. NW repre-sents the no warm-up condition, SW represents the short warm-up condition, and LW represents the long warm-up condition

Figure 2 shows the mean $VO_2$ during the TT for each warm-up condition. Again, there was no significant difference, but the NW condition resulted in a lower $VO_2$ at the 1K split compared to the SW and LW trials. This difference was not present at the com-pletion of the TT. The LW trial resulted in the highest $VO_2$ at the completion of the first kilometer.

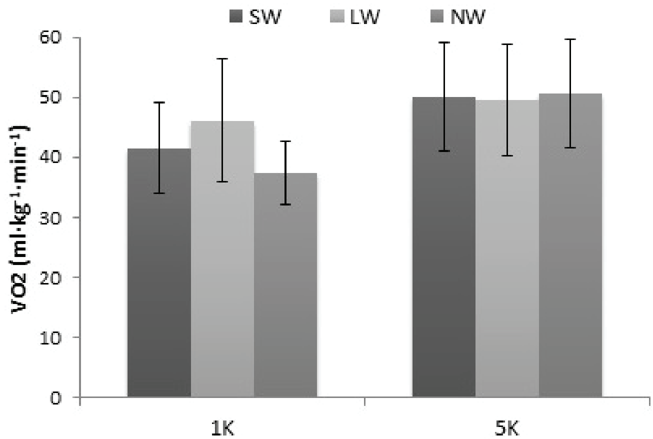


**Figure 2.** Mean $VO_2$ for the first kilometer (1K) and at the end of the 5K TT. NW repre-sents the no warm-up condition, SW represents the short warm-up condition, and LW represents the long warm-up condition

Figure 3 shows the differences in HR between the three warm-up conditions at the 1K split and at the completion of the TT. While there was no significant difference, HR in the NW condition was slightly lower at the 1K split by a mean of 8 bpm and 11 bpm compared to the SW and LW trials respectively. This differential was less at the completion of the TT, with a mean difference of 3 bpm compared to the SW trial, and 4 bpm compared to the LW trial.

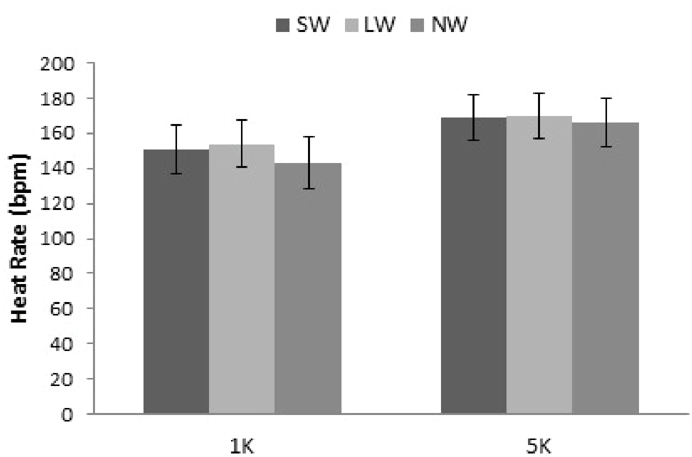


**Figure 3.** Mean heart rates for the first kilometer (1K) and at the end of the 5K TT. NW represents the no warm-up condition, SW represents the short warm-up condition, and LW represents the long warm-up condition

Table 1 shows all other performance-based parameters for both the first kilometer (1K) and completion of the TT. There was no statistically significant difference between the three warm-up conditions for any of these performance variables. Notably, the dif-ference between the NW trial compared to the SW and LW trials are greater at the 1K split than at the completion of the TT. In each variable, the NW trial had less favorable numbers than the other two warm-up trials at the 1K split. Lastly, there was also no dif-ference between type of warm-up for RPE prior to the onset of the TT (NW: N/A, SW: 10.3 ±1.2, LW: 10.3 ±1.3) or after TT completion (NW: 17.1 ±2.2, SW: 17.9 ±1.7, LW: 17.0 ±1.3).

**Table 1.** Comparison amongst type of warm-up for absolute power, relative power, ca-dence, and speed at the end of the first kilometer (1K) and at the end of the 5K TT. Blood lactate values are also shown at the end of the 5K time trial. NW represents the no warm-up condition, SW represents the short warm-up condition, and LW represent the long warm-up condition

| | 1K | | | 5K | | |
|---|---|---|---|---|---|---|
| | NW | SW | LW | NW | SW | LW |
| Absolute power (W) | 221.9 ±51.6 | 235.7 ±60.4 | 242.9 ±68.2 | 218.8 ±54.4 | 226.8 ±58.4 | 225.1 ±57.3 |
| Relative power (W/kg) | 2.92 ±0.56 | 3.08 ±0.59 | 3.19 ±0.77 | 2.88 ±0.61 | 2.98 ±0.65 | 2.96 ±0.64 |
| Cadence (rpm) | 84.3 ±11.5 | 86.6 ±9.8 | 86.4 ±10.6 | 90.1 ±8.4 | 89.8 ±8.84 | 89.6 ±8.74 |
| Speed (km/h) | 22.5 ±3.9 | 23.3 ±4.0 | 23.3 ±3.7 | 27.1 ±3.5 | 27.3 ±4.1 | 28.7 ±5.4 |
| Lactate (mmol/l) | – | – | – | 8.0 ±3.2 | 9.0 ±2.9 | 7.9 ±3.2 |

## Discussion

The results indicate that warm-up duration had no impact on performance time, $VO_2$, power output, HR, cadence, speed, or RPE at completion of the 5K TT or in the initial 1K. There was also no significant difference among types of warm-up for blood lactate accumulation at the end of the 5K TT. These results agree with previous studies that have demonstrated no improvement in performance when having completed a warm-up with no rest prior to long duration exercise performance (Andzel, 1978; Andzel, Gutin, 1976; Grodjinovsky, Magel, 1970), and with studies that employed a small rest period after the warm-up period (Gray, Nimmo, 2001; Gregson et al., 2002; Wittekind, Beneke, 2009).

Andzel and Gutin (1976) researched the effect of a short rest period, 30 or 60 seconds, between a warm-up and a bench stepping task. The study found that this rest period improved performance when compared to subjects who completed no warm-up or no rest between the warm-up and the step task. In a later study by Andzel (1978), the effects of no warm-up and varied rest times between warm-up, and a treadmill task were compared to no warm-up before the task. The rest periods of 30, 60, 90, and 120 sec-onds were tested, and the rest period of 30 seconds yielded the best performance. The authors suggested that the rest period might have been beneficial in allowing any lac-tate formed during the warm-up to be cleared out, as well as complete at least partial resynthesis of phosphagens. However, in the current study, the warm-up protocol was below that of anaerobic threshold, which would likely suggest that lactate accumulation would not have been a contributor to the exercise performance. Because lactate likely did not accumulate it would not have affected the overall 5K or the 1K split performanc-es.

Studies that showed a warm-up improved performance attributed the benefit to acceleration of $VO_2$ kinetics (Hajoglou et al., 2005), an increase in anaerobic threshold (Chwalbinska-Moneta, Hanninen, 1989), and structure of the warm-up (Johnson et al., 2014). Hajoglou et al. (2005) and Carter et al. (2005) both used varying intensities of warm-up prior to exercise, incorporating times of higher and lower intensities within the same warm-up. Hajaglou et al. found that performance was improved despite the inten-sity of warm-up. Carter et al. found that a heavy warm-up, three 73-second cycling ef-forts at 90% critical power, lengthened total time to exhaustion by 10% while a severe warm-up, three 60-second cycling efforts at 110% critical power, hindered the subse-quent exercise performance. In the current study, the data at 1K into the TT, while not statistically significant, indicate a small benefit in warm-up exercise prior to perfor-mance with faster times, higher power outputs, higher cadences, and higher $VO_2$ for both of the warm-up trials compared to the NW trial. The mean 1K time differential be-tween NW and either type of warm-up was approximately 10 seconds. While this was not substantial for the recreationally trained population utilized in this study, this would likely be substantial for a more competitive or elite level population. Further, when ad-dressing the finishing time for the 5K TT, the differences between the NW trial and the SW and LW trials were approximately 28 s and 33 s respectively, with the NW trial per-forming worse in each case. This differential would probably decrease over an extend-ed TT range like those used in professional cycling races, but would still be impactful regarding the overall standings in the race. For recreational individuals that embark on a training ride, a warm-up isn't going to significantly impact the workout and is not nec-essary. It should also be noted that this study was conducted in a thermoneutral envi-ronment, the impact of a warm-up for recreationally trained cyclists may be different when exercising in cooler or warmer temperatures.

Following completion of the study, participants were asked which trials they felt were their fastest and slowest times, and which trial they felt was the most difficult. The consensus from the participants was that the NW trial was much more difficult at the onset of exercise compared to the other trials, and they thought it was their slowest time. Ng, Cheng, Fung, Ngai, Wong, Yeung (2007) studied the effects of a warm-up in time to reach a specific rate of perceived exertion (RPE) using a cycling protocol. Sub-jects cycled under a constant power output until they felt they had reached an RPE of 15. The study found that the passive warm-up had significantly longer time to RPE than compared to the control of no warm-up and active warm-up. However, another study that compared subject's RPE to varying warm-up protocols found that both a cycling warm-up and a cycling and inspiratory muscle warm-up elicited higher RPE responses than the control of no warm-up (Johnson et al., 2014). These authors attributed the higher RPE responses from a warm-up to an increased motivation and effort in the subject that was caused by the active warm-up. Some indi-viduals use the warm-up time to help prepare them mentally to concentrate on the up-coming event. In the absence of a warm-up, this psychological preparation time is lost, and this may have an impact on performance (Bishop, 2003b).

Coaches, athletes, and personal trainers regularly emphasize the importance of completing a quality warm-up prior to aerobic exercise participation or athletic perfor-mance citing improved $VO_2$ kinetics, improved muscular thermal environment, en-hanced muscular blood flow, and improved cardiovascular system functioning. While these physiological changes are important to how one feels early during exercise by reducing oxygen deficit, they likely did not translate to significantly improved perfor-mance during the exercise bout. Thus, it may be unnecessary for recreational athletes performing long duration exercise to perform a lengthy structured warm-up prior to the exercise bout. However, coaches and athletes should still consider the use of a warm-up prior to aerobic exercise because the small difference seen during the onset of ex-ercise may affect the overall performance of the athlete while in competition. Additional-ly, including a warm-up prior to daily training could also help athletes establish a rou-tine, thus enhancing mental and physical preparedness prior to competition.

## Conclusions

To our knowledge, this is the first study that measured the effects of active warm-up duration below lactate threshold on performance in a competitive cycling time trial. Although no significant differences between types of warm-up were demonstrated at completion of the time trial, these findings are important as there were no significant differences after the first kilometer of the time trial. This indicates that the potential ef-fects of having completed a warm-up (e.g. enhanced $VO_2$ kinetics, increased muscle temperature, and improved muscle blood flow) were no longer present less than four minutes into the exercise activity. Additionally, completing a warm-up may be impactful on the mentality and subjective effort of the athlete.

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# THE USE OF ARTIFICIAL NEURAL NETWORKS IN SUPPORTING THE ANNUAL TRAINING IN 400 METER HURDLES

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**Abstract** This paper presents an evaluation of the annual cycle for 400 m hurdles using artificial neural networks. The analysis included 21 Polish national team hurdlers. In planning the annual cycle, 27 variables were used, where 5 variables describe the competitor and 22 variables represent the training loads. In the presented solution, the task of generating training loads for the assumed result were considered. The neural models were evaluated by cross-validation method. The smallest error was obtained for the radial basis function network with nine neurons in the hidden layer. The performed analysis shows that at each phase of training the structure of training loads is different.

**Key words** 400 meter hurdles, artificial neural networks, planning training loads

## Introduction

The 400 m hurdles race is a complex motor and rhythm (technical) athletics race. In terms of motor preparation, the dominant part is endurance of a specific character (anaerobic), supported by a high level of speed and strength. Given the interdisciplinary nature of race training those means, which combine both the technical and the motor aspects of the race, should be used on a very frequent basis (McFarlane, 2000; Iskra, 2012b).

The analysis of training loads in selected disciplines and sports competitions evokes different reactions among scholars and coaches. Some of them claim that the evaluation of an athlete's (or group of athletes) training can be an inspiration to other sportsmen. Others believe that sport is about individual cases where patterns or "average" data have no value (Hiserman, 2008; Iskra, 2012a).

In the analysis of training loads in athletics, including the 400 m hurdles, three approaches can be distinguished:

- Analysis of individual training programme – analysis of the intensity and content of the training of the best competitors, usually record holders and champions (Olympic, world and continent) (Alejo, 1993; Iskra, Widera, 2001; Winckler, 2009).
- Statistical analysis of average data – from a group of competitors, who often train over the long term (Brejzer, Wróblewski, Koźmin, 1984; Iskra, 2001; Guex, 2012).
- Mathematical analysis – it is an attempt to use basic science to provide training solutions in competitive sports (Iskra, Ryguła, 2001; Przednowek, Iskra, Cieszkowski, Przednowek, 2015; Wiktorowicz, Przednowek, Lassota, Krzeszowski, 2015).

Each of the above methods of training load analysis has its strengths and weaknesses. For example, the use of artificial neural networks allows a multidimensional analysis of training loads to be carried out, by creating a system that not only analyses the training already carried out, but also lets the coach decide on the size of the training loads to be applied at a given phase in the sports training. The system which is built on the basis of knowledge accumulated over many years of coaching will assist decision-making by providing valuable coaching tips (Przednowek, Iskra, Cieszkowski, Przednowek, 2015). It should be noted that such a system will act as a consultant, since a coach's intuition and the human capacity to analyse reality is still unsurpassed by computer systems.

The aim of this study is to evaluate the annual preparation cycle for 400 m hurdlers using neural networks. The analyses can be helpful in verifying the views adopted a-priori by coaches, taking into account long-term standards of periodization of training.

## Material and methods

The analysis included 21 Polish hurdlers aged 22.25 ±1.96 years participating in competitions from 1989 to 2011. The athletes had a high sport level (the result over 400 m hurdles: 51.26 ±1.24 s). They were the part of the Polish National Athletic Team Association representing Poland at the Olympic Games, World and European Championships in junior, youth and senior age categories. The best result over 400 m hurdles in the examined group was equal to 48.19 s. The collected material allowed for the analysis of 48 annual training plans.

In the presented solution the task of generating training loads (GT) for the assumed result were considered. The neural model generates training for the expected result and the parameters of the athlete (Figure 1 and Table 1).

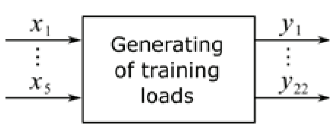



**Figure 1.** Block diagram of the model for generating training loads

Assistance in planning the training loads in terms of the annual training cycle is reduced to generating training loads recognized as the sum of the training means used throughout the macro-cycle. In planning the annual cycle, 27 variables were used, where 5 describe the competitor and 22 variables represent the training loads.

Table 1 contains the variables considered and their basic statistics, i.e. the arithmetic mean of $x$, the minimum value $x_{min}$, the maximum value $x_{max}$, standard deviation $SD$ and the coefficient of variation $V$.

**Table 1.** The variables and their basic statis

| Variables | Description | $x$ | $x_{min}$ | $x_{max}$ | $SD$ | $V$ [%] |
|---|---|---|---|---|---|---|
| $x_1$ | Expected result on 400 m hurdles (s) | 51.26 | 48.19 | 53.60 | 1.21 | 2.4 |
| $x_2$ | Age (years) | 22.3 | 19.0 | 27.0 | 2.0 | 8.8 |
| $x_3$ | Body height (cm) | 185.04 | 177.00 | 192.00 | 4.70 | 2.5 |
| $x_4$ | Body weight (cm) | 74.20 | 69.00 | 82.00 | 2.71 | 3.6 |
| $x_5$ | Current result on 400 m hurdles (s) | 51.91 | 48.70 | 54.70 | 1.37 | 2.6 |
| $y_1$ | Maximal speed (m) | 4,184.5 | 1,530.0 | 9,650.0 | 1735.7 | 41.5 |
| $y_2$ | Technical speed (m) | 5,244.3 | 300.0 | 11,790.0 | 2,921.9 | 55.7 |
| $y_3$ | Technical and speed exercises (m) | 4,253.3 | 240.0 | 9,450.0 | 1,752.8 | 41.2 |
| $y_4$ | Speed endurance (m) | 12,655.0 | 2,850.0 | 98,900.0 | 13,744.2 | 108.6 |
| $y_5$ | Specific hurdle (anaerobic) endurance (m) | 12,687.7 | 800.0 | 23,700.0 | 5,023.4 | 39.6 |
| $y_6$ | Pace (tempo) runs (m) | 163,796.3 | 88,000.0 | 393,800.0 | 60,101.9 | 36.7 |
| $y_7$ | Aerobic endurance (m) | 363,257.8 | 151,000.0 | 692,500.0 | 97,180.0 | 26.8 |
| $y_8$ | Strength endurance I (m) | 26,070.8 | 1,000.0 | 68,990.0 | 14,923.8 | 57.2 |
| $y_9$ | Strength endurance II (amount) | 5,999.5 | 300.0 | 40,110.0 | 6,065.7 | 101.1 |
| $y_{10}$ | General strength of lower limbs (kg) | 124,060.4 | 40,100.0 | 318,610.0 | 70,776.5 | 57.1 |
| $y_{11}$ | Directed strength of lower limbs (kg) | 58,379.2 | 8,240.0 | 134,400.0 | 25,912.3 | 44.4 |
| $y_{12}$ | Specific strength of lower limbs (kg) | 41,659.9 | 7,810.0 | 272,750.0 | 40,685.1 | 97.7 |
| $y_{13}$ | Trunk strength (amount) | 46,438.7 | 6,100.0 | 233,680.0 | 44,496.7 | 95.8 |
| $y_{14}$ | Upper body strength (kg) | 3,305.8 | 760.0 | 29,610.0 | 4,151.1 | 125.6 |
| $y_{15}$ | Explosive strength of lower limbs (amount) | 824.0 | 282.0 | 2,138.0 | 350.9 | 42.6 |
| $y_{16}$ | Explosive strength of upper limbs (amount) | 443.7 | 60.0 | 1,360.0 | 277.9 | 62.6 |
| $y_{17}$ | Technical exercises – walking pace (min) | 424.9 | 45.0 | 816.0 | 233.3 | 54.9 |
| $y_{18}$ | Technical exercises running pace (min) | 518.8 | 150.0 | 1,500.0 | 271.3 | 52.3 |
| $y_{19}$ | Runs over 1–3 hurdles (amount) | 95.6 | 23.0 | 231.0 | 40.3 | 42.2 |
| $y_{20}$ | Runs over 4–7 hurdles (amount) | 169.5 | 8.0 | 336.0 | 69.3 | 40.9 |
| $y_{21}$ | Runs over 8–12 hurdles (amount) | 151.6 | 32.0 | 377.0 | 87.7 | 57.8 |
| $y_{22}$ | Hurdle runs in varied rhythm (amount) | 857.0 | 36.0 | 1,680.0 | 360.2 | 42.0 |

This study uses artificial neural networks in the form of the multilayer perceptron (MLP) and the radial basis function (RBF). Multilayer perceptron is the most common type of artificial neural networks (Bishop, 2006). During MLP training, exponential and hyperbolic tangent function were used as the activation functions of hidden neurons. The feature of RBF network is the fact that the hidden neuron performs as a basis function that changes radially around the selected center. All the analysed networks have one hidden layer. For the implementation of neural networks, StatSoft STATISTICA software was used (Statsoft, 2011). The cross-validation method was implemented using Visual Basic language.

The models presented in this paper were evaluated by leave-one-out cross-validation (LOOCV) (Arlot, Celisse, 2010). The idea of this method is based on the separation from data set $n$ subsets, where $n$ is the number of all patterns. Each subset is formed by removing from the data set only one pair, which becomes the testing pair. The cross validation error ($CVE$) is expressed by the formula:

$$NRMSE_j = \frac{\sqrt{\frac{1}{n}\sum_{i=1}^{n}(y_{ij} - \hat{y}_{-ij})^2}}{y_{j_{max}} - y_{j_{min}}} \cdot 100,$$

$$CVE = \frac{1}{r}\sum_{j=1}^{r} NRMSE_j,$$

where: $NRMSE_j$ – the normalized root mean square error for the $j$-th output, $r$ – the number of outputs, $n = 48$ – the number of patterns, $y_{ij}$ – the real (measured) value, $\hat{y}_{-ij}$ – the output value constructed in the $i$-th step of cross-validation based on a data set containing no testing pair ($x_i$, $y_i$), $y_{jmax}$ – the maximal value of the $j$-th training load, $y_{jmin}$ – the minimal value of the $j$-th training load.

## Results with discussion

The main aspect of supporting sport training presented in this study is generating training loads for selected parameters of an athlete. In this way, the proposed approach allows, among others, for individualization of a training plan (Bompa, Haff, 1999).

Taking into consideration various topologies of networks, an optimal multi-layer perceptron was calculated. This model has 5 neurons in the hidden layer and hyperbolic tangent activation function. Compared to the best model with an exponential function it is superior because it generates the error smaller by 0.2%. The best perceptron generates the annual training plan with the error $CVE$ = 19.95% (Figure 2). The optimal RBF network has 5 hidden neurons and $CVE$ = 19.34%. This result is better than that obtained for the MLP networks. Therefore, as the optimal method, the RBF network with five hidden neurons was used.

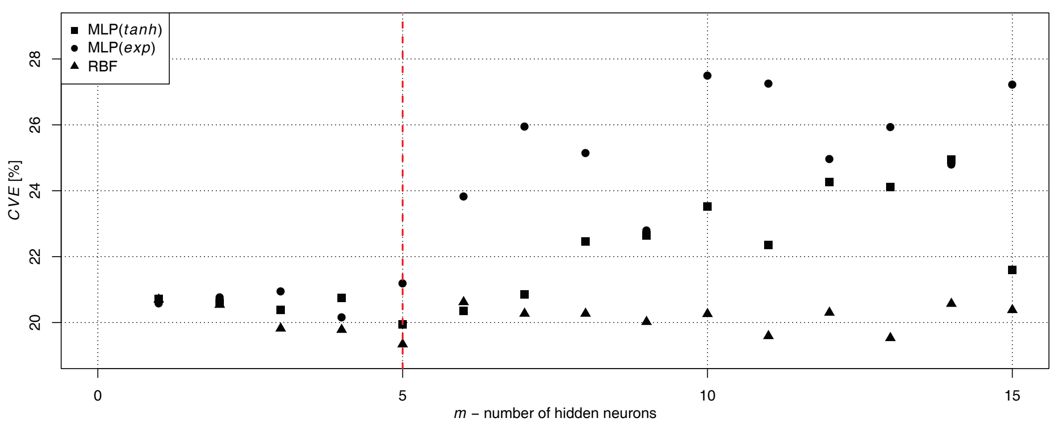



**Figure 2.** *CVE* error for artificial neural networks

The optimal model was analysed to determine the errors generated for different outputs, which allowed to identify which training means are generated with the smallest error (Table 2). The detailed analysis showed that $y_4$, $y_9$ and $y_{14}$

(speed endurance, strength endurance II, upper body strength) are generated with the highest accuracy ($NRMSE_j$ at the level of 14–15%), whereas the output representing technical exercises in march ($y_{17}$) has the largest error (30%).

**Table 2.** Errors for the outputs of the RBF network

| Variable | $y_1$ | $y_2$ | $y_3$ | $y_4$ | $y_5$ | $y_6$ | $y_7$ | $y_8$ | $y_9$ | $y_{10}$ | $y_{11}$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| $NRMSE_j$ [%] | 17.28 | 20.90 | 17.97 | 14.73 | 20.44 | 20.26 | 18.55 | 15.37 | 14.11 | 21.74 | 18.02 |
| Variable | $y_{12}$ | $y_{13}$ | $y_{14}$ | $y_{15}$ | $y_{16}$ | $y_{17}$ | $y_{18}$ | $y_{19}$ | $y_{20}$ | $y_{21}$ | $y_{22}$ |
| $NRMSE_j$ [%] | 16.02 | 20.25 | 14.63 | 20.81 | 21.41 | 29.95 | 21.58 | 19.96 | 20.55 | 22.38 | 18.47 |

The chosen neural network was tested by generating training plans for a hypothetical athlete (age: 21 years, body height: 185 cm, weight 75 kg). In every case the result was expected to improve by one second as a result of accepting the output from 56 to 49 seconds.

Training loads forming speed ($y_1$–$y_3$) are very similar in nature (Figure 3). At the beginning of an athlete's career, the highest content of these loads can be noted, and with their increasing competitive level, a decrease in loads (until the competitor achieves 51 s), can be observed. While obtaining the best results, the rates of training loads influencing speed go up with increasing sports level.

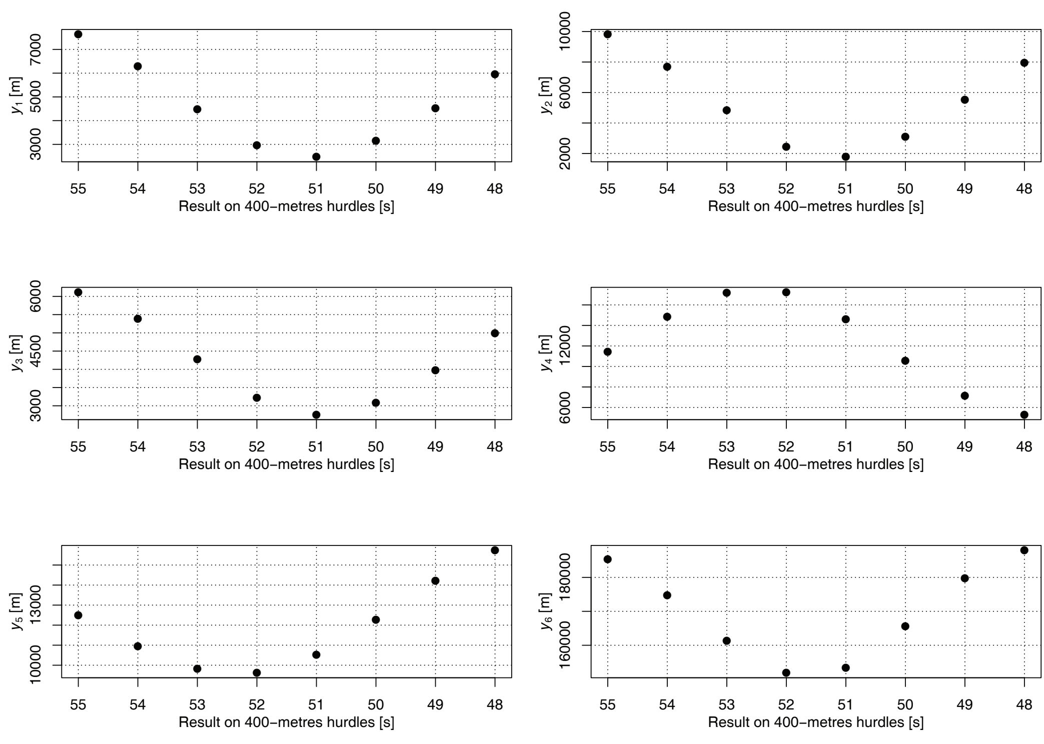
The 400 m hurdles race is still a sprint distance so the need for speed training is the priority, but requires a variety of assessments in terms of a year-round and long-term cycle of preparation. For "high-speed" hurdlers short races can be an important part of training, but in the group of other hurdlers ("endurance" and "rhythm" type) maximum speed exercises are only additional to the basic training (Iskra, 2012b; Balsalobre-Fernández, Tejero-González, del Campo-Vecino, Alonso-Curiel, 2013). Analyses show a characteristic tendency to reduce the importance of speed training in the middle phase of the development of a sports career with a return to speed exercises for the highest performance ($y_1$–$y_3$). This fact can be explained, on the one hand, by a particular emphasis on anaerobic exercise during the period of "growing up" to athletic championship level, and, on the other hand, by shortening distance of training at the final, highest phase. Such tendencies can be observed in the analysis of the content of training of the best Polish hurdlers who have been competing for many years (Iskra, Widera, 2001).

In the group of endurance training loads ($y_4$–$y_7$) two trends of changes depending on the level of training (Figure 3) were observed. The content of exercises that form speed endurance ($y_4$) and aerobic endurance ($y_7$) increases when the athlete obtains average results (up to 52–51 s), while at a later phase, when his/her form is improving, the value of these loads is consistently declining. Other training loads related to strength have similar tendencies to the speed loads. The values of these loads ($y_5$, $y_6$) at the beginning gradually decrease until the competitor achieves 52 s. The values start rising with the increasing competitive level of the athlete.

The whole essence of the running training of a 400 m hurdler, supported by research in the physiology of physical effort, lies in the statement above. The 400 m hurdles distance is a typical anaerobic effort, for which the value of lactate amounts to 20 mmol/l (Ward-Smith, 1997; Gupta, Goswami, Mukhopadhyay, 1999; Zouhal et al., 2010). Therefore, the best, in terms of motor skills, competitors use specific training means at the prime time of their career. Including "alternative" sets of exercises of reduced intensity in this period (the so-called "tempo endurance" system) can be explained by the difficult conditions for Polish winter training, which encourages coaches to reduce the speed of races in favor of training intensity (Iskra, Przednowek, 2016).

Another group of generated training loads included exercises developing strength endurance ($y_8$, $y_9$). In both cases, an increase in the work performed in the early phases of a career can be observed, whereas after reaching the value of 51 s the number of these exercises decreases. Many coaches believe that endurance-strength exercises, are typical of the best athletes (Hiserman, 2008). The test results did not confirm this thesis. Perhaps the commonly accepted theories in respect of training periodization should be verified.

The most diverse group of training loads used in the training of a 400 m hurdler are exercises for strength ($y_{10}$–$y_{16}$) (Figure 3–4). This group includes seven types of loads measured in kilograms, and the number of repetitions. In preparing the competitor, the right strength training, primarily of the lower limbs, is very important. In the generated training loads, the first three relate to the strength of the lower limbs (general strength – $y_{10}$; direct strength – $y_{11}$; specific strength – $y_{12}$). Training loads $y_{10}$–$y_{11}$ at the beginning of an athlete's career increase in content, until the athlete achieves 51 s. The content of these exercises remains at a more or less stable level as the athlete's competitive level increases. Characteristic changes in the content of training relate to specific strength ($y_{12}$), which is relevant only in the training of hurdlers. The value of the training load in the early phases of a career oscillates at the highest value, while its value declines after achieving 51 s. When analysing the trunk strength ($y_{13}$) it can be observed that the loads increase up to a result of 51 s; they then decrease until the athlete reaches the championship level. Different in nature are changes in loads of the upper limbs and the shoulder girdle ($y_{14}$). These loads decrease at the beginning of an athlete's career while at a higher level of training their value gradually increases with the increasing competitive level.



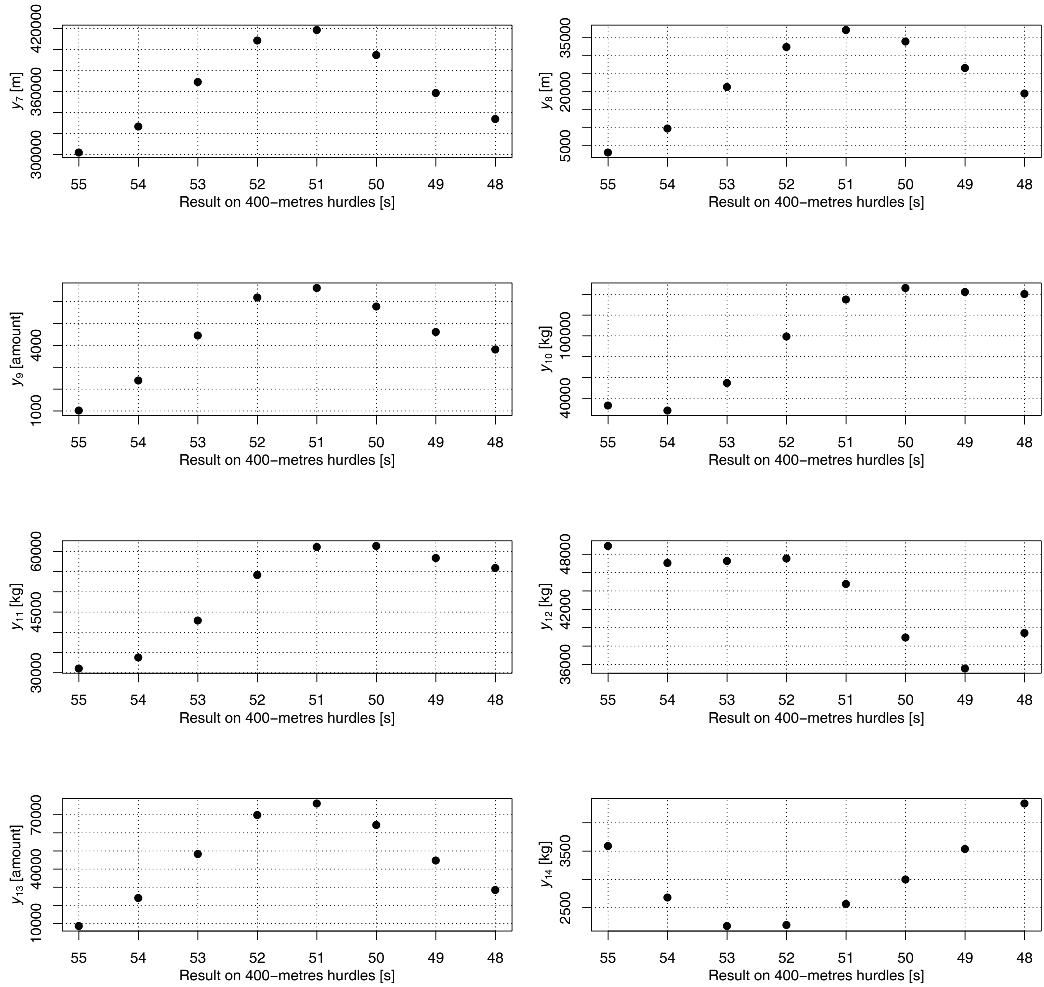


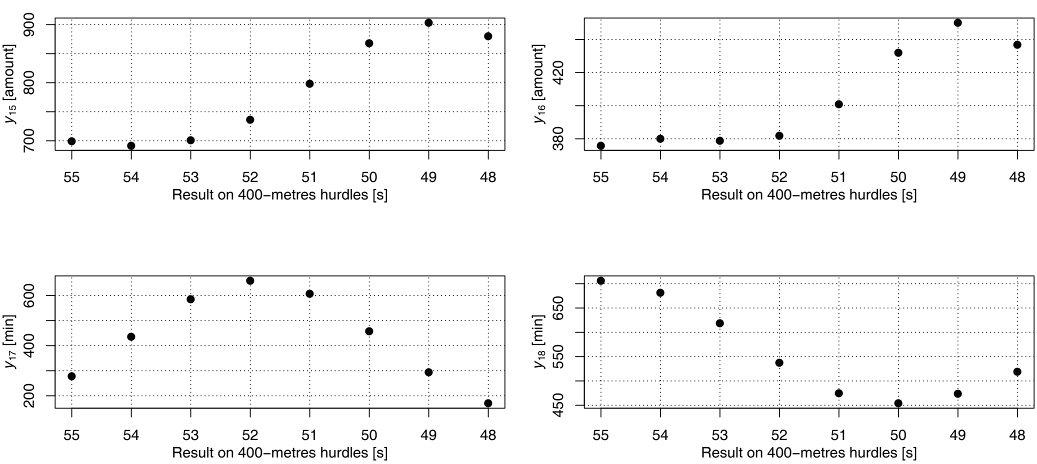

**Figure 3.** Training loads $y_1$–$y_{14}$ generated for results from 55 s to 48 s

Changes in the content of strength and speed exercises of lower and upper limbs ($y_{15}$, $y_{16}$) have similar variability (Figure 4). At first the changes are very small and the level of the loads is relatively small. The content of these loads is increasingly going up only when the competitor achieves results of 52 s. At the championship level the loads stabilize at a high level.

Improvement of the strength capacity in athletics speed races is now one of the trends in searching opportunities to improve results. It is mentioned by the classics of the theory of sports training (Bompa, Haff, 1999; Sozański, Sadowski, Czerwinski, 2015) and the best coaches of this sport (Smith, 2005; Husbands, 2013). The results of the analyses in the group of the best Polish hurdlers do not confirm entirely this trend. Only the basic strength training exercises of the lower limbs from the “average” level remain at the same high level ($y_{10}$–$y_{11}$). Attention should be paid to the growing importance of strength training exercises of a dynamic character, which at the highest phase of athletic championship take up significant content of training. This applies to both lower limbs and upper muscle groups. The emphasis on dynamic exercises is consistent with the speed-strength character of sprint effort.

The last group (Figure 4) of generated training loads are exercises shaping the technique and the so-called “hurdles rhythm” (runs in standard conditions over 1–12 hurdles) – ($y_{17}$–$y_{22}$). Changes in the content of training of technical exercises in walking ($y_{17}$) and hurdling exercises over 8–12 hurdles ($y_{21}$) are very similar. Training loads grow until the athlete obtains a score between 52 and 51 s, then with increasing competitive level their content decreases. In contrast, while considering the technical exercises performed in the run ($y_{18}$), it is noted that the largest content is observed at the lowest competitive level and along with its growth the content of the loads increases. At the highest competitive level the content of this load increases slightly. Taking into consideration the hurdling exercises over 4–7 hurdles ($y_{21}$) it is noted that the increase in competitive level follows the increase of the content of the loads. At the championship level the value of these exercises decreases. The analysis also showed that jumping 1–3 hurdles ($y_{19}$) and races with a varied rhythm ($y_{22}$) have very similar dynamics throughout the duration of an athlete’s career. Initially, the content diminishes and at the championship level the content is gradually increasing.

Training sessions including hurdles are specific for this competition form of training. Most analyses of training loads of a 400 m hurdler concentrate on this group of training means (Brejzer, Wróblewski, Koźmin, 1984; Iskra, 2001). The results indicate, however, differences in application of particular groups of exercises. At the initial phase of training, jumps over 1–3 hurdles and specific exercises in a diverse rhythm are preferred. This part of the analysis fully confirms the trends in training young people (Otsuka, Ito, Ito, 2010; Iskra, 2012a). During further development of a sporting career the best Polish hurdlers prefer jumping 4–12 hurdles which, according to coaches, is the basis for success in this athletics races (McFarlane, 2000; Iskra, 2012; Hiserman, 2008). From the point of view of training, the changes in the selection of hurdling exercises at the highest levels are interesting. Hurdlers at the championship level, give up the longer forms of running, returning to the exercises from the beginning of a sports career.



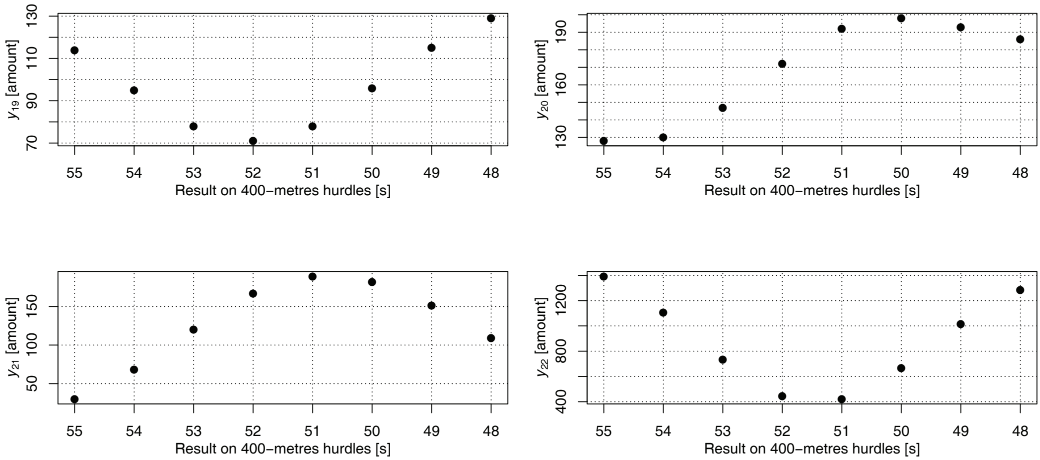



**Figure 3.** Training loads $y_{15}$–$y_{22}$ generated for results from 55 s to 48 s

## Conclusions

Trend analysis of training loads shows non-linear changes in the content of training. In most cases, at some phase, there is an increase of training loads, and at a later phase of an athletic career there is a reduction or stabilization at a similar level. This observation is important in the organization of a hurdler's training. The analysis allows to formulate the following conclusions:

1. Analysis of training loads in the multi-cycle training of 400 m hurdlers made it possible to establish the main training emphasis of 22 analysed groups of exercises.

2. The results show that at each phase of training (basic training, the period of obtaining significant outcomes and the period of athletic mastery) the structure of training loads is different.

3. The initial period is dominated by speed and jumping exercises, during the development of athletic mastery various forms of strength endurance and runs over 8–12 hurdles are focused on, and at the time of obtaining record results anaerobic endurance is predominant, along with basic strength exercises and runs over 4–7 hurdles.

4. Long-term analyses of the training loads of the best Polish 400 m hurdlers can be helpful in organizing training of competitors at different levels.

Future work will include, among others, construction of the interface for coaches and competitors. In addition, other methods of machine learning will be verified in the implementation of generating training. The authors are also planning to construct models for specific training periods, e.g. direct pre-competition preparation.

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# DISTANCE COVERED BELOW AND ABOVE THE ANAEROBIC THRESHOLD BY ELITE GERMAN GOALKEEPERS

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**Abstract** The study aimed to assess the total covered distance during a match, performance volume below and above the anaerobic threshold, as well as characterize physical activities of professional Bundesliga goalkeepers during soccer matches. 34 goalkeepers (606 observations) from all eighteen Bundesliga teams, who played in the 2014/2015 season were considered for the study. The performance of goalkeepers was analyzed with the use of the VIS.TRACK system. The variables measured included: total covered distance [km] in the whole match, the first half, and the second half; distance covered below and above the anaerobic threshold ($4 \text{ m} \cdot \text{s}^{-1}$) [km]; and distance covered in six intensity ranges [km]. The total distance covered by the goalkeepers was 5.48 ±0.56 km. The distance covered by goalkeepers below the anaerobic threshold was 5.28 ±0.52 km, whereas the distance covered above the anaerobic threshold amounted to 0.21 ±0.09 km. The ratio between the goalkeepers' volumes of aerobic and anaerobic performance was 25:1. The total distance covered by goalkeepers in match play and the distances covered by goalkeepers below and above the anaerobic threshold (96.17% and 3.83%, respectively) indicate that during a match the goalkeepers undertake predominantly aerobic exercises.

**Key words** soccer, goalkeeper, anaerobic threshold, Bundesliga, covered distance

## Introduction

Modern association football demands high levels of physical preparation from goalkeepers (Hazir, 2010; Boone, Vaeyens, Steyaert, Vanden Bossche, Bourgois, 2012; Chmura et al., 2015). More and more often, goalkeepers tend to cooperate with different players in all other positions and engage in offensive actions outside the penalty area (Szwarc, Lipińska, Chamera, 2010). This is related to the goalkeepers' necessity to perform a greater number of activities of variable intensity such as sprinting, low-, moderate- and high-speed running, jogging, walking and standing (Di Salvo, Benito, Calderón, Di Salvo, Pigozzi, 2008). It also affects the changes in the distance covered by goalkeepers during a match. According to Chmura et al. (2015) covered distance is one of practical measures of players' endurance capacity. Boone, Vaeyens, Steyaert, Vanden Bossche, Bourgois (2012) showed that a goalkeeper covers a distance of 4 km during a single soccer match. Other authors showed that goalkeepers can run up to 5.65 km in a match (Di Salvo, Benito, Calderón, Di Salvo, Pigozzi, 2008; Ademović, Čolakhodžić, Talović, Kajmović, 2012; Chmura et al., 2012), and even, in some cases, up to 6.99 km (Bojkowski, Śliwowski, Wieczorek, Eider, 2015).

A goalkeeper's physical activity, like outfielders' activity, requires a proper level of aerobic capacity (Bravo et al., 2007; Hazir, 2010; Wiacek, Andrzejewski, Chmura, Zubrzycki, 2011; Alghannam, 2012; Boone, Vaeyens, Steyaert, Vanden Bossche, Bourgois, 2012). It should be noted that 73% of distance covered by goalkeepers is walking (0.3 – 7.2 km • $h^{-1}$) (Di Salvo, Benito, Calderón, Di Salvo, Pigozzi, 2008). According to Di Salvo, Benito, Calderón, Di Salvo, Pigozzi (2008) and Ademović, Čolakhodžić, Talović, Kajmović (2012) goalkeepers also perform from 2.00 ±2.00 to 8.10 ±5.58 sprints in a game, as well as numerous other short-lasting and explosive motor activities such as jumps, digs, and ball catches (Hazir, 2010). Fast game play during which players perform many high-intensity actions involves a great deal of anaerobic energy metabolism (Bravo et al., 2007; Hazir, 2010; Wiacek, Andrzejewski, Chmura, Zubrzycki, 2011; Alghannam, 2012; Boone, Vaeyens, Steyaert, Vanden Bossche, Bourgois, 2012). Thus, like in outfielders, the goalkeepers' level of anaerobic capacity is also highly significant.

Determining exercise intensity at the anaerobic threshold (AT) is crucial in training practice (Chmura et al., 2015). There are different methods of determining AT, which occurs at 4 mmol • $l^{-1}$ of lactate concentration (Keul, Dickhuth, Berg, Lehmann, Huber, 1981; Magiera, Janczak, Niemierzycka, Cabak, Zbrodowska, 2006). The anaerobic threshold also appears frequently during running at 4 m • $s^{-1}$ (Śliwowski et al., 2013; Chmura et al., 2015; Andrzejewski, Konefał, Chmura, Kowalczuk, Chmura, 2016). Crossing the AT leads to rapid accumulation of metabolic acidosis and blood lactate (Śliwowski et al., 2013; Chmura et al., 2015; Andrzejewski, Konefał, Chmura, Kowalczuk, Chmura, 2016).

During a soccer match players perform efforts above and below the anaerobic threshold. Each short-term maximal intensity exercise is regarded as an above-the-threshold effort. The performance of such exercise by soccer players may lead to an increase in lactate blood level to 14 mmol • $l^{-1}$ (Bishop, Girard, 2013). During match play a goalkeeper must maintain a high level of mobilization and concentration, quickly react to audiovisual stimuli, make optimal decisions, and display a high level of differentiation between important and unimportant stimuli. All of these capacities can be only reached, if a goalkeeper is able to cross the anaerobic threshold at an exercise intensity close to psychomotor fatigue threshold (PFT) (Chmura, Nazar, Kaciuba-Uściłko, 2007; Chmura, Wiśnik, 2008; Chmura, Nazar, 2010).

Research provides numerous data on the total distance covered by goalkeepers. There have not been, however, studies on the total distance covered by goalkeepers in the first half and the second half of the match, and on the distance covered below and above the anaerobic threshold. There have been also few studies on the range of intensity of activities performed by goalkeepers. Such data are of key significance for the optimization of goalkeeping training. The aim of the present study was to determine the total distance covered below and above the anaerobic threshold, and to analyze physical activities by professional German goalkeepers during actual competitive matches.

## Material and methods

The study group consisted of 34 goalkeepers (606 observations, 34 rounds) representing all eighteen German Bundesliga teams in the 2014/2015 season. Only goalkeepers who played the whole matches were examined. They were 26.79 ±4.05 years of age, 189.64 ±3.32 cm of body height, 84.73 ±4.96 kg of body mass, and BMI of 23.55 ±1.03 kg/m$^2$. The study did not require the players' informed consent as it was carried out by an external company (IMPIRE AG).

Goalkeepers' activity was assessed using the VIS.TRACK system (IMPIRE AG, Germany) using the recording frequency of 25 Hz. Each goalkeeper's movement was recorded by two cameras (Link, Weber, 2015). The VIS.TRACK system uses the state-of-the-art algorithms and 2D and 3D video recording technology, allowing a detailed motion analysis of entire soccer matches (www.impire.de). The system can analyze the covered distance, running speed and actions in match play, also acknowledging players' performance below and above the anaerobic threshold amounting to 4 m • s$^{-1}$ (Śliwowski et al., 2013; Chmura et al., 2015). The reliability and accuracy of the VIS.TRACK system have been attested by various authors (Tiedemann, Francksen, Latacz-Lohmann, 2010; Stulp, Kordsmeyer, Buunk, Verhulst, 2012; Chmura et al., 2015; Link, Weber, 2015).

The following variables were subject to analysis: total covered distance [km] during the whole match, in the first half, and in the second half; distance covered [km] below and above the anaerobic threshold [km] in six intensity ranges: 0–11 km • h$^{-1}$, 11–14 km • h$^{-1}$, 14–17 km • h$^{-1}$, 17–21 km • h$^{-1}$, 21–24 km • h$^{-1}$, and ≥24 km • h$^{-1}$; percent of the covered distance below and above the AT in the entire match; and ratio between aerobic and anaerobic performance volume. Additionally, the percent of covered distance in individual intensity ranges was also calculated.

For all examined variables their conformity with normal distribution was checked with the Kolmogorov-Smirnov test ($p > 0.2$). Arithmetic means, standard deviations and minimum and maximum values were calculated. Student's t-test was used to compare the covered distances in the first and the second halves. The level of statistical significance was set at $p \leq 0.05$. All statistical calculations were made with STATISTICA 12.0.

## Results

The analysis revealed that the total distance covered by the goalkeepers was 5.48 ±0.56 km (min – 3.77 km, max – 6.92 km). The mean covered distance in the first half was 2.74 ±0.29 km, and in the second 2.75 ±0.32 km. No statistically significant differences were found between the covered distances in the first and the second halves of the match (Figure 1).

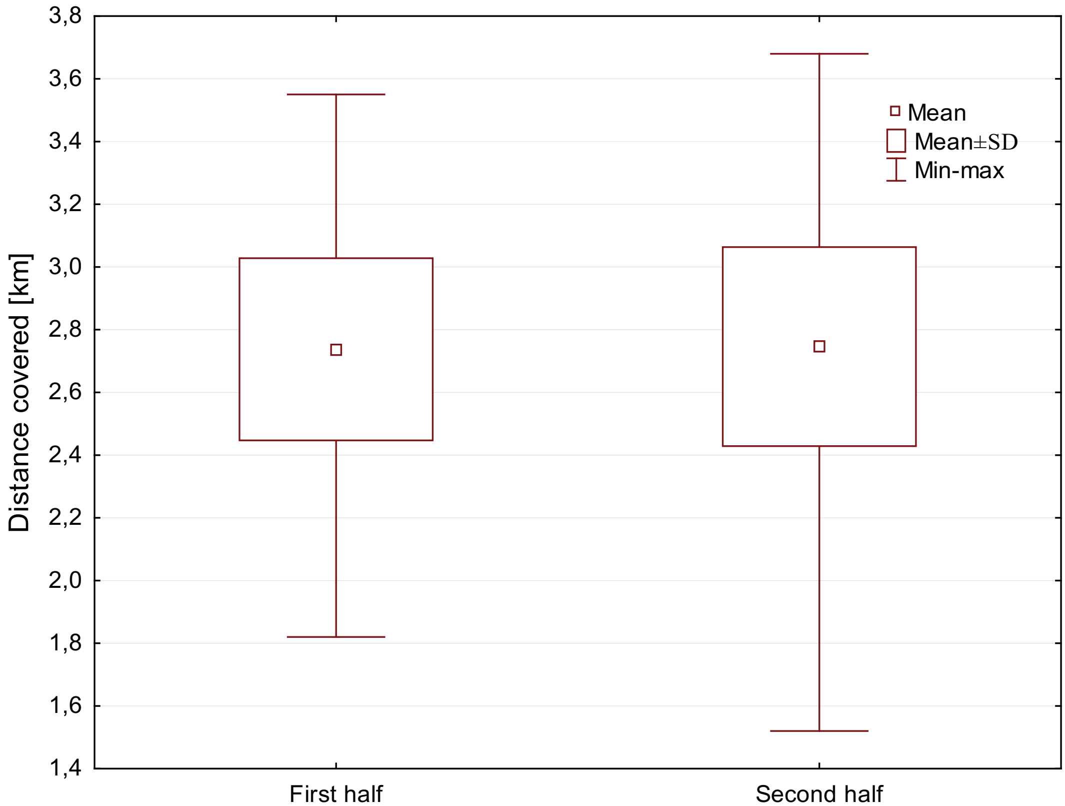


**Figure 1.** Differences in distance covered by goalkeepers in the first and the second halves of the match

The distance covered by goalkeepers below the anaerobic threshold amounted to 5.28 ±0.52 km, i.e. 96.17% of total covered distance (min – 3.57 km, max – 6.64 km). The distance covered by goalkeepers above the AT was 0.21 ±0.09 km, i.e. 3.83% of total covered distance (from 0.03 km to 0.58 km). The ratio between aerobic and anaerobic performance volume was 25:1.

The studied goalkeepers covered the distance of 4.92 ±0.47 km at 0–11 km • $h^{-1}$ (89.86 ±3.01% of total covered distance); 0.33 ±0.11 km (5.95 ±1.71%) at 11–14 km • $h^{-1}$; 0.14 ±0.06 km (2.59 ±0.89%) at 14–17 km • $h^{-1}$; 0.07 ±0.04 km (1.22 ±0.58%) at 17–21 km • $h^{-1}$; 0.02 ±0.01 km (0.29 ±0.25%) at 21–24 km • $h^{-1}$; and 0.01 ±0.01 km at ≥ 24 km • $h^{-1}$ (0.10 ±0.18%) (Table 1).

**Table 1.** Mean distances covered by goalkeepers during a Bundesliga match

| Intensity range | Distance covered [km] | | | Distance covered [%] | | |
|---|---|---|---|---|---|---|
| [km • h⁻¹] | x̄ ± SD | Min. | Max. | x̄ ± SD | Min. | Max. |
| < 11 | 4.92 ±0.47 | 3.33 | 6.13 | 89.86 ±3.01 | 79.00 | 96.50 |
| 11–14 | 0.33 ±0.11 | 0.10 | 0.73 | 5.95 ±1.71 | 2.10 | 11.20 |
| 14–17 | 0.14 ±0.06 | 0.03 | 0.36 | 2.59 ±0.89 | 0.60 | 5.50 |
| 17–21 | 0.07 ±0.04 | 0.00 | 0.24 | 1.22 ±0.58 | 0.10 | 3.80 |
| 21–24 | 0.02 ±0.01 | 0.00 | 0.10 | 0.29 ±0.25 | 0.00 | 1.70 |
| > 24 | 0.01 ±0.01 | 0.00 | 0.09 | 0.10 ±0.18 | 0.00 | 1.40 |

## Discussion

In recent years increased game speed and distance covered by goalkeepers have been observed in soccer competitions (Ademović, Čolakhodžić, Talović, Kajmović, 2012). The results of the present study show that goalkeepers playing in the German Budesliga in the 2014/2015 season covered the distance of 5.48 ±0.56 km, with the longest recorded distance of 6.92 km. These results correspond to the findings of Di Salvo, Benito, Calderón, Di Salvo, Pigozzi (2008) in the English Premier League (5.61 ±0.61 km). Bojkowski et al. (2015) noted that goalkeepers taking part in the 2014 World Cup covered the mean distance of 5.65 km, with the longest distance of 6.99 km. This indicates that goalkeepers covered a two-time shorter distance that the outfielders (Andrzejewski, Chmura, Pluta, Kasprzak, 2012; Di Salvo, Baron, Tschan, Calderon Montero, Bachl, Pigozzi, 2007; Ionică, 2013; Soroka, 2013). The present study did not reveal statistically significant differences between the distances covered by a goalkeeper in the first and the second half of the match. Similar observations were made by Di Salvo, Benito, Calderón, Di Salvo, Pigozzi (2008), which indicates that goalkeepers' performance in both match halves is at similar level. Alghannam (2012) found that the distance covered by outfielders in the second half of a match decreases due to their increased fatigue. Considering the distance covered in both halves of the match, differences in performed physical activities can be noted between goalkeepers and outfielders (Di Salvo, Baron, Tschan, Calderon Montero, Bachl, Pigozzi, 2007; Di Salvo, Benito, Calderón, Di Salvo, Pigozzi, 2008; Andrzejewski, Chmura, Pluta, Kasprzak, 2012).

During a match a goalkeeper performs both aerobic and anaerobic activities. The former is confirmed by the distance covered below the anaerobic threshold, which amounted to 5.28 ±0.52 km in the present study, i.e. 96.17 % of the total covered distance. A goalkeeper, therefore, mostly performs exercises below the anaerobic threshold. The analysis of goalkeepers' activities above the anaerobic threshold showed that the studied Bundesliga goalkeepers covered 0.21 ±0.09 km during a match, i.e. 3.83% of total covered distance. The level of anaerobic exercise performed by goalkeepers is eight-times lower than that of outfielders. This is confirmed by Ionică (2013), who revealed that anaerobic performance by all players amounted to 30% of all match activity. The present study only focused on covered distance; however, it did not consider such goalkeepers' activities as jumps, digs and ball catches, which are definitely anaerobic exercises characteristic for goalkeepers. Since goalkeepers perform a great number of such exercises during a game, which also generate anaerobic power, the percent of anaerobic exercises by all team players can be even lower. Due to the frequent performance of short-duration activities by goalkeepers, their training must account for development of power and explosive strength (Chmura, Chmura, Ciastoń, 2008). Data on distance covered below and above the anaerobic threshold during a match reveal the aerobic to anaerobic exercise ratio of 25:1. This underlines the significance of aerobic processes for goalkeepers' motor preparation. The proper aerobic to anaerobic exercise ratio can also improve the effectiveness of power and explosive strength training (Chmura, Chmura, Ciastoń, 2008).

The goalkeeper's performance is also characterized by the distance covered in match play at various running intensities. The analysis showed that the distances of 4.92 ±0.47 km covered by goalkeepers below 11 km • $h^{-1}$, (89.86 ±3.01%) and 0.33 ±0.11 km at 11–14 km • $h^{1}$ (5.95 ±1.71%) constitute together 95.63% of the total covered distance. Similar results were obtained by Ademović, Čolakhodžić, Talović, Kajmović (2012). Moreover, Soroka (2013) noted that depending on game tactics, goalkeepers cover from 3.53 km to 3.72 km at ≤ 11 km • $h^{-1}$, and from 0.23 km to 0.25 km at 11 ≤ 14 km • $h^{-1}$, i.e. 90% of total covered distance during the entire match. In the present study the Bundesliga goalkeepers covered 4.37% of the total distance in the intensity range from 14 km • $h^{-1}$ to above 24 km • $h^{-1}$, similarly to Di Salvo, Benito, Calderón, Di Salvo, Pigozzi (2008). Despite the uses of different systems of motion analysis in different studies, the results concerning covered distances in different intensity ranges are similar (Di Salvo, Benito, Calderón, Di Salvo, Pigozzi, 2008; Ademović, Čolakhodžić, Talović, Kajmović, 2012; Soroka, 2013). The obtained data on distances covered by goalkeepers in six intensity ranges show that the higher intensity of exercise goalkeepers tend to cover shorter distances.

## Practical application

Appropriate anaerobic training of soccer players based on aerobic foundations can be a significant determinant of match outcome. A goalkeeper who performs activities at a high maximal oxygen uptake, crosses the anaerobic threshold, maintains exercise intensity between the anaerobic threshold and the threshold of psychomotor fatigue, is able to quickly respond to rapidly changing situations in match play, including shots at goal. Activities performed by soccer players, including goalkeepers, between the two thresholds increase reaction speed, accuracy and concentration (Chmura, Wiśnik, 2008; Chmura, Nazar, 2010). However, in match conditions goalkeepers are not often forced to undertake exercises of such intensities. Thus coaches should draw goalkeepers' attention to the necessity of performing stimulating exercises allowing crossing the anaerobic threshold. Goalkeepers' pre-competitive preparation should accommodate endurance-speed training to enhance the tolerance of incremental fatigue.

## Conclusions

1. The total distance covered by goalkeepers in a match and the distances covered by goalkeepers below and above the anaerobic threshold (96.17% and 3.83%, respectively) indicate that during a soccer match goalkeepers undertake predominantly aerobic exercises.

2. Similar distances covered by goalkeepers in the first and the second halves of the match are evidence of the similar levels of goalkeepers' activity in both halves of the match.

3. The ratio between activities performed below and above the anaerobic threshold, amounting to 25:1, is a significant factor for modern goalkeeping training. Goalkeepers' preparation must account for the appropriate volume of aerobic and anaerobic training.

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# THE EFFECT OF FAST, LIGHT AND FAVORITE MUSIC ON PHYSIOLOGICAL FUNCTION AND PHYSICAL PERFORMANCE OF THE MALE ATHLETE STUDENTS

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**Abstract** Listening to music can be useful for athletic performance because of the similarities between the rhythm of the music and the movements of the human body. Given the ambiguity in the lead for better music, the goal of this study was to investigate the effect of fast, light and favorite music on physiological function and physical performance of the male athlete students. 25 healthy male athlete students with the age of 20.8 ±1.20 years, height of 180.5 ±7.02 cm and weight of 70.8 ±10.9 kg participated in this study voluntarily. The present study was a repeated based test (4 times without music, fast, light and favorite music in 4 consecutive weeks with a one week rest apart them to control the effects of fatigue during the test). Results showed that fast music caused a significant changes in anaerobic power, sprint, agility, muscular endurance, aerobic power, rating of perceived exertion (RPE) ($p < 0.05$). Also, favorite music caused significant changes in explosive power and agility ($p < 0.05$). But, light music just made significant effect on minimum power ($p < 0.05$). According to this study, it seems that listening to fast music before aerobic and anaerobic activities can be effective on maximum and submaximal functions.

**Key words** music, rating of perceived exertion, physical function, athlete

## Introduction

It has been shown that there are similarities between musical rhythm and movement patterns of the human body. So, matching the music with sport always increases the efficiency of the exercise participant. The relationship between music and mental physiological changes in the human body had been considered by scientists. History of research on the effects of music on motor behavior goes back to the beginning of the last century. In recent years, the use of music as a factor affecting on sports performance has attracted the attention of researchers in science (Nittono, Tsudakai, Nakajima, 2000). It has been shown that music impetuses for the strengthening or adapting the rhythm and movement. Four principal ways that music may develop athletic performance are; reduce fatigue (Van Eck et al., 1996), increase the level of mental arousal, improve coordination (Simpson, Karageorghis, 2006) and increase the sedation (Copeland, Franks, 1991). Some of the results of the effect of music on physiological improvements show things such as: changes in heart rate, breathing, blood pressure, levels of endorphins, skin reactions, brain waves, nervous system and the automatic nervous system controls and reduce physical pain (Schmidt Peters, 1991). Music increases the motivation of athletes to continue (Karageorghis, Drew, Terry, 1996) and fatigue will be delay by decreasing the amount of perceived exertion on the body (Smolen, Topp, Singer, 2002; Boutcher, Trenske, 1990). Based on current assumptions, the music narrowing attention and divert the mind from fatigue caused by lead, it changes mental arousal, it is a means of stimulating or sedative before or during activity and finally body react to the implementation rhythm of the music on submaximal activities (Costasi, Terry, 1997). Studies have shown that listening to music while performing physical activity can reduce stress (Copeland, Franks, 1991; Ghaderi, Rahimi, Azarbayjany, 2009) and increase understanding of the emotional state (Boutcher, Trenke, 1990). This effects may indirectly divert attention from internal signals (physical) to external signs (music) (Simpson, Karageorghis, 2006). So, listening to music during exercise can improve performance especially aerobic (Atkinson, Wilson, Eubank, 2004; Ghaderi, Rahimi, Azarbayjany, 2009) and anaerobic activities (McMordie, 2009; Simpson, Karageorghis, 2006). Music effectiveness, related to function and characteristic features of music listener, music with slow rhythm leads to relaxation and reduce tension in the listener (Labbe, Schmidt, Babin, Pharr, 2007) while fast-paced music is provocative and can increase muscles tension (Makoto, Asami, Chie, 2005) Barwood and colleagues (2009) reported that in terms of stimulating listening to music, attendees who were running on a treadmill can travel farther, they were less lactate accumulation and in contrast, perceived exertion did not change significantly (Barwood at al,. 2009). Crust and Clough (2006) in a study of young subjects rod performance in different conditions; such as light and fast music as a isometric, they showed that motivational music in compare with light and beat music can increase more endurance in goal (Crust, Clough, 2006). Koc (2009) searches in a review study to evaluate the effect of music on athletic performance. He noted that the overall positive effects of music can be physiological (heart rate, blood pressure and body temperature), psychological (perceived exertion) and even physical performance factors (sprint, power, endurance and aerobic capacity) (Koc, Turchian, 2009).

Research on the effects of music on submaximal and maximal exercise intensity is small and imprecise. Some of the findings showed that listening to music improves anaerobic performance (McMordie, 2009), but the type of music can be an exercise on peak power is effective or not? It is not exactly clear (Yamamoto, et al. 2003). Nittono and colleagues (2000) concluded that fast music can only be improved speed performance athletes (Nittono, Tsudakai, Nakajima, 2000). In contrast, Ferguson and colleagues (1994) demonstrated that both types of music (fast and slow) can improve performance in karate training (Ferguson, Carbonneau, Chambliss, 1994). Eliakim and colleagues (2007) study the effects of listening to music at 140 beats per minute during the warm-up began and the results showed that music can yield a significant effect during the Wingate test (Eliakim et al., 2007). Karageorghis and colleagues (2009) test for anaerobic Wingate to measure the elite volleyball players use, these individuals when exposed to favorite music with the rhythm 140 bpm ten minutes before the test Wingate were, increased peak anaerobic power in 5 seconds First Was seen. Based on these results, it seems that the motivation or acute favorite music during exercise can be effective and useful. Previous research has shown that listening to music during exercise by shifting attention to external signs (music), due to fatigue and discomfort associated with exercise, will prevent (Karageorghis et al., 2009; Nakamura et al., 2010). Yamamoto research on the effects of two types of music listening during the warm-up spicy looked on anaerobic performance Concluded between those who listened to music and those who have not heard, there is no significant difference (Yamamoto et al., 2003). Other findings showed that listening to music during anaerobic activities have no effect on performance (Pujol, Langenfeld, 1991; Karageorghis, Drew, Terry, 1996). According to a few studies with contradictory results in this field, this research aims to address the effects of listening to music with a fast pace, calm and understanding the desired pressure, aerobic and anaerobic power of male college athletes in check.

## Material and methods

In this quasi-experimental study, 25 healthy male athlete students at the age of 20.8 ±1.20 years, 180.5 ±7.02 cm and 70.8 ±10.9 kg voluntarily participated in this study. After explaining the test conditions, including the potential risks and sign individual consent by the subjects was performed. Study with a repeated-test (four times under the condition without music (control), play fast music, slow and arbitrary in four consecutive weeks with a one week rest (to control the effects of fatigue when tests) was conducted. According to the plan, no music in the first week, second week with fast music, light music in the third week and finally, fourth week to test with their favorite music. This study was in accordance with the guidelines of the University Institutional Review Board.

In this study, the agility test (4 • 9 m), explosive power (jump), muscular endurance (push up), sprint (60 m), anaerobic power (RAST) and aerobic power test (1600 meters or one mile) were used. Test sessions were held between 8:30 to 11:30 am with an interval of one week between each step. 48 hours before the test participants were prevented from doing strenuous activity. Participants before the test sessions were identical meals. Also, all participants 12 hours before the tests deprive from eating any food and banned consumption of caffeine substance (26). The average temperature of the test in all four phases 25°C ±2 were recorded. In each trial participants used the same clothes. Before starting the meeting, a briefing to learn about test conditions and learning how to express RPE during exercise were allocated for subjects. Also, it was considered that none of the participants had trouble in hearing.

All the tests in 4 steps without music, fast music, slow and arbitrary were conducted in four consecutive weeks. Before starting the test, the subjects took 15 minutes to warm up.

Agility test (4 • 9 m): This test is used to assess the general agility. The best record of the subject was recorded using a chronometer (Q&Q, Japan).

Explosive power test (long jump): This test is intended to measure explosive power. The test was repeated three times for each subject and the best record was considered. Between each trial, 3–5 min interval was considered.

Muscular Endurance test (push up): This test is used to measure muscular endurance. The movements without pause were performed by subject for 30 seconds and full repetitions were recorded.

Sprint test (60 m): In a straight line with a distance of 60 meters was used to measure speed. The participants ran the distance and theirs time were recorded by a stopwatch (Q&Q, Japan).

Anaerobic power test (RAST): RAST test is similar to Wingate bike test to measure power and fatigue index is used. Times were taken for 6 × 35 meters with 10 seconds rest between them, using a stopwatch (Q&Q, Japan) for each subject separately and the four indices calculated using the following formula (Alex, Adelino, Claudio, 2008):

Speed = distance ÷ time

Acceleration = velocity ÷ time

Force = mass • acceleration

Power = power = (weight • distance) ÷ time

Maximum power = lowest elapsed time

Minimum power = maximum elapsed time

Mean power = total full time ÷ 6

Fatigue index = (maximum power - minimum power) ÷ total running time for the sixth time.

Cardio-respiratory endurance (one mile): This test was used for the assessment of aerobic power of subjects. Subjects ran as quickly as possible so that the designated route and time traverse this distance was recorded by a stopwatch and was placed on a corresponding formula:

$$VO_{2max}\ (ml/kg/min) =$$
$$132.853 – 0.0769\ (weight) – 0.3877\ (age) + 6.315\ (gender) – 3.2649\ (time) – 0.1565\ (heart\ rate)$$

Rating of Perceived exertion: At the end of each stage of anaerobic test, RPE (15-point Borg perceived exertion) of the subjects were asked in the work sheet. Borg scale of perceived exertion test is a subjective test to determine exercise intensity. Borg scale, subjective to the individual in his quest score of 6 (without trying) to 20 (maximum effort) gives. Light aerobic activity score 13 (partially hardened), activity at anaerobic threshold score of 15 (hard), and anaerobic activity score 17 (very hard and above) takes place.

Music: Two pieces of music after an investigation by 1.5 Music audition Adobe software to suit the number of beats per minute were available to participants. For fast and slow music to the music with a tempo of 145 beats per minute Sachs Invisible thieves and songs here's to the night with the rhythm of 120 beats per minute were used. Participants were free to choose the music. They can choose any kind of music with any kind of rhythm. Sony NWZ–W273 sports a music player with wireless technology manufactured by Sony, which was designed to remain stationary when performing the tests on the ear.

## Results

The mean and standard deviation of variables is presented in Table 1. Within-group differences of values were statistically significant among the four tests (without music, fast, light and favorite) ($p < 0.05$). The significant changes in explosive power, speed, agility, muscular endurance and aerobic power was observed during fast music condition ($p < 0.05$). Also, favorite music created significant changes in explosive power and agility. Only fast music led to significant changes in the rating of perceived exertion ($p < 0.05$).

In addition, fast music caused a significant effect on maximum power, minimum power, mean power and fatigue index ($p < 0.05$). Also, change the minimum power in light music condition was statistically significant ($p < 0.05$).

**Table 1.** Comparisons of physical and physiological performance during four music conditions (no music, fast, light and favorite)

| Variables | Fast | Light | Favorite | No Music |
|---|---|---|---|---|
| 1 | 2 | 3 | 4 | 5 |
| Explosive Power (cm) | 143.24 ±15.7* | 141.12 ±16.01 | 140.23 ±17.28* | 136.24 ±18.22 |
| Speed (s) | 9.23 ±3.45* | 9.49 ±2.56 | 9.33 ±3.01 | 10.23 ±2.13 |
| Agility (s) | 8.45 ±1.05* | 9.01 ±1.16 | 8.70 ±1.89* | 9.18 ±1.26 |
| Muscular Endurance (rep) | 33.46 ±8.34* | 31.05 ±3.99 | 30.21 ±9.02 | 28.13 ±9.11 |
| Aerobic Power (ml/kg/min) | 49.36 ±8.5* | 47.73 ±10.3 | 48.55 ±6.9 | 46.09 ±9.68 |

| 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|
| RPE (6-20) | 12.61 ±4.27* | 12.05 ±4.30 | 12.91 ±5.01 | 11.55 ±4.68 |
| Maximum Power (w) | 427.73 ±91.24* | 402.61 ±69.3 | 409.75 ±105.27 | 403.33 ±89.69 |
| Minimum Power (w) | 311.50 ±74.12* | 288.22 ±81.7* | 305.46 ±70.55 | 301.74 ±91.27 |
| Mean Power (w) | 362.19 ±69.38* | 345.11 ±75.47 | 354.17 ±68.10 | 343.66 ±81.59 |
| Fatigue Index (w/s) | 3.74 ±1.93* | 2.84 ±1.57 | 3.39 ±1.87 | 2.39 ±2.04 |

* Significantly different with no music condition at $p < 0.05$. The values were expressed as mean ± standard deviation. RPE: Rating of perceived exertion.

## Discussion

The results showed that fast music led to the significant changes in explosive power, speed, agility, muscular endurance and aerobic power. Also, favorite music did not change significantly in the explosive power and agility. Also, fast music caused a significant change in maximum power, minimum power, mean power and fatigue index. Light music also caused the significant effect on minimum power.

Reducing fatigue, coordination, increased levels of arousal, and ultimately relaxation and improve cognitive processes increase level of performance. These positive changes proposed as a musical work (Szabo, Small, Leigh, 1999).

First finding of this study showed that rating of perceived exertion declined in music mode. Overall, the results of previous studies has shown that listening to music during exercise, reduce perceived exertion, by reducing the pressure caused by exercise (Karageorghis, Drew, Terry, 1996; Karageorghis, Mouzourides, Priest, Sasso, Morrish, Walley, 2009; Birnbaum, Boone, Huschle, 2009). Research findings show that music does not have any significant effect on perceived exertion. But listening to fast music was along with a significant decrease in rating of perceived exertion. Various studies have reported contradictory findings. In some studies to reduce perceived exertion (Ghaderi, Rahimi, Azarbayjany, 2009; Mohammadzade, Tartibiyan, Ahmadi, 2008), which is consistent with the results of the present study and in some, no significant changes in perceived exertion (Barwood, Weston, Neil, Thelwell, Page, 2009) have been reported. According to some researches, uncomfortable effects of music during exercise test reduces in mind, while the removal of audio, such as music and visual elements may be paid according to internal working pressure and reduced ability to withstand fatigue. In fact, listening to music, individuals from the same attention prevent fatigue. It works by lowering levels of serotonin and dopamine in the brain when run incremental changes in conditions related to music (Boutcher, Trenke, 1990). One study showed the effects of music therapy on cardiovascular responses and reported listen to music during exercise caused a significant decrease in rating of perceived exertion and significant increase in heart rate, respiratory rate per minute, oxygen consumption and minute ventilation (Miller, Manire, Robertson, John, Barbara, 2010). Based on music attention from internal factors (pain and fatigue) and external factors alter to pursue the matter and can be seen changes in the level of perceived exertion (Dave, Sam, Duncan, 2005). In this study, only fast music reduced rating of perceived exertion.

Barwood and colleagues (2009) reported that listening to motivating music, the participants while running on a treadmill, distance walked more, had lower levels of blood lactate accumulation. In contrast, no significant change was observed in perceived exertion (Barwood, Weston, Neil, Thelwell, Page, 2009). The results of this study uncrossed Sousse. This difference can result due to individual differences (age, gender, favorite music, etc.). Koc (2009) in a review article investigated the effect of music on athletic performance. He noted that the overall positive effects of music can be physiological (heart rate, blood pressure and body temperature), psychological (perceived exertion) and even physical performance factors (sprint, strength, endurance and aerobic power) (Koc, Turchlan, 2009).

The second findings of this study showed that listening to fast and favorite music had a positive effect on anaerobic performance. This result is antithetic with previous findings showed listening to music in an activity that was performed with low intensity was more effective to activities that was performed with maximum intensity (Karageorghis, Drew, Terry, 1996). Pujol and Langenfeld (1999) studied the effect of music on Wingate anaerobic test. In the study participated 12 males and 3 females. The results showed that the time to exhaustion, fatigue index, the average power output, the maximum and minimum power output in comparison to listening to music, there was no significant differences (Pujol, Langenfeld, 1999). That is inconsistent with results, of course, favorite and light music didn't cause any significant changes in fatigue index, the average power output and maximum power and minimum power had significant change in light music condition. Leslie (1967) investigated the effect of music on the runners speed. He didn't find an impact on the speed of runners that is in line with our results, only speed significantly changed with fast music (Leslie, 1967). Nittono and colleagues (2000) also investigated the effect of music on speed performance and found that fast music with compared to light music accelerated performance that is consistent with the study (Schwartz, Fernhall, 1990). The findings of Ferguson and colleagues (1994) reported the effect of fast and quiet music on the implementation of karate training (Ferguson, Carbonneau, Chambless, 1994). Karageorghis, Drew and Terry (1996) investigated the effect of hearing the kinds of music before the hand grip. They conclude that the hand grip strength after the stimulus music compared with the light music and non-music condition is increased (Karageorghis, Drew, Terry, 1996). However, the value of this effect varies depending on the aspects of personality athletes (Crust, 2004), which correspond to the present investigation. Elsewhere, McMordie (2009), in a study evaluated the effect of listening to music on the mean anaerobic power (which was measured using the Wingate test) repetitions of bench press and leg press exercise to exhaustion. The mean listening to music with mild and spicy without music was significantly increased in comparison with the case. Also, Bench press and leg press repetitions were more with listening to music compared to no music condition. In general, the results of this study showed that listening to music can impact on performance, especially in the case of fast rhythm music, the impact is greater (McMordie, 2009) Which corresponded with the results. Geisler and Leith (2001) demonstrated the difference between a variety of musical rhythms on basketball penalty shooting. They didn't observe significant effects in non-athletes (Geisler, Leith, 2001). This result may be due to the different songs and subjects were employed.

Finally, the study showed that fast music condition was only effective on aerobic power and subjects with fast music had better aerobic performance. This finding is consistent with results of Copeland and Franks (1991), Baulddoff and colleagues (2002), Nittono and colleagues (2000), (Copeland, Franks, 1991; Baulddoff, Hoffman, Zullo, Sciurba, 2002; Nittono, Tsudakai, Nakajima, 2000), But with the findings of Pujol and colleagues (1999), Schwartz and colleagues (1990), Litwack and colleagues (1992) is antithetic (Pujol, Langenfeld, 1999; Schwartz, Fernhall, 1990; Litwack, Schmidt, 1992). The music may replace physical work-related information that reaches from the sensory organs to the central nervous system, and increase work efficiency and improve the excitement of activities (Hayakava, Miki, Akada, Tanaka, 2000). From the viewpoint of nerve - muscle can also be said that every external stimulus such as blasting music while performing physical activity increases the amount of motor neurons in the primary centers and as a result of more workload through stronger muscle contractions even in fatigue condition (Shephard, 2001). Ghaderi and colleagues (2009) studied the effect of motivating music and calming music on aerobic performance, rating of perceived exertion and cortisol in male non-athletes. All participants with 80 to 85 percent of their maximum heart rate ran to exhaustion on a treadmill. Motivating aerobic performance in music group was significantly higher than the other groups that are in keeping with the results. In addition, rating of perceived exertion and cortisol concentrations, 5 minutes after the end of the exercise in light music was significantly lower than the other groups (Ghaderi, Rahimi, Azarbayjani, 2009). In this study, only fast music caused a significant change in the rating of perceived exertion.

Based on the results of this study, exercise stress may be modulated in the form of perceived exertion with fast music condition as distracting attention. But, favorite and light music can't decrease enough the exercise stress. Also, the fast music can improve aerobic and anaerobic performance. Listening to fast music improves aerobic and anaerobic performance and reduces rating of perceived exertion and hardness of physical work or test. Music is a simple, cheap, and available way to enhance the many physical functions and performance. Therefore, it is recommended to coaches and athletes to aid improving sports performance via listening to fast music during their exercises and tests.

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# SOCIO-DEMOGRAPHIC DETERMINANTS OF LEISURE TIME PHYSICAL INACTIVITY OF ADOLESCENTS FROM THE VOIVODESHIPS OF CENTRAL POLAND

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**Abstract** The aim of the study is to assess the physical leisure time activity among the students of grade I–III of junior high school (aged 13–16) – during the school year and holidays – and identify possible causal factors of physical inactivity in this social group. The relationship between participation in sport for all during the school year (regular, periodic, sporadic) and during holidays (physically active/passive) and socio-demographic variables characterizing the structure was analyzed using the Chi$^2$ test. The relationship between respondents inactivity and those traits was assessed using log-linear analysis. The higher the grade (especially among girls), the more physically inactive individuals, the number of which grew during the school year as well as during holidays. The risk factors for inactivity included high BMI, living in the countryside and female sex. In case of girls (76.3%) the risk of inactivity increased by almost 1.4 times, as it did (OR = 0.75) with regard to living in rural areas (76.4%). The chance of being active increases more than 3-fold among those with normal BMI (28.0%) and the underweight (29.9%). Adolescents' inactivity (increasing along with the grade pupils are in) points to the shortcomings of Polish process of education and an urgent need for system-based approach to promote active lifestyle in this social group.

**Key words** adolescent, leisure activities, sedentary lifestyle, physical activity, social determinants of health

## Introduction

Numerous connections between physical activity and health clearly indicate that in the current civilization the concern about physical condition is a duty and an integral part of the rhythm of life of a modern man (Vuori, 2004; Lee et al., 2012). Despite generally known recommendations, almost half of young Europeans do not undertake the recommended dose of physical activity (EU Physical Activity Guidelines, 2008).

Global organizations concerned about huge losses borne by society as a result of increasing hypokinesis and low level of physical aptitude – especially among young people – are calling for the promotion of health-enhancing physical activity as essential to modern public health strategies. Due to the extent of the problem – more important than the other, the individual risk factors of non-communicable diseases – are mobilizing research centers in the world to do cross-sectional research of physical activity (Soos et al., 2012; Parvizi, Hamzehgardeshi, 2014; Soos et al., 2014; Sterdt et al., 2014; Wang et al., 2014). Forming positive habits of spending free time, ways of recharging vitality and active recreation requires not only knowledge of the consequences of their absence, but also familiarity with the current level of physical activity of the young generation and the factors determining it, but also the awareness of factors determining this inactivity and the knowledge of current level of physical activity of young generation (Trang et al., 2009; Dias et al., 2015; Lo et al., 2015). Its assessment is the starting point of action of the environments activating children and school students and pro-health policy-makers.

The aim of study is to assess the physical leisure time activity among the students of grade I–III of junior high school (aged 13–16) – during the school year and holidays – and identify possible causal factors of physical inactivity in this social group. It was assumed that the objective of the research will require answers to two research questions: 1) what is the frequency (regular, periodic, sporadic) of taking recreational physical activity among junior high school pupils outside school? and 2) how (actively /passively) junior high school pupils spend their holidays? Given that, the authors hypothesised that the lack of participation of junior high school students in sport for all is significantly associated with specific socio-demographic determinants, especially the stage of education.

## Material and methods

The study included a representative (random-intentional) group of 1,067 junior high school students (the assumed error is 3%; typical choice is 95%) of the selected voivodeships in Poland (Masovia, Lodz Voivodeship, Greater Poland, Cuiavia and Pomerania, Warmia and Masuria).

The sampling frame was Central Statistical Office Local Data Bank collections, which showed that in Poland the number of junior high school for children and adolescents (excluding special schools and for adults) was in the school year 2012/2013 over 1.1 million (1,133.709). Pupils socio-cultural diversity along with lower capital intensity and greater availability and acceptance of schools authorities to do this kind of research contributed to the choice of this part of Poland region as an area of exploration. The study was conducted at the end of the summer season, i.e. September and early October 2013.

In order to select the test group a two-stage draw system was applied. The first stage consisted of random selection among all junior high school located in central Poland, covering two spatial layers: towns and rural areas. Then, in each school, one class of a given grade (first, second, third) was deliberately chosen, where research included all pupils present that day in geography class.

A questionnaire survey was used as a research tool and a standardized interview was conducted by trained interviewers. In the questionnaire there were two closed questions and respondents' particulars. The author's own survey (modified after a pilot version) included questions on participation in sport for all (except for mandatory physical education classes) over the last year. Sport for all was defined as "all forms of physical activity which, through casual or organized participation, aim at expressing or improving physical fitness and mental well-being, forming social relationships or obtaining results in competition at all levels" (European Sports Charter, 1992). The respondents were asked about the frequency of undertaking these forms of physical activity during the school year. Regular participation meant sport for all at least once per week, periodic – a few or more days in a row, several times per season, sporadic – a few times a year. Questions were also asked about the way of spending holidays (active/passive). Spending holidays in an active way meant the respondents participation in individual or organized recreational activities in their permanent place or residence and during tourist trip. Inactive (passive) way of spending holiday involved staying in permanent place of residence (tourist inactivity) and choosing passive forms of spending free time, such as: watching TV programmes, using a computer, reading books, etc. Taking into account respondents answers concerning recreational physical activity during school year and during holiday, two groups were distinguished – physically active and inactive respondents.

- physically active (regularly undertaking sport for all during school year and at the same time actively spending their holidays),
- physically inactive (periodically or occasionally taking up a sport for all during school year and physically inactive during the holiday season).

**Table 1.** Characteristics of the researched group of junior high school students (n = 1,067)

| Variables | Boys | | Girls | | Total | |
|---|---|---|---|---|---|---|
| | n | % | n | % | n | % |
| Grade | | | | | | |
| I (13/14 years old) | 226 | 44.8 | 209 | 37.2 | 435 | 40.8 |
| II (14/15 years old) | 130 | 25.7 | 160 | 28.5 | 290 | 27.2 |
| III (15/16 years old) | 149 | 29.5 | 193 | 34.3 | 342 | 32.1 |
| Place of residence | | | | | | |
| Town | 279 | 55.2 | 280 | 49.8 | 559 | 52.4 |
| Rural area | 226 | 44.8 | 282 | 50.2 | 508 | 47.6 |
| Voivodeships | | | | | | |
| Cuiavian-Pomerania | 355 | 70.3 | 369 | 65.7 | 724 | 67.9 |
| Warmian-Mazurian | 49 | 9.7 | 71 | 12.6 | 120 | 11.2 |
| Greater Poland | 31 | 6.1 | 28 | 5.0 | 59 | 5.5 |
| Łódź | 38 | 7.5 | 45 | 8.0 | 83 | 7.8 |
| Masovian | 32 | 6.3 | 49 | 8.7 | 81 | 7.6 |
| BMI | | | | | | |
| Underweight | 151 | 32.2 | 183 | 36.5 | 334 | 34.4 |
| Norm | 283 | 61.8 | 310 | 60.3 | 593 | 61.1 |
| Overweight/obesity | 35 | 7.5 | 9 | 1.8 | 44 | 4.5 |

In addition to information on participation in sport for all, interviewers collected data on sex, year of birth, grade (level of education), place of residence and the height and weight of respondents (Table 1).

The relationships between participation in sport for all (regular, periodic, sporadic) during the school year and holidays (physically active/passive) and socio-demographic variables characterizing the structure of junior high school students (sex and level of education) was determined using a Chi² test. The relationships between respondents inactivity and variables characterizing the demographic structure (sex, level of education, BMI, place of residence, voivodeships) were assessed using a Chi² test. The results are shown using fractions, and the odds ratios and 95% confidence intervals. Analyses were made using the statistical package IBM SPSS version 21. In assessing the significance of the effects, the assumed level of significance was $p \leq 0.05$.

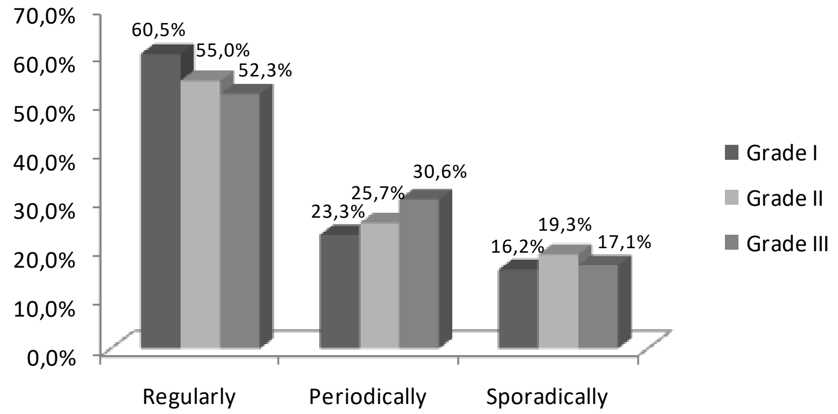
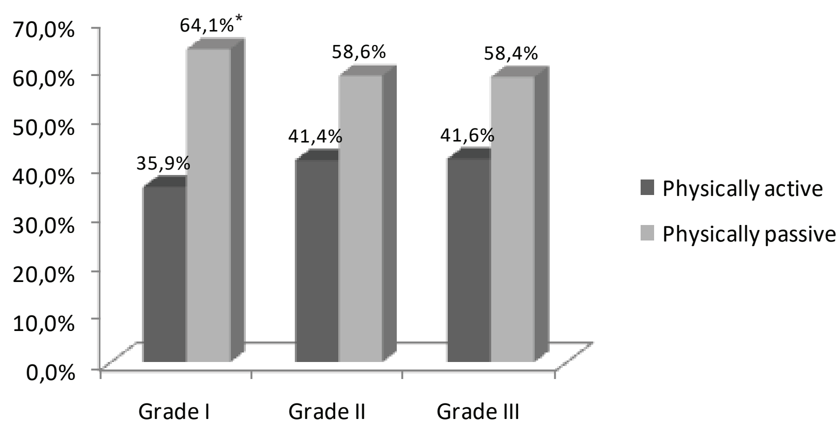



**Figure 1.** Participation in sport for all (regular, periodic, sporadic) junior high school students depending on the level of education

## Results

Sport for all as it is widely and universally understood was undertaken by 95.7% of the researched junior high school students (equally frequently by the 1st graders – 93.8%, the 2nd graders – 96.6%, as well as the third grade pupils – 97.4%). At the same time, regular participation was reported by 56.3% of them – 26.3%, and the occasional – 17.3%. Chi² test analysis revealed no significant differences in the nature of this participation (regular, periodic, sporadic) depending on the level of education (Figure 1). However, it was noted that with the transition to a higher grade, the fraction of regularly active pupils decreased (1st grade – 60.5%, 2nd grade – 55.0%, 3rd grade – 52.3%), and periodically active – increased (respectively 23.3%, 25.7 % and 30.6%).




* significantly different from physically active ($p \leq 0.001$).

**Figure 2.** The way of spending holidays (physically active/passive) for junior high school students depending on their level of education

Similarly, there was no statistical relationship between passive and physically active holiday and the level of education (Figure 2). Unfortunately, the percentage of pupils inactive during a holiday – regardless of age – was much higher than the active ones (Grade II. – 58.6 vs. 41.4%; Grade III. – 58.6 vs. 41.6%). Statistical differences – but only at the level of $p \leq 0.001$ ($Chi^2 = 3.48$, df = 2; $p \leq 0.001$) – were noted in this regard only in case of first graders who declared an active holiday (35.9%) less frequently than the passive one (64.1%).

Gender was a factor that had a significant relationship ($Chi^2 = 13.30$, df = 2; $p \leq 0.05$) with undertaking sport for all. Regardless of the grade of junior high school they were in boys often declared a regular character of undertaken physical activity (62.3%) than girls (50.9%) (Table 2). These differences were particularly evident in the third grade (boys – 63.0%; girls – 43.9%). Meanwhile, third grade girls more often than their male counterparts (23.3%) practiced sport regularly (36.4%).

The analysis of the group of boys and girls (only) showed that among the first – regardless of their level of education – there was no significant difference in making sport for all (regular, periodic, sporadic). In the group of girls, however, the relationship was significant ($Chi^2 = 11.41$, df = 4; $p \leq 0.05$). The girls of the first class more often than other female secondary school pupils practice various forms of sport regularly (58.5%), and grade III vice versa – periodically (36.4%).

In examining the determinants of physical inactivity respondents were taken into account the variables presented in Table 3 junior high school students were classified as physically active people (regularly undertaking sport for all and at the same time actively spending holidays) and inactive (other).

**Table 2.** The participation of junior high school students in sport for all (regular, periodic, sporadic) during the school year and during the holiday season (active/passive)

| Factors | | Grade I | | | | Grade II | | | | Grade III | | | | Total | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Boys (n = 226) | | Girls (n = 209) | | Boys (n = 130) | | Girls (n = 160) | | Boys (n = 149) | | Girls (n = 193) | | Boys (n = 505) | | Girls (n = 562) | |
| | | n | % | n | % | n | % | n | % | n | % | n | % | n | % | n | % |
| Sport for all | | | | | | | | | | | | | | | | | |
| Do not undertake | | 11 | 4.9 | 13 | 6.2 | 6 | 4.6 | 4 | 2.5 | 3 | 2.0 | 6 | 3.1 | 20 | 4.0 | 26 | 2.6 |
| Undertake* | Regularly | 134 | 62.3 | 113 | 58.5[b] | 76 | 61.3 | 78 | 50.0 | 92 | 63.0[a] | 82 | 43.9 | 302 | 62.3[a] | 273 | 50.9 |
| | Periodically | 45 | 20.9 | 50 | 25.9 | 31 | 25.0 | 41 | 26.3 | 34 | 23.3 | 68 | 36.4[a,c] | 110 | 22.7 | 159 | 29.7 |
| | Sporadically | 36 | 16.7 | 30 | 15.5 | 17 | 13.7 | 37 | 23.7 | 20 | 13.7 | 37 | 19.8 | 73 | 15.1 | 104 | 19.4 |
| Holidays | | | | | | | | | | | | | | | | | |
| Physically active | | 82 | 36.3 | 74 | 35.4 | 56 | 43.1 | 64 | 40.0 | 60 | 40.5 | 82 | 42.5 | 198 | 39.3 | 220 | 39.1 |
| Physically passive | | 144 | 63.7 | 135 | 64.6 | 74 | 56.9 | 96 | 60.0 | 88 | 59.5 | 111 | 57.5 | 306 | 60.7 | 342 | 60.9 |

* percentages calculated on the basis of number of pupils undertaking sport for all; ** significantly different ($p \leq 0.05$): [a] – boys vs. girls; [b] – regularly vs. periodically and sporadically; [c] – occasionally vs. regularly and periodically.

**Table 3.** Determinants of physical activity of junior high school students (n = 1,067) and odds ratios (OR) and the boundaries of 95% confidence interval (95% CI) of inactivity

| Variables | Lower secondary school pupils | | | | p | OR | 95% CI |
|---|---|---|---|---|---|---|---|
| | Active | | Inactive | | | | |
| | n | % | n | % | | | |
| Sex | | | | | 0.026 | | |
| Boys | 150 | 29.7 | 355 | 70.3 | | 0.73 | 0.56–0.96 |
| Girls | 133 | 23.7 | 429 | 76.3 | | 1 | |
| Grade | | | | | NS | | |
| I | 109 | 25.1 | 326 | 74.9 | | 1 | |
| II | 81 | 27.9 | 209 | 72.1 | | 0.86 | 0.62–1.21 |
| III | 93 | 27.2 | 249 | 72.8 | | 0.90 | 0.65–1.24 |
| BMI | | | | | 0.036 | | |
| Underweight | 100 | 29.9 | 234 | 70.1 | | 0.3 | 0.11–0.78 |
| Norm | 166 | 28.0 | 427 | 72.0 | | 0.33 | 0.13–0.85 |
| Overweight/obesity | 5 | 11.4 | 39 | 88.6 | | 1 | |
| Place of residence | | | | | 0.041 | | |
| Town | 163 | 29.2 | 396 | 70.8 | | 0.75 | 0.57–0.99 |
| Rural area | 120 | 23.6 | 388 | 76.4 | | 1 | |
| Voivodeships | | | | | NS | | |
| Cuiavian-Pomeranian | 182 | 25.1 | 542 | 74.9 | | 0.88 | 0.52–1.52 |
| Warmia-Masurian | 42 | 35.0 | 78 | 65.0 | | 0.55 | 0.29–1.04 |
| Greater Poland | 19 | 32.2 | 40 | 67.8 | | 0.63 | 0.30–1.32 |
| Łódź | 19 | 22.9 | 64 | 77.1 | | 1 | |
| Masovian | 21 | 25.9 | 60 | 74.1 | | 0.85 | 0.42–1.73 |

Significant differences ($p \leq 0.05$) between inactivity and activity; odds ratios (OR) were computed with reference to the inactive.

Factors significantly differentiating respondents in this respect included their sex ($Chi^2 = 4.96$, df = 1; $p \leq 0.05$), BMI ($Chi^2 = 6.67$, df = 2; $p \leq 0.05$) and place of residence ($Chi^2 = 4.19$, df = 1; $p \leq 0.05$) (Table 3). The majority of respondents were characterized by normal weight (61.1%) or underweight (up 34.4%). The existence of a correlation between the frequency of physical inactivity and sex of the respondents was found only among girls. Designated for the analyzed variables, the odds ratios indicate that the risk of inactivity increased by almost 1.4 times (76.3%). A risk of a similar magnitude (OR = 0.75) was also noted in relation to all junior high school students living in the rural areas (76.4%). On the other hand, the chance of being an active person increases more than 3-fold among junior high school students with normal BMI (28.0%) and the underweight ones (29.9%).

## Discussion

The results of recent epidemiological and clinical studies have shown that lifestyle diseases commonly occur among people who take little physical activity or do not take it at all (Vuori, 2004). Unfortunately, this problem is becoming more common in case of children and adolescents (Dowda et al., 2001; Sterdt et al., 2014). According to the EU Physical Activity Guidelines (2008) the school children should undertake daily physical activity (in developmentally appropriate forms) at a moderate or intensive level for 60 minutes or longer (full dose can be cumulated in at least 10-minute rounds). At the same time, the first criterion of physical activity is its regularity.

In the community of researched junior high school students, on the whole, the declarations of participation in sport for all are very high (95.7%). Higher than in the American youth population, where 77% undertake recreational activity in leisure time and 39% – organized sports (Duke et al., 2003). Unfortunately, however, regularly only 56.3% of Polish junior high school students practice sport. The widely known phenomenon has been confirmed that if we ask about any physical activity at all – almost all respondents replied in an affirmative manner. If, however, the respondents are asked to describe in detail the frequency – the active fraction decreases drastically. In our case, it decreased by almost half. Given the above, it has to be assumed, following Wojtyła et al. (2011), that the Polish youth physical activity is limited largely to physical education classes; assuming at the same time that the examined junior high school students obligatorily attend these classes (3 hrs. weekly) and thus their physical activity (even in case of those who exercise regularly in their spare time) is too small to sustain health (not to mention proper development). This is not an isolated phenomenon. Researchers around the world are reporting that many young people do not apply the recommended dose of physical activity. For example, 3 out of 10 boys and 4 of 10 girls (aged 5–18 years) in the UK do not do it (Department of Health, 2003). Moderate efforts, lasting no less than 30 minutes at least five days a week, are taken by only 36% of the American and 35% of the Polish school children (Department of Health, 2003; Cabak, Woynarowska, 2004). It is not surprising that in Finland sport (4–5 times a week) is practiced by 13% of girls and 20% boys of school age. Quite surprising, though, is high level of physical activity of Lithuanian youth. According to Bergier, Bergier and Wojtyła (2012) it is achieved by 90.0% of boys and 71.9% of girls of school age. Perhaps such result is partly due to applying the long version of IPAQ in which all efforts of everyday life are analyzed. However, the earlier Polish studies (using the short version of the IPAQ among pupils in last year of lower secondary school and high school and the students in 1st and 4th years) reveal that a high level of physical activity applies to only 28.2% of young people (Biernat, Tomaszewski, 2013).

The above mentioned study – just like the previous one by Allender, Cowburn and Foster (2006) indicates even a downward trend in physical activity as pupils move to a higher grade. Payne, Townsend and Foster (2013) proved that along with the increasing pupils' age, their participation in active forms of recreation declines, particularly among girls. It is a very disturbing phenomenon. The more so that as Huk-Wieliczuk and Litwiniuk (2003) claim, in addition to reducing the level of physical activity, the range of forms of motor involvement becomes limited.

A non-gradual adverse change is noted between first graders (39.5% inactive) and third graders (47.7% inactive) – which confirms the hypothesis. It can obviously be explained by the fact that 3rd graders devote more time to prepare for entrance exams for secondary schools. It is arguable, however, to say that education for recreational physical activity takes place at school stage (Kriemler et al., 2011). School education is expected to have far greater effect on physical culture of young people (both in terms of quantity and quality, both in the classroom and in their free time) (Lubowiecki-Vikuk, Podgórski, 2016). The interactions between school activities and sports education towards active leisure in later life are of virtuous circle nature. Unfortunately, Polish researchers pay attention to the low level of physiological knowledge of physical education teachers, the lack of sharing with pupils elementary knowledge of the impact of physical activity on the human body, the lack of interest in their own physical activity, not to mention promoting it among their pupils (Dębicki, Kuśnierz, 2003). They also show that, despite the introduction of the reform program, extracurricular and after-school physical activity is not at a satisfactory level, and young people possess too low level of knowledge about health, its maintenance and prevention (Dobbins et al., 2013). In European countries, not only schools but also families and peer groups are expected to have their share inn improving the lifestyle of the researched social group (Viner et al., 2012). It is all reflected in the behavior of the surveyed junior high school students (both during the school year and during holidays). It turns out that as many as 60.8% of the respondents prefer passive recreation, such as: watching TV programs, playing computer games, reading books etc. (Lubowiecki-Vikuk, Paczyńska-Jędrycka, 2010). Thus, taking into account pupils who regularly undertake sport for all during the school year and at the same time actively spend their holidays – physically active (all year round), they account for only 27%. It seems that the way out of this difficult situation – apart from increasing the awareness of the need for a permanent physical activity – is a practical action, such as prevalence of organized forms (in the place of residence as well as and during trips). Research done by Lubowiecki-Vikuk and Paczyńska-Jędrycka (2010) conclusively shows that over 90% of children and adolescents eagerly participate in organized sport activities at summer camps.

Statistical analysis indicated that the respondents' inactivity was conditioned by the majority of studied factors. Factors increasing the risk were high BMI, living in the countryside and female sex. As for girls, the risk of lack of movement was more than 1.4 times higher than among boys. Most researchers show girls as less active (Aibar et al., 2013; Hardman et al., 2013; Pindus et al., 2014). One should also remember that junior high school is a period of physiological maturation (in Poland, very frequently, the stereotypes of not taking part in physical education classes during menstruation are still prevalent). Much qualitative data (own observations, reactions of the respondents, the expressed emotions and so on) confirmed this state of affairs. This fact is of significant importance since increased recreational physical activity, especially in childhood and in case of adolescent reduces the risk of many diseases (Ruiz et al., 2011).

Living in rural areas also contributes to the prevalence of low level physical activity among junior high school students. The risk in this case is 1.4 times higher than among pupils living in urban areas. Scientific research conducted among children and adults living in rural areas reveal the existence of numerous obstacles to undertake physical activity (Salmon et al., 2013). In contrast, Wojtyła et al. (2011) indicate that the problem of inactivity relates to the inhabitants of towns and the countryside as well. Until recently, the residents of rural areas – because of the acute shortage of free time, commitment to work on the farm, aversion to unnecessary physical effort, limitations on the access to the equipment and sports facilities, resistance to new and alien cultural patterns – showed little interest in recreational activity. Currently, the differences in the use of free time between urban and rural population is becoming blurred (Ruiz et al., 2011; Salmon et al., 2013; Pindus et al., 2014). The state of sports infrastructure in rural areas is improving. The number of people with higher education is increasing, which inevitably leads to a change of attitudes of rural families to physical education (Salmon et al., 2013; Lubowiecki-Vikuk, Biernat, 2015).

Another factor shaping the physical activity of junior high school students was BMI (Kantanista et al., 2015). Among students with a normal BMI the underweight ones, the risk of inactivity decreased over threefold. It would confirm Tremblay and Willms (2003) thesis that the lower BMI, the higher the activity. It does not, however, change the fact that being underweight can also be a factor increasing the risk of physical activity deficiency, which is the issue raised by Kantanista and Osiński (2014).

## Limitations

Surveys were carried out on the basis of the declaration of junior high school students, which – despite a thorough explanation of the terminology used – could lead to an overestimation of physical activity.

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# QUALITY OF LIFE AND PHYSICAL ACTIVITY AFTER LIVER TRANSPLANTATION. LITERATURE REVIEW

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**Abstract** Liver transplantation has become one of the most effective treatments for end-stage renal disease. For patients, however, the decision to have orthotopic liver transplantation (OLT) is often made in an effort to improve their quality of life and to reduce their risk of mortality and morbidity. Quality of life is an important aspect of therapy for transplant patients because this category reflects the subjective evaluation of one's own life in the physical, psychological and social dimensions. One of the means to achieve a better quality of life is not only good health, but also physical activity. Physical activity has been demonstrated to be of significance not only in the assessment of fitness levels but also could be of importance in long term recovery process after major surgical operations. The aim of this study was a review of literature showing the improved quality of life in patients after liver transplantation as well as the influence of physical activity on their physical health, mental health and quality of life after transplantation. Longitudinal data showed remarkable improvement of common domains of QOL comparing pre- and post-transplant items. Gender, occupation and regular physical activity have an influence on the quality of life after liver transplantation.

**Key words** quality of life; liver transplantation; physical activity

## Introduction

Liver transplantation surgery (LTx) provides patients with a chance to return to an active life. Above all, LTx saves patients from premature death, and in doing so delivers an opportunity for continued development and a normal life. In recent years the follow up treatment of patients has taken into account assessments of their quality of life, where this measurement is used as a marker of the effectiveness of the treatment. One of the means to achieve a better quality of life is not only better health, but also physical activity. Regular exercise has a long-term positive impact on recovery following various surgical procedures including transplants, giving patients the opportunity to return to an active life in their families, society and also in their professional life.

Naturally, quality of life improves considerably following LTx. Nevertheless, transplant recipients still show lower health related quality of life (HRQOL) scores than the general population (Masala et al., 2012). Regular physical activity has been demonstrated to be of significance in the long term recovery process following LTx, and to positively affect the quality of life (Painter et al., 2001). However, many LTx recipients remain sedentary (Beyer et al., 1999; Kallwitz et al., 2013) and their low physical activity contributes to the development of post LTx metabolic abnormalities and cardiovascular complications, the third leading cause of long-term mortality following LTx (Beyer et al., 1999; Watt et al., 2010). Yet to date there has only been limited data on factors related to low physical activity and impaired HRQOL in LTx recipients.

Therefore, this paper reviews the body of research on the improvement of quality of life in post LTx patients, and on the influence of physical activity on their physical health, mental health and quality of life (QOL).

## The concept and measurement of quality of life

HRQOL is a multi-dimensional concept that includes subjective evaluations in domains related to physical, mental, emotional and social functioning, in the context of a disease or disability and its treatment (World Health Organization, 1998). The evaluation of HRQOL denotes an effort to define how the variables within the dimensions of health relate to the specific measurements that have been found to be of importance to the subjects (Ware, 1995). With subsequent improvements in medical treatments effecting a prolonged survival, HRQOL has emerged as an important clinical issue.

HQOL is an important measure in the treatment of chronic diseases. It quantifies the subjective evaluation of a patient’s life in physical, psychological and social spheres. HRQOL takes into account the natural course of the disease, its consequences and outcomes, and reflects the individual patient's perspective on the disease. It is increasingly frequently emphasized that an analytical approach is not sufficient in the care of the chronically ill. In these patients, it is often difficult and sometimes impossible to draw a line between physical and psychological aspects of the disease (Pietrzykowska et al., 2007). The questionnaires used in quality of life evaluations can be divided into general, specific and mixed types. The general surveys assess physical, psychological and intellectual functions, independently of health and coexisting diseases, and can be applied in the general population. However, it is recommended to use disease-specific scales, such as the Sickness Impact Profile, Nottingham Health Profile and Medical Outcomes Survey Short Form 36 (SF-36), WHOQOL 100, and Quality of Life (QOL) by Ferrans and Powers in the general version (Chrobak, 2009).

Short Form-36 (SF-36) is the most often used. The SF-36 was developed to measure eight of the most important areas of health. The results from the SF-36 enables comparisons across a broad range of conditions, and between studies on health-related QOL in the same settings [4]. It contains 36 items grouped into 8 domains in the areas of physical health (physical functioning, physical role limitation, bodily pain, general health) and mental health (vitality, social functioning, emotional role limitation, mental health). Each domain is scored from 0 to 100 points, with higher scores indicating a better HRQOL. Two summary scores, a physical component and a mental component, are obtained as mean values calculated from the appropriate domains (Ware et al., 1992; 1993).

## Definition and evaluation of physical activity

Physical activity is one of the factors that affects the health of patients before and after transplantation. Physical activity is usually associated with a significant improvement in functional abilities and health, and can often prevent or reduce the severity of certain disease. The results of numerous studies affirm that regular physical exercise undertaken at different intensities increases the resistance and exercise capacity of most patients in almost all groups following transplantations (kidney, lung, liver, heart, bone marrow). With properly selected physical activity, transplant recipients can obtain results comparable to healthy individuals at a similar age (Kjaer et al. 1999).

One method of assessing physical activity is via a questionnaire for specific ages, conditions and types of activity (regular, daily and weekly). Questionnaires that evaluate shorter periods of time are more accurate; such data allows assessment of the energetic consumption of the body, which is important in evaluating the intensity of the effort for disease prevention. It is important to use simple, inexpensive and easy to perform questionnaires. Each type of physical activity can be expressed in MET (metabolic equivalent) units, counting intensity by the number of days and time in minutes. MET is a unit of energy related to oxygen consumption at rest, i.e. 3.5ml O2/kg/min [22].

The common questionnaires in adult studies are: Minnesota Leisure Time Physical Activity Questionnaire (MLTPAQ), Paffenbarger Physical Activity Questionnaire (PPAQ), Stanford Usual Activity Questionnaire (SUAQ) and the Seven-Day Activity Recall (SDPAR). MLTPAQ covers physical activity in leisure time over the last 12 months. It contains several categories of activity: walking, general activity, water sports, winters sports, garden activity and housework. The intensity of activity is divided into 3 degrees: low (<4 MET), medium (4–6 MET) and large (>6 MET). The PPAQ questionnaire seeks information about activity in the past year as well as in the last week, but with no specific kinds of sports or housework, and is used to describe usual physical activity. The Stanford Usual Activity Questionnaire assesses activity in leisure time in the last 3 months, based on "yes" or "no" answers. The intensity of physical activity is described as moderate, high or very high. The SDPAR questionnaire is based on activity during occupation and leisure time in the last 7 days and categorizes small (<4 MET), medium (4–6 MET) and high activity (>6 MET) (Desai et al., 2008; Nowak, 2006; Pereira et al., 1997).

Firstly, we believe that this is an opportune moment to undertake a systematic review of post LTx QOL, in which particular attention is paid to studies using the SF-36. We review specific aspects of QOL after LTx, including available data on whether gender influences post LTx QOL, and review employment as a marker of QOL. Then we evaluate the impact of selected aspects of physical activity in patients following liver transplantation.

### Assessment of health-related quality of life studies using the SF-36 in LTx patients

Several studies have shown that HRQOL improves considerably following LTx. Nevertheless, transplant recipients demonstrate lower HRQOL scores and remain less physically active than the general population (Cordoba et al., 2003; Hauser et al., 2004; Younossi et al., 2000; 2001; Belle et al., 1997; Bona et al., 2000; Gross, 1999). This refers in particular to those subjects with liver cirrhosis complicated by hepatic encephalopathy, ascites or pruritus (Arguedas et al., 2003; Les et al., 2010; Marchesini et al., 2001; Wunsch et al., 2013). However, several HRQOL parameters are also impaired in non-cirrhotic patients with chronic liver diseases, such as those suffering from primary biliary cirrhosis (PBC) (Mells et al., 2013; Selmi et al., 2007; Huet et al., 2000). QOL improved following liver transplantation in all domains compared to the preoperative status (Sainz-Barriga et al., 2005; Aberg et al., 2012; Dupuis-Girod et al., 2010; Sirivatanauksorn et al., 2012).

Physical function is a strong benefactor of liver transplantation (Dupuis-Girod et al., 2010). Patients report reductions in feelings of loneliness, anxiety and hopelessness, allowing a higher quality of social interactions (Duffy et al., 2010). Sainz-Barriga et al. reported improvements in all domains of QOL except the psychological domain (Sainz-Barriga et al., 2005). Similarly, Bravata et al. (2001) in meta-analysis concluded that generally there were improvements in the patients' general health, physical health, daily activity functioning and sexual functioning. There was, however, less consistent evidence of improvement in psychological health, including social isolation and social functioning. Those findings are consistent with studies on recipients of other organ transplants (lung, kidney and heart) which also found the post transplantation quality of life of organ recipients is better than their pre-transplantation quality of life, particularly in physical health domains (Bravata et al., 1999).

In a Danish study published in 2002, 130 liver transplant recipients were assessed via SF-36 against the Multidimensional Fatigue Inventory and Hospital Anxiety and Depression Scale. They self-reported poorer health than the general population in physical but not in mental areas, and they experienced physical rather than mental fatigue. Diagnosis was found to be a predictor of postoperative physical function and fatigue because patients with an alcoholic or cryptogenic cirrhosis background had significantly poorer physical function and experienced more physical fatigue that patients with other diagnoses. Work status and survival time after LTx had a significant effect on post-operative physical function and fatigue – occupation and a post LTx time of 4 to 5 years were associated with better physical function and less physical fatigue that not working and a shorter post-LTx time (Aadahl et al., 2002).

### Gender differences

Analyzing the gender of patients, Kober et al. reported that men had lower QOL scores after LTx than women (Kober et al., 1999). In another composite analysis published in 1999, Bravata et al. concluded that there were no differences between the sexes in post-LTx QOL, although the authors commented on the scarcity of studies dealing with this topic (Bravata et al., 1999). Moore came to the same conclusion in a single-center prospective study of 10 LTx recipients compared to normal controls (Moore et al., 2000).

Cowling reported a study specifically designed to consider whether gender influenced QOL outcome after LTx (Cowling et al., 2004). Among 88 male and 61 female LTx recipients who matched for prevalence of HCV infection and who had received QOL assessment pre-LTx, men displayed higher levels of health-related QOL than women at 1 and 2 years following LTx (Cowling et al., 2004). The differences were partially corrected after adjustment for educational level. A similar result was reported by Spanish investigators who reported that psychosocial adjustment after LTx was reported higher in males compared to female recipients (Blanch et al., 2004). Similarly, in research by Kotarska et al. HRQOL was significantly worse in female patients in the majority of the SF-36 domains (Kotarska et al., 2014).

### Employment

There is a clear consensus in literature that patients are more likely to feel better after liver transplantation if they were professionally active after the surgery. The possibility to return to work after liver transplantation also depends on the type of work previously held (Loinaz et al., 1999; Sahota et al., 2006; Adams et al., 2006). Interestingly, despite the socio-cultural differences that could affect work patterns and perceptions of QOL, these same results were found among transplant recipients in Japan (Kita et al., 1996), Taiwan (Shih et al., 2000), Sweden (Hellgren et al., 1998) and the United States (Bravata et al., 2001).

According to the study carried out by Aadahl et al. (2002), patients with a low PF (physical functioning)) are often unemployed and more frequently experience fatigue than those engaged in any educational or working activity. An association between external stimuli through work and a sense of fatigue is also suggested in a Dutch study, which observed that an unemployed patient is less stimulated/ motivated, and by being less active is more exposed to fatigue; thus, the patient has a reduced physical function (de Rijk et al., 1999). Patients who return to work have a better QOL perception.

The majority of patients undergoing liver transplantation are of working age (28–59 years) at the time of surgery, with up to half being employed at the time of follow-up. The overall rate of employment declined after 5 years, with 67% retired at 8 years (Sainz-Barriga et al., 2005; Aberg et al., 2012). Across the studies assessing employment, patients returning to work post-operatively reported higher QOL scores (Sainz-Barriga et al., 2005; Aberg et al., 2012; Cowlinget et al., 2000). Employment status differed according to the etiology of the liver disease. Rates of resumption of work were highest in primary sclerosing cholangitis, and lowest in acute liver failure, primary biliary cirrhosis and alcoholic liver disease (Ho JK et al., 2006).

### Assessment of physical activity after liver transplantation

Common to all candidates before transplantation is an impaired physical performance level that not only interferes with the ability to perform leisure-time exercise, but often also limits the ability to perform even simple physical tasks such as climbing stairs (Badenhop, 1995). It has been widely described that after receiving a donor organ these patients reported improved quality of life and were frequently able to successfully return to employment (Tarter et al., 1991).

The US Surgeon General's Report on Physical Activity and Health states that "regular physical activity appears to improve health-related quality of life by enhancing psychological well-being and improving physical functioning in persons compromised by poor health" (Office of the US Surgeon General, 1996). This report also states that regular physical activity reduces many of the cardiovascular comorbidities and risk factors often seen in longer term transplant recipients. Thus, it seems justified to further investigate the contribution of physical activity in HRQOL. Improvements in self-related physical functioning result from exercise training in other patient populations (Painter et al., 2000) and it is well documented that self-reported physical functioning is highly predictive of outcomes (e.g. hospitalization and mortality).

### Health-related quality of life and physical activity

Systematic physical activity contributes to better QOL (Masala et al., 2012; Dupuis-Girod et al., 2010; Rongies et al., 2011; Painter et al., 2001; Kirchner et al., 2006). Greater involvement in social and physical activities is attributed to the amelioration of physical symptoms, fatigue and worry related to CLD (Sirivatanauksorn et al., 2012). Active patients achieved better scores in the domains of physical functioning, bodily pain, general health, social functioning, emotional role limitations, and physical and mental component summary scores. The physical component summary scores of active individuals achieved levels similar to the general population.

Physical activity after surgery is also associated with health benefits in addition to QOL, such as decreases in surgical complications and new onset comorbidities following surgery (Masala et al., 2012; Painter et al., 2001). Painter et al. report significant differences in SF-36 scores between transplant recipients who were physically active and those who were sedentary. In another study of the same group from 2001, they indicated that physical activity is related to HRQOL after LTx independently of other coexisting medical conditions. Patients who participated in regular physical activity had significantly higher scores on all physical scales and physical component scale (PSC). The regression model, which included age, gender, time post transplantation, re-transplantation, recurrence of hepatitis C and a number of comorbid conditions, showed that both the number of comorbid conditions and participation in physical activity were significant independent contributors to the physical functioning scale and PCS (Painter et al., 2001; Łubkowska et.al., 2015).

### Gender differences

Payne demonstrated that regular physical activity improves the general health of patients after liver transplantation (Payne et al., 1996). Kotarska et al. noted that female patients remained significantly less active than male subjects. In many reports males reveal a higher level of activity in all age groups. Men are more likely to undertake regular exercise and more frequently (Kotarska et al., 2014; Malina, Bouchard, 2003; Ainsworth, 2000). It has been found that younger patients after LTx are more physically active. Overweight and obesity reduce physical activity and deteriorate the quality of life (Painter et al., 2001; Osiński, 2002). Although an age-related decrease in fitness and exercise capacity is physiologically inevitable, this may occur at a different pace and intensity and may even be delayed by a maintained or increased physical activity (Osiński, 2002). Studies confirm that obesity and overweight in patients after LTx coincides with low levels of physical activity. They also show lower levels of physical activity among Polish women, which could be related to their lifestyle. The etiology of the disease and time following transplantation had no influence on the physical activity of individuals.

### Employment

Low physical functioning is consistently reported following transplantation and is related to employment status, as well as overall quality-of-life ratings post transplantation. (Dew et al., 1997; Nicholas et al., 1994; Hicks et al., 1992; Hellger et al., 1998; Hunt et al., 1996). Reported symptoms before LTx include weakness, loss of range of motion, pain, and arthritis, primarily in the lower extremities. These symptoms may lead to limitations in physical activity and physical functioning, resulting in quality-of-life levels lower than those of the general population (Hellgren et al., 1998; Hunt et al., 1996; Bryan et al., 1998). Given the significant deterioration in function associated with physical inactivity and end-stage liver disease, it is reasonable to speculate that increased physical activity would attenuate or alleviate these symptoms post transplantation.

We earlier reported significant differences in SF-36 scores between transplant recipients who were physically active and those who were sedentary (Painter et al., 1997). Patients undertaking their professional work had significantly better SF-36 scores, mainly related to the physical aspects of well-being (i.e. physical functioning, physical role limitation, bodily pain, physical component summary and emotional role limitation) and were significantly more physically active than those out of work (pensioners). These observations are in agreement with selected studies in which persons that had an active work life had a significantly better HRQOL compared to those out of work (Masala et al., 2012; Aberg et al., 2012; 1995; Bownik et al., 2009). Liver transplant recipients experienced fatigue more frequently and demonstrated lower SF-36 physical functioning scores than those engaged in any educational or working activity (Aadahl, Hansen, 2002). This has been attributed to the fact that professional work provides external stimuli, and assists in the return to a normal lifestyle and social integration (de Rijk et al., 1995). Also, fulfillment of professional tasks and work satisfaction enhance their sense of independence. Thus, patients who remain out of work may potentially be less motivated and have more impaired physical activity than those with an active work life. Kotarska noted a significantly worse HRQOL in female patients in the majority of SF-36 domains (Kotarska et al., 2014).

## Discussion

Traditionally, both clinicians and researchers have been mainly interested in two outcomes of liver transplantation: survival rate and postoperative complications. Liver transplantation is beneficial for long-term QOL as it provides persistent relief of symptoms. Survival rates after liver transplantation continue to improve across a majority of indicators, leading to increasing attention being placed on the well-being of patients after the procedure. However, compared to the standard population, LTx patients show considerable deficiencies, an observation that has been supported by a reduced QOL in specific patient cohorts and in particular domains. Moreover, physical activity has been demonstrated to be of significance, not only in the assessment of fitness levels, and could also be of importance in long term recovery processes following major surgical operations. Functional domains such as employment, emotional role limitation and physical activity are significant for liver transplant patients who are often young and of working age.

In the long-term, overall QOL scores and general health perception remain enhanced and comparable to the general population. However, physical functioning continues to be inferior compared with the general population despite marked improvements from preoperative physical functioning. Suboptimal physical health is likely to be a major contributor to the frequency of surgical morbidity, both early and late, compared to the general population (Yang et al., 2014).

It must be emphasized that the level of physical activity following transplantation is also an indicator of a patient’s freedom from disease and capacity beyond undertaking normal daily activities. Clinicians may consider encouraging physical activity following surgery to improve HRQOL in addition to the well-known benefits of physical activity. Inpatient post-operative rehabilitation would be a useful consideration to optimize physical function (Cortazzo et al., 2005; MacDougall et al., 1980).

It can be assumed that a decrease in patient's physical activity may be related to the fact that they had not exercised much before the procedure and were still unwilling to exercise. They may also have unfounded fears regarding the adverse effects of post-procedure systematic exercise.

The systematic and reliable assessment of quality of life and physical activity in patients can bring important information about the areas which require significant changes. Such an assessment is increasingly often an important endpoint of many clinical trials. However, a lack of standardized testing methods for the assessment of quality of life and physical activity in patients after liver transplantation makes it difficult or impossible to compare studies from different centers, as well as preventing referencing results between similar studies.

Therefore, further research is necessary, as the information obtained during such studies can be of great use in the overall assessment of patients in terms of their physical and mental health, making it a valuable addition to the medical examination. This is especially important since most patients assess their physical and mental state prior to transplantation as poor.

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# SURGICAL TREATMENT AND REHABILITATION OF TRIGGER THUMB AND FINGER

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**Abstract** The aim of the study was to evaluate the results of surgical treatment and rehabilitation of patients with trigger thumb and finger. In 40 patients, comprising 30 women and 10 men aged 26 to 64, a total of 42 cases of trigger thumb and finger. In the preoperative period, the severity of changes were studied according to the classification developed by Newport et al. Five patients were classified in the first stage, 28 in the second, 6 in the third, and 1 in the fourth. The mean duration of symptoms was five months. The indication for surgery was a lack of improvement following conservative treatment. All of the patients were treated surgically using the open method by cutting the flexor tendon sheath in part A1. The rehabilitation treatment included exercises to improve the range of mobility of the thumb and fingers and to stretch, grelax, and strengthen muscles. Neuromobilisation and automobilisation exercises were conducted. After 5 months, swelling, pain and restricted mobility of the thumb and fingers subsided in all patients. There were no 'jumping' symptoms. Apart from a slight transitory inflammatory reaction in 2 patients there were no complications. In patients with trigger finger, open surgery and competent rehabilitation therapy enables the achievement of very good results, with a low complication rate.

**Key words** trigger thumb and finger, surgical treatment and rehabilitation of trigger thumb and finger

## Introduction

Trigger thumb and finger (Latin: tendovaginitis stenosans) is also known as stenosing tenosynovitis of the flexor tendon and its sheath. A characteristic symptom of this disease is an audible crack and frequently perceptible pain in the affected thumb or finger when being bent and straightened. The reason for this is the 'jumping' of a thickened flexor constricted by a fibrous sheath in part A1. The initial 'jumping' can develop into complete blockage at the entrance of the tendon sheath. The disorder often occurs in women around 50 years of age and mostly affects the thumb. The cause of such changes may be frequent repeated, minor injuries and overload of the flexor tendons. Cases of trigger thumb and fingers are common in individuals participating in sport climbing, and tennis, or playing various instruments involving the fingers. The condition also affects carpenters and people laundering items by hand (Cakmak, Wolf, Bruckner, Hahn, Unglaub, 2012; Lange-Riess, Schuh, Honle, Schuh, 2009).

In the initial phase of the disease, where there are no symptoms of the tendon conservative treatment, involving local and general use of anti-inflammatory drugs is recommended. If there is no improvement following conservative treatment, open or percutaneous surgery is conducted. Surgical treatment achieves better results than conservative treatment, with fewer relapses. Some argue that there is no difference between the results of percutaneous and open surgical treatment (Wang et al., 2013). In trigger thumb syndrome cutting of the annular ligament is done with a thick injection needle. Surgical treatment using the open method produces a 97–99% cure; relapses occur in 2–3% of cases and complications in 2% of patients; however, the percutaneous method results more often in restricted mobility of the fingers, soreness or infection (Finsen, Hagen, 2003; Lange-Riess, Schuh, Honle, Schuh, 2009; Turowski, 1997; Will et al., 2010). Following the surgery, rehabilitation is recommended as soon as possible. Patients are warned against performing excessive gripping movements and lifting heavy objects (Deskur, Deskur, Zawadzki, 2014).

## Material and methods

In the years 2006–2013, 40 patients were treated, comprising 30 women and 10 men, aged 26 to 64, with 42 cases of trigger thumb and finger (Table 1).

**Table 1.** Number of men and women treated with trigger thumb and fingers

| The age of patients in years | Number of patients | | | | Together | |
|---|---|---|---|---|---|---|
| | women | | men | | | |
| | n | % | n | % | n | % |
| 21–30 | – | – | 1 | 2.5 | 1 | 2.5 |
| 31–40 | 4 | 10.0 | 1 | 2.5 | 5 | 12.5 |
| 41–50 | 9 | 22.5 | 4 | 10.0 | 13 | 32.5 |
| 51–60 | 17 | 42.5 | 3 | 7.5 | 20 | 50.0 |
| 61–70 | 1 | 2.5 | – | – | 1 | 2.5 |
| Together | 31 | 77.5 | 9 | 22.5 | 40 | 100.0 |

Treatment and testing was carried out at the SP Regional Hospital in Nowogard by the authors. The severity of clinical changes in the thumb and fingers was rated according to the classification of Newport et al. (Cakmak, Wolf, Bruckner, Hahn, Unglaub, 2012) – Table 2.

**Table 2.** Classification of trigger digits according to Newport et al.

| Stage | Characteristics |
|---|---|
| 1 | Pain and tenderness on the level of the A1 pulley, no palpable nodule or triggering |
| 2 | Tenderness, swelling or tendon nodularity with occasional triggering or catching during active movements |
| 3 | Manifestations of stage 2 with frequent triggering or catching, additionally locking of the digit |
| 4 | Digit is flexed in the proximal interphalangeal joint |

Limitation of mobility of the thumb and fingers was examined using the Buck- Gramcko classification (Cakmak, Wolf, Bruckner, Hahn, Unglaub, 2012).

**Table 3.** Classification of severity of limitation of motion finger according to Buck-Gramcko

| Grade | Finger-palm distance | Severity of limitation |
|---|---|---|
| 0 | 0 | No limitation |
| 1 | >0–2.5 | Light |
| 2 | >2.5–4 | Moderate |
| 3 | >4–6 and fixed digit | Severe |
| 4 | Whole hand | |

The range of motion of the thumb was examined using goniometer (Table 4).

**Table 4.** Classification of severity of limitation of motion thumb according to Buck-Gramcko

| Thumb (IP-joint) | Range of motion | Severity of limitation |
|---|---|---|
| 0 | >70 | No limitation |
| 1 | 50–70 | Light |
| 2 | 30–45 | Moderate |
| 3 | <29 | Severe |

The extent of swelling in the fingers was studied by following the appropriate scale (Table 5).

**Table 5.** Extent of swelling of thumb and fingers

| Swelling | Severity of swelling |
|---|---|
| 0 | No swelling |
| 1 | Light, without limitation of motion |
| 2 | Moderate, with limitation of motion |
| 3 | Severe, with limitation of motion of the whole hand |

Pain in the thumb and fingers was assessed using the VAS scale (Table 6).

**Table 6.** Grade of pain thumb and finger

| VAS | Grade of pain |
|---|---|
| 0 | No pain |
| 1–3 | Light |
| 4–6 | Moderate |
| 7–10 | Intense |

All patients were treated with open surgery. A transverse incision of approximately 1 cm was made on the palmar side of the hand circumferentially from the distal palmar flexion crease. On the thumb, an incision was made in the metacarpophalangeal area. The vascular-nervous bunch was moved aside. Following the introduction of the probe to the entrance of the channel sheath, the thumb was incised with a knife in the initial portion of the A1 sheath. The free passage of the thickened tendon was tested. If needed, tenolysis was performed to remove adhesions (Choudhur, Tay, 2013; Froimson, 1999). On the fourth day following surgery, exercises were cautiously introduced to improve full flexion and to straighten the fingers as well as stretch, relax and strengthen muscles. Neuromobilisation and automobilisation exercises were conducted. The soft tissue surrounding the scar was mobilised. Patients were taught how to prevent overloads of the fingers (Deskur, Deskur, Zawadzki, 2014; Kużdżał, 2009).

## Results

Forty-two cases of trigger thumb and fingers in 40 patients, treated with surgery and rehabilitation were studied. The changes affected 24 fingers on right hands and 18 on left hands. The finger most frequently affected by changes was I (21 cases), followed by IV (10) and III (9) – Table 7.

**Table 7.** Number of men and women treated with trigger thumb and fingers

| Thumb and fingers | Numer of hands | | | | Together | |
|---|---|---|---|---|---|---|
| | right | | left | | | |
| | n | % | n | % | n | % |
| I | 12 | 28.6 | 9 | 21.4 | 21 | 50.0 |
| II | – | – | – | – | – | – |
| III | 5 | 11.9 | 4 | 9.5 | 9 | 21.4 |
| IV | 5 | 11.9 | 5 | 11.9 | 10 | 23.8 |
| V | 2 | 4.8 | – | – | 2 | 4.8 |
| Together | 24 | 57.1 | 18 | 42.9 | 42 | 100.0 |

The mean duration of symptoms was 5 months. Prior to surgery, the severity of changes in lesions thumbs and fingers was assessed according to the classification of Newport et al. (Cakmak, Wolf, Bruckner, Hahn, Unglaub, 2012). Most patients were characterized by the second level of severity (Table 8).

**Table 8.** Number of patients with varying degrees of severity changes hands trigger thumb and fingers according to the classification of Newport before surgery

| Degrees | Number of patients | |
|---|---|---|
| | n | % |
| 1 | 5 | 12.5 |
| 2 | 28 | 70.0 |
| 3 | 6 | 15.0 |
| 4 | 1 | 2.5 |
| Together | 40 | 100.0 |

Following surgery, and during rehabilitation, a study of persisting symptoms, such as swelling, pain and limitation of movement of the thumb and fingers, was carried out. After 1 month, 15 patients were symptom-free. In the third month of the study, pain subsided; after 5 months, swelling and limitation of movement disappeared (Table 9). All patients were very satisfied with the results of the treatment.

**Table 9.** The number of thumb and fingers with persisting symptoms after the surgery

| Degrees | The number of thumb and fingers that with persisting symptoms in the coming months scrutineering | | | |
|---|---|---|---|---|
| | 1 | 2 | 3 | 5 |
| Swollen | 25 | 12 | 1 | 0 |
| Pain of thumb and fingers | 4 | 2 | 0 | |
| Restriction of mobility | 7 | 3 | 1 | 0 |
| Pain regional scars | 6 | 1 | 0 | |

## Discussion

In this study, cases of trigger thumb and fingers were more common in women aged 51 to 60 and involved the thumb and fingers III and IV, which is consistent with other reports (Cakmak, Wolf, Bruckner, Hahn, Unglaub, 2012; Choudhury, Tay, 2013; Lange-Riess, Schuh, Honle, Schuh, 2009; Moriya, Uchiyama, Kawaji, 2005). Surgical treatment of trigger thumb and finger is indicated by lack of improved results following conservative treatment. Incision of the initial part of the flexor tendon sheath can done using either the open or percutaneous method. While the presently recommended treatment is percutaneous, many authors see no significant difference between the results of the two methods (Wang, Zhao, Liang, 2013). The open surgery method enables better control of the tendon and the opportunity to carry out additional procedures where necessary. In our study, swelling, pain and restricted mobility of the thumb and fingers subsided after 5 months in all patients. There were no signs of 'jumping'. Apart from slight transient inflammatory reaction in 2 patients there were no complications. In recent years, not many results of open-method surgical treatment of trigger thumb and fingers have been published. I will cite some of these here. Papież, Trybus, Stepańczak, Łoboda, Pokrowiecki, Gądek (2013) studied 50 patients undergoing surgery and recorded that after 3 months most patients achieved total restoration of motion in their thumbs and fingers, full dexterity, and hand grip strength, as well as the abolition of pain. Further improvement was shown after a year had passed. The majority (84%) of patients were very satisfied with the treatment. Choudhury and Tay (2013) found that 25 months following surgery 216 thumbs and fingers had achieved average mobility 84% according to TAM. One patient experienced minor wound dehiscence. Patients undergoing tenolysis also experienced worse results. Cakmak, Wolf, Bruckner, Hahn, Unglaub (2012) reported that 6 months following operations on 117 thumbs and fingers all symtoms had disappeared. One patient experienced dysaesthesia and 2 experieced inflammation of the wound. Lim, Lim, Rasheed, Narayanan, Beng-Hoi (2007) reported that 483 patients had achieved good results 6 months after surgical treatment, with minor complications in 1% of patients. There was no recurrence 'jumping'. Moriya, Uchiyama, Kawaji (2005) studied 110 fingers and reported that 3 weeks after surgery 64% of the fingers were characterized by limited mobility in the PIP joint and patients felt pain while flexing and extending the fingers. None had trigger fingers.

## Conclusions

1. Cases of trigger thumb and finger are most common in women aged 51 to 60 and involve the thumb and fingers III and IV.

2. Lack of improvement following conservative treatment of trigger thumb and finger is an indication for surgery.

3. Open surgery of the thumb and fingers and competent rehabilitation treatment enables a significant and rapid improvement in the efficiency of the hand, with a relatively low rate of complications.

4. In the treatment of trigger thumb and finger, the best results can be achieved in patients treated by a team of specialists.

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# ELECTROPUNCTURE IN NON-SPECIFIC NECK PAIN: A PILOT STUDY

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**Abstract** The aim of the study was to evaluate the effect of electropuncture, i.e. the stimulation of acupuncture points by TENS electrotherapy, on non-specific neck pain and the associated symptoms regularly reported. 16 participants, 10 female and 6 male, completed the study. A TENS machine with a point electrode was used to stimulate a selection of acupuncture points. The primary outcome measure was the intensity of neck pain as measured by changes in scores on pain VAS, the secondary measure was the degree of the associated symptoms regularly reported such as headaches, restriction in daily activities, stress, troubled sleep and general health satisfaction. The results showed that participants who received 3 treatments over 8-14 days experienced a significant short-term reduction in neck pain and restriction in daily activities immediately after the treatment and at 1-month post-intervention follow-up. Our findings also show improvement in the intensity of headaches, degree of stress, quality of sleep and general health satisfaction but the changes were not statistically significant. The present pilot study suggests that stimulation of acupuncture points by the means of TENS electrotherapy may effectively reduce neck pain.

**Key words** acupuncture, electropuncture, TENS, neck pain

## Introduction

Neck pain constitutes a serious public health problem, being one of major causes of disability in many countries (van Randeraad-van der Zee et al., 2015). A variety of therapeutic interventions for neck pain are available including manual therapy, strengthening exercises, laser therapy (Nunes, Moita, 2015) and electrotherapy (Nunes, Moita, 2015; Kroeling et al., 2013). A systematic review of electrotherapy for neck pain showed that TENS might be more effective than placebo for patients with chronic and myofascial neck pain (Kroeling et al., 2013). Another review assessed TENS as effective in treating neck pain, however the evidence was of low quality (Nunes, Moita, 2015). The treatment modalities include also therapies based on acupuncture points. Acupuncture is accepted and recommended for the treatment of neck pain (Nunes, Moita, 2015; Yuan et al., 2015; Liang et al., 2010; Witt et al., 2006; Vas et al., 2006; He et al., 2004; Irnich et al., 2001). Acupressure reduces neck pain intensity, neck stiffness and stress level (Yuan et al., 2015; Matsubara et al., 2011; Yip, Tse, 2006).

Since both acupuncture points therapies and TENS are effective in neck pain, we decided to investigate a combination of the two. In this study we designed an intervention where acupuncture points are stimulated by TENS by means of a point electrode. We called this electropuncture (as opposed to electroacupuncture). There are studies investigating the effect of electroacupuncture in neck pain therapy (Zhang et al., 2013; Cameron et al., 2011; Sahin et al., 2010). In all the studies, however, acupuncture needles were insterted into acupuncture points and then an electracupuncture machine was attached to the needles. In one study (He et al., 2004) "electroacupuncture" involved placing electrodes on the body acupoints without the use of needles. In this study, however, electrotherapy on acupoints was only a part of the intervention. The treatment was a combination of body acupuncture, ear acupressure and body electroacupuncture (He et al., 2004). In all the above mentioned studies the electrotherapy was provided by means of a specialist electroacupuncture equipment. We decided to use a TENS machine with a point electrode.

The aim of our study was to evaluate the effect of electropuncture, i.e. the stimulation of acupuncture points by TENS electrotherapy, on non-specific neck pain and the associated symptoms regularly reported such as headaches, restriction in daily activities, stress, troubled sleep and general health satisfaction.

## Material and methods

The study and its protocol were approved by the Ethical Committee of the Medical University of Silesia, Poland (KNW/0022/KBI/56/II/14). All participants were informed about the purpose of the study, the treatment procedures and contraindications for electrotherapy treatment.

Participants for the study were recruited from May 2011 to January 2012 by advertising at the School of Health Sciences, Medical University of Silesia, Poland and via the website www.Qi-med.com of a physiotherapy practice. The advertisement regarding electropuncture treatments and the study protocol was directed at individuals suffering from dysfunctions, tension and other ailments causing neck pain.

The inclusion criteria for participating in the study were: 1) reporting neck pain, classified by a pain score >0 on a pain Visual Analogue Scale (VAS); 2) not undergoing any other therapy for the pain during the study.

Candidates were assessed in order to ensure they had non-specific neck pain and were safe to participate in the study. Non-specific neck pain was pain in the area of neck and shoulders experienced by a person on most days in the past two weeks. Non-specific pain was not caused either by any pathologies including systemic rheumatic disorders, spinal tumors, fractures, infections or by any known causes including degenerative changes, trauma or surgical intervention (Yip, Tse, 2006). The patients were excluded who suffered from any systemic disease, neurological disorders, infections, fractures or degenerative disorders as well as those with contraindications to the treatment. Also pregnant and breastfeeding women were excluded. Administration of sedatives, analgesic or other medication was an exclusion criteria as well.

The results were measured using Visual Analogue Scales in an anonymous questionnaire on pain and related symptoms which all participants agreed to complete before the first treatment, immediately after the last treatment and one month after the last treatment.

The questions were related to neck pain and the associated symptoms such as headaches, restriction in daily activities, stress, troubled sleep and general health satisfaction. A VAS with the range 0–100 was attached to every question. The range was coloured green from 0 to 25, yellow from 25 to 50, orange from 50 to 75 and red from 75 to 100. Each VAS was accompanied by an explanation what 0 and 100 scores meant. The colour and description on each VAS indicated that scores near 0 were more positive (e.g. lack of pain) and those near 100 were more negative (e.g. the worst pain imaginable).

All treatments were free for the participants.

A total of 35 acupuncture points were used, both local and distal to the neck area. It was shown (Matsubara et al. 2011) that using both local and distal acupuncture points improved pain-related condition. Local points included *Dazhui* (GV14), *Yamen* (GV15), *Fengfu* (GV16), *Fengchi* (GB20), *Jianjing* (GB21), *Tianzhu* (BL10), *Fengmen* (BL12), *Tianliao* (TE15), *Naoshu* (SI10), *Tianjing* (SI13), *Jianwaishu* (SI14), *Jianzhongshu* (SI15); distal ones were located on the upper limbs: *Hegu* (LI4), *Quchi* (LI11), *Houxi* (SI3); and on the lower limbs: *Fengshi* (GB31), *Yanglingquan* (GB34), *Shenmai* (BL62), *Taichong* (LR3). The selection of acupuncture points was based on previous publications. The points chosen proved to be effective in neck pain (Yip, Tse, 2006; Vas et al., 2006; He, Veiersted, Høstmark, Medbø, 2004; Irnich et al., 2001).

A TENS machine (EMS/TENS 271513; Handelshaus Dittmann GmbH Germany) with a point electrode was used to stimulate the points. Participants received electropuncture treatments with TENS at a frequency of 10Hz with 200-microsecond pulse widths and 1mA amplitude. Each point was stimulated for about 30 seconds. The points were stimulated for a total of 18 minutes (35 points, 30 seconds each) and the treatment procedure lasted from 30 to 40 minutes as some time was needed for the points' localisation. All participants received 3 treatments within 8–14 days.

The primary outcome measure in this study was the intensity of neck pain as measured by changes in scores on pain VAS (0 = lack of pain; 100 = the worst pain imaginable). The secondary measure was the degree of the associated symptoms regularly reported such as headaches, restriction in daily activities, stress, troubled sleep and general health satisfaction as measured by changes in scores on Visual Analogue Scales attached to each question about the symptoms: the degree of restriction in daily activities caused by the neck pain (0 = the neck pain did not affect the everyday activities at all; 100 = the neck pain prevented the person from performing everyday activities); the intensity of headaches (0 = lack of pain; 100 = the worst pain imaginable); the degree of stress experienced in life by a person (0 = lack of stress; 100 = the worst stress imaginable); the quality of sleep (0 = the perfect sleep; 100 = lack of sleep); the satisfaction with the general state of health of a person (0 = total satisfaction with the state of one's health; 100 = complete dissatisfaction).

Data analysis was conducted using the Statistica PL software. For each parameter the following descriptive statistics were calculated: arithmetic mean, minimum, maximum, standard deviation. The statistical significance was set at 0.05.

To compare the differences between results pre- and post-intervention Student's t-test or ANOVA were used. The results are presented as mean ±SD.

## Results

During the recruitment 20 people were screened but 4 of them did not meet the inclusion criteria. The study was completed by 16 participants, 10 female and 6 male. The average age was 24 years (age range 19–29 years). There were no drop-outs either during the treatment period or during the 1-month follow-up.

The intensity of neck pain was reduced significantly. It fell from the baseline of 51.31 ±18.88 to 30.63 ±20.07 after the last treatment and remained significantly lower at 29.13 ±18.52 at the 1-month post-intervention follow-up ($p < 0.05$; $p = 0.001$). The results are presented in Table 1.

Among the secondary outcomes only the degree of restriction in daily activities caused by the neck pain was significantly reduced. Before the intervention the scoring here was 47.06 ±20.61 and fell significantly first to 26.63 ±18.66 immediately after the treatments and then to 21.13 ±13.42 at a month follow-up ($p < 0.05$; $p = 0.0003$). There were no significant differences in the intensity of headaches, degree of stress, quality of sleep and general health satisfaction, although all the parameters improved. The results are presented in Table 1.

## Discussion

This pilot study investigated the effect of electropuncture on non-specific neck pain. This is, to our knowledge, the first study investigating the stimulation of acupuncture points by TENS in non-specific neck pain. The results show that participants who received 3 treatments over 8–14 days experienced a significant short-term reduction in neck pain and restriction in daily activities immediately after the treatment and at 1-month post-intervention follow-up. Our findings also show improvement in the intensity of headaches, degree of stress, quality of sleep and general health satisfaction but the changes were not statistically significant.

The results of our study are in line with several studies investigating the effect of therapies based on acupuncture points in neck pain. Electroacupuncture proved to significantly reduce neck pain after therapy and at 3 months post-therapy (Cameron et al., 2011; Sahin et al., 2010) as well as significantly reducing restriction in daily activities after the treatment and at the 3-month and 6-month follow-up (Cameron et al., 2011). Acupuncture and acupressure also could be efficacious in neck pain and the related disability (Yuan et al., 2015). An overview of Cochrane reviews concluded that acupuncture is effective in reducing some types of pain but not all of them. Neck pain is proved to be reduced by acupuncture treatments (Lee, Ernst, 2011).

The participants in our study were young people (age range 19–29 years) without any serious degenerative changes. Therefore it cannot be assumed that the same effect of a 1-month pain reduction would be obtained in older people. Another study focusing on older population is needed.

Our pilot study suggests that stimulation of acupuncture points by the means of TENS electrotherapy may effectively reduce neck pain. It implies that electropuncture may be performed not only by acupuncturists equipped with a specialist electroacupuncture machines but also by physiotherapists equipped with a TENS machine and instructed about the location of acupuncture points used in non-specific neck pain therapy.

There are several limitations to this study, including the lack of a control group to eliminate the placebo effect and a short follow-up. This was, however, a pilot study and a larger randomized controlled trial is planned. The study also lacks individual diagnosis according to Traditional Chinese Medicine, which resulted in the use of 19 local and distal acupuncture points. The TCM diagnosis would reduce the number of points as only those related to a specific syndrome would be used for each case. Another limitation is the fact of high values of SD in all outcomes measures which may suggest that the treatment group was heterogenous.

## Conclusion

This pilot study shows that electropuncture reduces non-specific neck pain intensity and restriction in daily activities, caused by the pain, for a month period.

**Table 1.** Comparison on the mean change in the pre-intervention and post-intervetion outcomes immediately after therapy and at 1 month post therapy

| Outcome variables | Baseline mean ±SD | Post last treatment mean ±SD | Post 1 month mean ±SD | p-value |
|---|---|---|---|---|
| Intensity of neck pain | 51.31 ±18.88 | 30.63 ±20.07 | 29.13 ±18.52 | 0.001* |
| Degree of restriction in daily activities | 47.06 ±20.61 | 26.63 ±18.66 | 21.13 ±13.42 | 0.0003* |
| Intensity of headaches | 40.25 ±28.11 | 29.69 ±22.23 | 25.25 ±24.91 | 0.234 |
| Degree of stress | 49.94 ±18.24 | 40.75 ±25.81 | 36.19 ±22.37 | 0.219 |
| Quality of sleep | 46.75 ±23.40 | 34.38 ±21.98 | 29.31 ±23.60 | 0.099 |
| General health satisfaction | 47.38 ±24.12 | 36.63 ±22.05 | 34.69 ±20.53 | 0.232 |

* significant difference ($p < 0.05$)

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# MONITORING SYSTEM OF FUNCTIONAL ABILITY OF UNIVERSITY STUDENTS IN THE PROCESS OF PHYSICAL EDUCATION

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**Abstract** Given research is devoted to the regional criteria development for evaluation of educational achievements and preparation of practical recommendations for teachers of higher educational institutions on the application of methodology for assessing the functional opportunities in process of physical education. During the research evaluation standards of functional opportunities of students were developed with the usage of mathematical statistics on the basis of the average arithmetic value (M) and standard deviation (σ). The study involved 150 students (86 girls and 64 boys, who belonged to the main medical group).Appropriate norms provide more complete information about positive (negative) changes of functional opportunities' level compared with traditional pedagogical tests. There are represented practical recommendations on the usage of functional testing during training sessions at universities in order to optimize the process of physical education.

**Key words** students, physical education, functional testing, academic achievement, functional abilities, physical health

## Introduction

For successful implementation of their profession in Ukraine graduates of higher education institutions need to have good health and sufficient level of physical performance. The main role in solving this problem is played by formation of students' healthy lifestyle. The main source of information about health are education classes on physical education, especially methodological and practical and educational training sessions.

In Ukraine during the years of independence there was some system of physical education of students the general features of which are fixed by number of regulation documents (Domashenko, Raievs'ky, Kanishevs'ky, 2003; Operaylo, 2006). The Provision about the organization of physical training and mass sports in universities sets the total amount of mandatory lessons of physical training in universities, which is at least 4 hours a week, except for the last semester of graduation course (Domashenko, Raievs'ky, Kanishevs'ky, 2003). Estimation of learning achievements in higher education in accordance with the provision of the exhibiting credits in physical education provides for a complex monitoring on the basis of indicators of physical fitness, technical performance of motor actions and theoretical training. A key components of the estimation of educational achievements are tests and assessment standards of physical fitness of students, developed in higher education in coordination with the ministry or agency to which they are subordinated (Domashenko, Raievs'ky, Kanishevs'ky, 2003). Given that developed by higher education institution regulations in some cases do not have enough scientific and practical justification and in general give a superficial knowledge of the physical condition and efficiency of students, it is possible to use functional tests on practical lessons on physical education.

A variety of methods caused differences represented in literature in terms of physical performance, even such as PWC170. This leads into the category of topical tasks necessity of improvement and unification of methods for determining the functional abilities of students.

In our opinion (Bosenko, Samokish, Dubinin, 2008; Samokysh, 2005; Samokysh, Bosenko, 2009) the most accurate, efficient and informative is cyclical handling test (Davidenko, Andrianov, Yakovlev, 1984), in which the power of exercise varies by closed cycle. This method allows detecting not only indicators of physical efficiency and response of the cardiovascular system, but also allows to set regulatory and energy components of the system reaction of the human body. However, qualifications for athletes, require the development of criteria for estimation and adapting it for research the students during physical education classes.

## Material and methods

Regional criteria for assessment of student achievement and prepare practical recommendations for teachers of higher educational institutions and application of evaluation methods of functional abilities in a process of physical education need to be developed. The study involved 150 students of first and second courses aged 18–19 years, who studied in the South National Pedagogical University named after K.D. Ushinsky (c. Odessa) and A.S. Popov Odessa National Academy of Telecommunications. During the research methodology of Davidenko, Andrianov, Yakovlev (1984) was used. The load was set on ergometers at a frequency of pedaling 60 rev/min. Power of physical load initially increased from zero with the set speed of 33 W • $min^{-1}$ to planned values (HR = 153 – 156 b • $min^{-1}$), and then decreased at the same speed to zero. The meaning of the method is a graphical record in two-co system of frequency of heart rate depending on the power load and set on ergometer.

## Results

Studies have shown that settings of functional abilities received during bicycle exercise load with the change of power in a closed loop during physical education classes in high school to assess educational progress can successfully be used. The modified method allowed obtaining indicators of systemic reactions, as tensions of functions when performing load tests, energy, regulatory components of cardiac activity and a number of indicators of overall physical efficiency. After the test results can be obtained in printed form in 5–10 sec. Studied informational content about 25 test parameters that characterize the functional abilities of the students.

The corresponding indicators of functional test play a role of criteria play in the estimation of educational achievements but their information content is not the same: high, medium and low. That’s why on base of correlation

- regression and factor analysis we selected the most informative indicators that reflect the different sides of the level of functional abilities. Assessment is made with the help of special developed evaluation standards for boys and girls aged from 18 to 19 years (Table 1, 2).

**Table 1.** Evaluation standards of functional abilities of students in higher education institutions

| Indexes | MARKS, POINTS | | | | |
|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 |
| $PWC_{170}$, W | <204.80 | 204.90–214.90 | 215.00–235.00 | 235.10–245.10 | >245.20 |
| $W_{rev}$, W | <159.80 | 159.90–169.90 | 170.00–186.00 | 186.10–194.10 | >194.20 |
| $HR_{thresh}$, $b.\cdot min^{-1}$ | >101.20 | 96.10–101.10 | 86.00–96.00 | 80.90–85.90 | <80.80 |
| $HR_{out}$, $b.\cdot min^{-1}$ | >124.20 | 118.10–124.10 | 106.00–118.00 | 99.90–105.90 | <99.80 |
| $HR_{ave}$, $b.\cdot min^{-1}$ | >134.20 | 128.10–134.10 | 116.00–128.00 | 109.90–115.90 | <109.80 |
| $S_1$, $W\cdot min^{-1}$ | <3252.00 | 3253.00–3453.00 | 3454.00–3854.00 | 3855.00–4055.00 | >4056.00 |
| $T_{it}$, s | <37.80 | 37.90–39.90 | 44.00–48.00 | 48.10–50.10 | >50.20 |
| $C_{eff}$, c.u. | >0.12 | 0.10–0.11 | 0.07–0.09 | 0.05–0.06 | <0.04 |
| $W_{max}$, W | <203.80 | 203.90–214.90 | 114.00–236.00 | 236.10–247.10 | >247.20 |
| $W_{out}$, W | <189.80 | 189.90–199.90 | 200.00–220.00 | 220.10–230.10 | >230.20 |
| $W_{1\ out}$, J | <1.20 | 1.21–1.22 | 1.23–1.25 | 1.26–1.27 | >1.28 |
| $W_{2\ out}$, J | <1.08 | 1.09–1.19 | 1.20–1.22 | 1.23–1.24 | >1.25 |
| Possible amount of points | 1–12 | 13–24 | 25–36 | 37–48 | 49–60 |

The scorecard includes the following indicators: physical efficiency $PWC_{170}$ and $W_{rev}$, threshold pulse – $HR_{thresh}$, heart rate at the time of completion of the load, testing – $HR_{out}$, arithmetic average of pulse beats for functional test – $HR_{ave}$, rate of redistribution of power of heart rate (HR) in the full cycle of testing – $S_1$, inertia time – $T_{it}$, efficiency of ratio regulation of cardiac activity – $C_{eff}$, the level of internal power at the time of the reverse $W_{rev}$, level of internal power at the end of testing – $W_{out}$, outer work of heartbeat by increasing the load – $W_{1out}$, outer work of heartbeat by decreasing the load – $W_{2out}$.

**Table 2.** Evaluation standards of functional abilities of students in higher education institutions

| Indexes | MARKS, POINTS | | | | |
|---|---|---|---|---|---|
| | 1 | 2 | 3 | 4 | 5 |
| $PWC_{170}$, W | <156.80 | 156.70–165.70 | 165.80–184.20 | 184.30–193.50 | >193.60 |
| $W_{rev}$, W | <141.20 | 141.30–149.60 | 149.70–166.30 | 166.40–174.70 | >174.80 |
| $HR_{thresh}$, $b.\cdot min^{-1}$ | >103.20 | 98.10–103.10 | 88.00–98.00 | 82.90–87.90 | <82.80 |
| $HR_{out}$, $b.\cdot min^{-1}$ | >131.20 | 125.10–131.10 | 113.00–125.00 | 106.90–112.90 | <106.80 |
| $HR_{ave}$, $b.\cdot min^{-1}$ | >140.20 | 134.10–140.10 | 122.00–134.00 | 115.90–121.90 | <115.80 |
| $S_1$, $W\cdot min^{-1}$ | <2984.00 | 2985.00–3169.00 | 3170.00–3538.00 | 3539.00–3723.00 | >3724.00 |
| $T_{it}$, s | <36.80 | 36.90–38.90 | 39.00–43.00 | 43.10–45.10 | >45.20 |
| $C_{eff}$, c.u. | >0.13 | 0.11–0.12 | 0.08–0.10 | 0.06–0.07 | <0.05 |
| $W_{max}$, W | <190.80 | 190.90–200.90 | 201.00–221.00 | 221.10–231.10 | >231.20 |
| $W_{out}$, W | <174.80 | 174.90–184.90 | 185.00–205.00 | 205.10–215.10 | >215.20 |
| $W_{1\ out}$, J | <0.90 | 0.91–1.01 | 1.11–1.31 | 1.32–1.42 | >1.43 |
| $W_{2\ out}$, J | <0.97 | 0.98–1.08 | 1.09–1.29 | 1.30–1.40 | >1.41 |
| Possible amount of points | 1–12 | 13–24 | 25–36 | 37–48 | 49–60 |

For according tables, individual indicators are considered average if the same points with the average value (M) and are in the range M ±0.5σ. When finding values within M – 0.5σ ... M – 1σ and M + 0.5σ ... M + 1σ functional indicator is considered lower or above average, respectively, while the difference of +1σ and higher and from –1σ and lower – high or low. If the regression indicator, that is, the smaller the certain parameter, the higher its manifestations (e.g. heart rate indicators during exercise testing), were used the following gradation: the level below average and above average determined by range M + 0.5σ ... M + 1σ and M – 0.5σ ... M – 1σ, low or high – respectively from +1σ and higher and from –1σ and lower.

With the help of developed evaluation standards for physical education teacher can get a more complete and accurate information about the level of functional abilities of students which expressed qualitatively and quantitatively for sum of points.

We offer the following practical advice on assessment of student achievement in high school.

1. Evaluation of functionality should be spent in the classroom for physical education, in some cases after school. The organizers of testing of physical education are teachers who mastered technique well. Testing should be held in the gym or the premises, the presence in several high school of ergometer software. The students of preparatory and special medical groups performing functional tests with the permission of the doctor, it is desirable that a medical professional was there during the test. Previously, before the test at the beginning of the school year, held the meetings to inform students about the related activities.

2. We propose to held a staged, current and operational control of functional ability level. Staged control need to held 3 times during the school year. In the first stage (the second half of September) is defined the output level by indicators of bicycle exercise testing. In the second (beginning of December) and third (second half of April) stages are assessed change of functional ability of students during training. Current control need to held one time a month to identify the level of changes on adaptive abilities in the dynamics of the learning process. Operational control is performed to obtain immediate information about the functional status of some students.

3. Functional tests on staged control should be carried out from 11 to 13 pm, when the body of the overwhelming number of students according to biorhythmology physical efficiency the most favorable react on muscle load. For this testing period, schedule of classes, if it is necessary changes so that the pair of physical education was the third or fourth timetable. Appropriate physical education classes entirely devoted to evaluation functional abilities. Bicycle exercise testing of students while current control is performed for several pairs as physical exercise included in the outline for the session. In operational control main number of students with significant positive (negative) growth dynamics and high (or low) level of functional abilities. In this stage of testing is held individually in training time and after all pairs.

4. At the beginning of the school year in the first half of September trial test are held in the form of physical exercise in the classroom for physical education. Bicycle exercise testing during staged, current and operational control in the classroom and after a pair in free time from education performed without warming up. During the functional test the teachers of physical education should monitor compliance pedaling rate of students (60 rev/min). Exactly, according the planned indicators of heart rate on the reverse (HR = 153 – 156 b · $min^{-1}$) to reduce bicycle exercise loading. Follow the well-being of students while performing functional tests thus rely on external indicators of fatigue (discoloration of skin, sweating rate, respiratory rate, etc.).

5. To assess the level of functionality using approximate legislative table in terms of heart rate, physical performance, efficiency and regulation of cardiac parameters of the energy developed by the test results with the

change of power in a closed cycle. On the bases of the assessment of functional abilities for physical education teachers correcting process of physical education in the school that would contribute the expansion of functional reserves of the body of students and improve physical health.

## Discussion

In area of physical culture and sports for monitoring of physical health of pupils and students widely adopted methods for quantitative estimation of physical efficiency, among which Rufye's test, a Harvard step test and PWC170. However, the obtained results by an appropriate methods through certain inaccuracies in the obtaining results and the wrong approach of finding the appropriate indicators, which do not take into account the age-related changes that occur in organism of children and young people are low informative. Researches of such character are also accompanied, unfortunately, the lack of a common approach and accordingly the contradictory of results, as evidenced the analysis carried out by us. Some of the data not only differ significantly, but also exceed the mapped numbers almost in two times. Fluctuation ranges of physical efficiency are so great that their practical usage is possible with some caution.

According to our opinion, the method of testing the physical efficiency of the human body using a physical activity, capacity of which changes in a closed cycle (Davidenko, Andrianov, Yakovlev, 1984), corresponds to the majority of known requirements. On the basis of obtained results of physical efficiency, can be estimated the state of health as well as in complex with physical preparedness to make a correction of teaching and educational process of physical education in universities.

Given methodic is not widely used and has been used in a few studies of functional reserves of sportsmen of high qualification (Davidenko, Andrianov, Yakovlev, 1984; Bosenko, Samokish, Dubinin, 2008), and was implemented in teaching and educational process of physical education of elementary school in some educational institutions (Samokish, 2005). In open literature there are no complex researches of functional opportunities of students based on of physical efficiency and physical preparedness.

Obviously, using the proposed method of Davidenko, Andrianov, Yakovlev (1984), we can give a more accurate and comprehensive assessment to the level of functional abilities of students. According to Kornienko and Sonkyna (1999) is ergometric testing as a key component of the assessment of physical efficiency, absent in education programs. The results of the research, according to physical activity in a closed cycle with has real opportunity to get as much practice in popular usage as indicators of physical fitness, confirming the relevance and prospects of research in this area.

## Conclusion

Regulations Proposed in our study give more information on the positive (negative) change in the level of functional abilities during the school year, which will help the teacher to perform the correction of the educational process, apply individual and differentiated approach in the classroom for physical education, determine the level of physical health of students etc.

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# THE APPLICABILITY OF USING PARAMETERS OF THE AUTOCORRELATION FUNCTION IN THE ASSESSMENT OF HUMAN BALANCE DURING QUIET BIPENDAL STANCE

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**Abstract** The purpose of the study was to analyze the parameters of the autocorrelation function when assessing time series ground reaction force (GRF) signals during quiet standing. GRF in the three directions were recorded on two Kistler force plates during three 15-s trials in a sample of 82 (31 females and 51 males) participants. Autocorrelation was performed on the GRF data and four parameters characterizing the function were computed. Comparisons of the right- and left-foot parameter means showed significant differences in mediolateral GRF for the time of the function's decay to 0, magnitude of the derivative output, and mean decay velocity to the extremum. Significant correlations were observed among all parameters – weak correlations between the time of the function's decay to 0 and the time to the first extremum and strong correlations between the derivative output and mean decay velocity to the extremum. The analyzed autocorrelation function parameters can serve as a precise measure of the motor control process during quiet standing. The strong correlations observed between the four parameters indicate that they evaluate similar properties of the central nervous system as a regulator of balance maintenance.

**Key words** symmetry, asymmetry, foot, force, balance, quiet standing, autocorrelation

## Introduction

While human movement and locomotion has many modes, almost all tasks rely on some form of postural stability (Skelton, 2001; Van Ooteghem et al., 2008). Maintaining balanced erect posture, contrary to appearances, is a very complex and dynamic process (Morningstar et al., 2005). While the postural control processes responsible for balance are almost entirely automatic and reflexive, the effects of aging and disease can introduce a number of impairments and deficits (Brown et al., 1999; Woollacott, Shumway-Cook, 2002).

In static conditions, bipedal standing is most commonly modeled as an inverted pendulum (Winter et al., 1998; Loram, Lakie, 2002; Chao, Xin, 2004). This model assumes that the control mechanisms of standing are guided by changes in the ground reaction force vector at the base of support (Golema, 2002; Kuczyński, 2003; Winter, 1995). The body needs to continuously adapt to any change in the center of gravity (itself dependent on changes in body position and posture). Therefore, any change in the center of gravity is actioned by changes in the ground reaction force vector. For this reason, this variable can be treated as the neuromuscular response (regulator) to imbalances in the body's center of gravity. Even the most simple activities of daily living involve a very high level of neuromuscular function involving a multitude of systems (Brown et al., 1999; Lafond et al., 2009).

Quantitative assessments of balance control are most commonly performed by measuring ground reaction forces with a force platform (Onell, 2000; Lafond et al., 2004; Doyle et al., 2007; Kijowski, 2013; Liang et al., 2015). By determining the magnitudes of the ground reaction force vectors, clinically useful data can be extrapolated on the relationship between the whole body and individual body segments with respect to the supporting surface (Ayyappa, 1997). The registration of ground reaction force data as a function of time has allowed researchers to effectively albeit indirectly measure upright balance control. The acquired time history has been described as a stochastic process (Theiler et al., 1992). To determine the descriptive characteristics of such a time series, probabilistic tools and techniques from statistical mechanics can be applied. Since force data can be treated as a signal, signal processing can aid in comparing the spatial or temporal characteristics of time-varying signals or identify a pattern within a signal such as by comparing it with its own time-shifted copy. Such comparisons involve a phase delay, where one signal is shifted forwards and backwards in time against another. This produces a correlation function of the two signals at each increment of the phase shift and can define the linear relationship between each point in the signal (Szabatin, 2002). When a time-varying signal is compared against itself, this is called an autocorrelation.

The autocorrelation function is a powerful and efficient alternative to quantifying associated patterns and events between variables. Autocorrelations can be calculated using large or small data sets based on a stationary or non-stationary time series that do or do not show trends. If the time-series data exhibits a trend, by definition the curve of the autocorrelation function shows a slow decay to a value of 0, whereas a rapid decay of the autocorrelation function in effect indicates the presence of uncontrolled change (typically through noise) in the time series. Furthermore, the autocorrelation function of data with a periodic component will also show periodicity (similar to the frequency of the input signals). In this way, autocorrelation can provide an objective measure of the dependencies relating two variables in a time series (random or not) at a given moment in time from the phase shift of preceding and succeeding events. Therefore the aim of the work was to calculate the autocorrelation function of GRF time series data during quiet standing and determine which autocorrelation parameter best characterizes the strategies utilized by the postural control system to maintain balance. Based on the acquired GRF signals, two research questions were formulated:

1. What are the values of the parameters of the autocorrelation?
2. Do any dependencies exist between the individual parameters?

For the purposes of the study, we assumed that changes in ground reaction force (direction and amount of force applied by the muscles) as a function of time during quiet standing can indirectly quantify the ability to maintain balance. By analyzing the nature of these changes as a time series, the autocorrelation function can identify the characteristics of neuromuscular control (regulator) and therefore serve as an indicator of central nervous system function during erect posture (Traczyk, Trzebski, 2001).

## Material and methods

A sample of 82 individuals (31 females and 52 males) representing a wide age range (14–55 years of age) was recruited among an athletic and sedentary population. Mean age was 22.56 ±1.81 years, height 181.69 ±6.39 cm, and body mass 78.73 ±10.7 kg. All individuals provided their written informed consent to participate in the study. Approval from the local ethics committee was obtained. The study was performed at the Laboratory of Biomechanical Analysis of the University of Physical Education in Wrocław, Poland (ISO 9001:2001 certified).

The study protocol involved measuring ground reaction forces (GRF) during quiet standing on two 600 × 400 mm piezoelectric force plates (type 9286B; Kistler Instruments AG, Switzerland) each placed under one foot. The force plates were integrated with the prepackaged BioWare 4 software to synchronize the force–time characteristics from both plates. Four tri-axial force sensors located in the corners of the plates quantified GRF signal components in the mediolateral ($F_x$), anteroposterior ($F_y$), and vertical ($F_z$) directions at a sampling frequency of 50 Hz (measurement range was from 10 kN to 20 kN). All instruments were properly calibrated and the BTS Smart system (BTS Bioengineering, USA) was used to synchronize all data.

The measurement protocol required the participant to stand with feet parallel (no ankle rotation) to one another with a stance width of 30 cm. The participated was asked to assume a relaxed upright posture with the upper extremities resting freely against the trunk. Three trials of 25 s quiet standing were executed one after the other with no change in foot position. GRF signals were recorded 10 s after trial commencement, giving a 15 s time window of data acquisition. In total, 246 trials of quiet standing GRF were collected. The net forces were normalized to participants' body mass and expressed for the right and left foot. An exemplary plot of raw vertical ground reaction force ($F_z$) synchronized between the right and left foot force platforms is given in Figure 1.

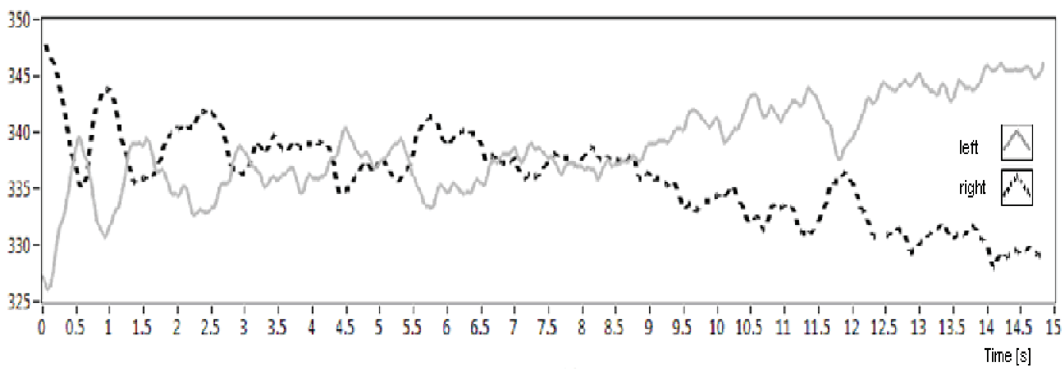


**Figure 1.** Exemplary plot of vertical ground reaction force (Fz) synchronized between the right and left foot force platforms

The autocorrelations from the raw ground force data were calculated based on the equation (Greene 2012):

$$R_x(\tau) = \lim_{T \to \infty} \frac{1}{T} \int_0^T x(t)x(t+\tau)dt$$

The signal X (t) at time t (stationary time) was self-correlated but shifted by 1/48 s (t + τ) to represent the phase delay whereas T is the duration of the record in seconds. The increment size for τ was defined by the data sampling frequency. Figure 2 provides an exemplary plot of the autocorrelation function for right and left foot vertical ground reaction force ($F_z$) during a 15-s standing trial. Based on the computed autocorrelations, a number of relevant parameters were determined to interpret the results:

$T_0$ – as the elapsed time from the beginning of the record (zero phase shift) when the autocorrelation function by definition has a peak value of +1 to when a value of 0 was reached,

$T_{ex}$ – as the elapsed time from the beginning of the record (zero phase shift) to when the autocorrelation curve reached the first extremum (reversal of direction),

$D_{ex}$ – as the extremum of the derivative output of the autocorrelation function, obtained by differentiation (an exemplary plot is provided in Figure 3),

$G_S$ – as the gradient strength of the autocorrelation function, or the mean decay velocity from a value of 1 to when the extremum is reached (i.e. the quotient of the autocorrelation coefficient by the time to reach the first extremum).

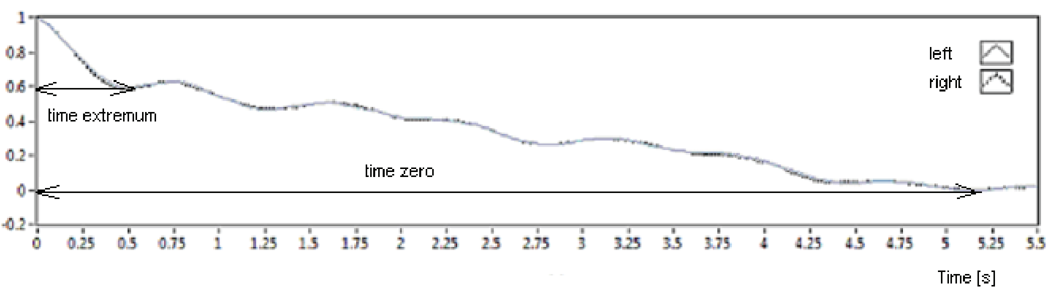


**Figure 2.** Exemplary plot of the autocorrelation function for right and left foot vertical ground reaction force ($F_z$) to the point where it reaches a value of 0 and the first extreme

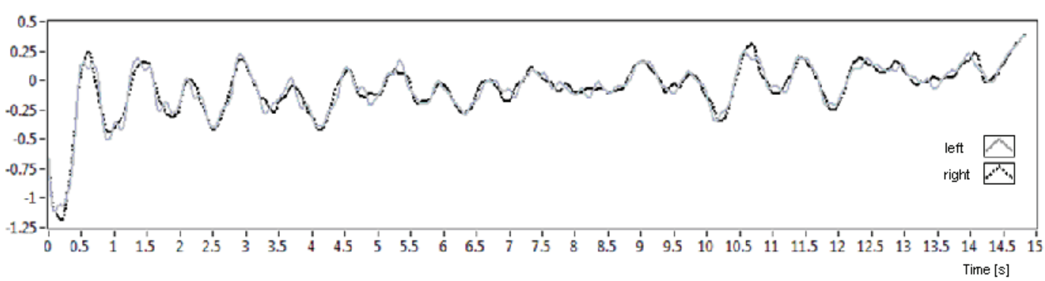


**Figure 3.** The derivative of the autocorrelation function

## Statistical analysis

Basic descriptive statistics were calculated (means ± standard deviations) for all variables. The distribution of the data set was screened for normality using the Shapiro–Wilk test. The means were compared using Student's t test whereas Pearson's correlation coefficients were calculated to determine the dependencies between the variables. The significance level for all statistical procedures was set at $\alpha = 0.05$ ($p \leq 0.05$). Data processing was performed with the Statistica 9.0 software package.

## Results

Testing the assumption of normality revealed the data to show a normal distribution. No significant between-sex differences for right and left foot GRF were observed. Hence, data were analyzed for the entire sample (n=246 trials). Comparisons of the mean right- and left-foot autocorrelation parameters revealed significant differences only in mediolateral (Fx) GRF for T0, Dex, and GS. Some differences were noted in the other two directions although these were not statistically significant (Table 1).

**Table 1.** Means and standard deviations of the autocorrelation function parameters (n =246 trials), significant differences (p ≤ 0.05) between right- and left-foot values are marked in bold

| Indexes | Foot | Variable | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Time zero | | Time extremum | | Derivative extremum | | Gradient strength | |
| | | Means | SD | Means | SD | Means | SD | Means | SD |
| Mediolateral | right | 2.549 | 1.666 | 1.997 | 1.986 | -1.736 | 0.948 | 0.847 | 0.529 |
| | left | 2.842 | 1.541 | 2.137 | 1.819 | -1.437 | 0.831 | 0.705 | 0.457 |
| Anteroposterior | right | 2.918 | 1.746 | 1.521 | 1.418 | -1.481 | 0.693 | 0.811 | 0.401 |
| | left | 2.925 | 1.712 | 1.518 | 1.400 | -1.485 | 0.697 | 0.815 | 0.407 |
| Vertical | right | 3.081 | 1.655 | 1.513 | 1.597 | -1.779 | 0.839 | 0.832 | 0.492 |
| | left | 3.126 | 1.652 | 1.648 | 1.733 | -1.753 | 0.809 | 0.799 | 0.444 |

When analyzing Tex (time to the first extremum), it was possible to determine the frequency content of the signal responsible for changes in the direction of GRF. A mean frequency of 0.5–0.7 Hz was found, although the large standard deviations indicate considerable inter-individual variance. Although no significant differences were observed between right- and left-foot Tex, comparisons of the magnitudes of this parameter in each of the three directions revealed that the frequency of the control processes responsible for balance in the mediolateral GRF ($F_x$) was evidently lower than in the other two directions.

Correlative analysis revealed statistically significant correlations between all of the parameters of the autocorrelation function for both right- and left-foot GRFs in all three directions (Table 2.). The coefficients were the smallest for the relationship between $T_0$ and $T_{ex}$ ($r = 0.383$, mean for all right and left-foot GRF directions) whereas the highest was between $D_{ex}$ and $G_S$ ($r = 0.898$, respectively).

**Table 2.** Pearson's correlations (r) observed between the autocorrelation function parameters (n = 246 trials), significant differences ($p \leq 0.05$) between right and left foot values are marked in bold

| Indexes | Foot | Variable: Time zero – time extremum | Time zero – derivative extremum | Time zero – gradient strength | Time extremum – derivative extremum | Time extremum – gradient strength | Derivative extremum – gradient strength |
|---|---|---|---|---|---|---|---|
| Mediolateral | right | 0.59 | 0.72 | -0.73 | 0.67 | -0.69 | -0.91 |
| | left | 0.44 | 0.56 | -0.52 | 0.67 | -0.66 | -0.92 |
| Anteroposterior | right | 0.32 | 0.63 | -0.65 | 0.56 | -0.62 | -0.90 |
| | left | 0.32 | 0.62 | -0.65 | 0.55 | -0.61 | -0.91 |
| Vertical | right | 0.33 | 0.67 | -0.66 | 0.54 | -0.55 | -0.89 |
| | left | 0.30 | 0.60 | -0.53 | 0.58 | -0.61 | -0.86 |
| r | | 0.383 | 0.633 | 0.623 | 0.595 | 0.623 | 0.898 |

## Discussion

The measurement of GRF provides clinically relevant information in the field of human movement research by indirectly assessing balance function and related motor control processes during gait or standing. As a static condition, standing can be quantified by the spatial positioning of body segments at different angles to form a whole-body kinematic model (Zatsiorsky, 2002). However, upright bipedal stance is itself unstable and features constant mediolateral and/ or anteroposterior sway. Every postural action by an individual requires autonomous neuromuscular input via activation of key muscle groups in order to maintain balance. This requires the central nervous system to integrate information from multiple sensory systems before activating the postural muscles necessary for balance (Traczyk, Trzebski, 2001). For this reason even quiet standing, contrary to appearances, is a complex biomechanical process that requires multiple actions in order to maintain balance. In most cases it is a process entirely involuntary and has no set time duration (although standing is frequently a long-duration task).

The available methodologies to recognize patterns and events in balance maintenance are incredibly complex, as they need to meet multiple conditions in order to provide valid and reliable measures from which relevant biophysical findings can be extracted during the data analysis stage. Duarte and Freitas (2010) indicated that this process can be confounded by various factors including health status, body characteristics, physical fitness, age, environment, and internal causes. The latter is considered the most influential, in that neuromuscular deficits, impaired motor control, and even small perturbations within the body (breathing, shifting weight from one foot to the other, heartbeat) can induce significant imbalance. Hence, as a mechanical event, postural balance is an unattainable state as the forces acting on the body are never at perfect equilibrium.

Currently, the literature has accepted the measurement of ground reaction forces via force plate as the gold standard in balance assessments especially in human movement and rehabilitation research (Lorkowskim et al., 2009; Czamara, 2007; McComis et al., 1997). For example, Czamara (2007; 2011) confirmed the applicability of this methodology in the treatment of foot injury. Due to differences in foot loading during standing between the feet, these authors used two force plates to interdependently determine the GRF time series of the right and left foot. Another aspect contemplated in functional balance assessments via GRF was the standardization of foot positioning (Chiari et al., 2002). For these reasons the present study's investigation of balance during quiet standing considered the differences between the right and left foot completely parallel to one another.

Raymakers et al. (2005) compared GRF-derived parameters from different age and health status groups to find significant differences in the discriminatory ability of said parameters. They concluded that the observed inconsistencies were due to a lack of standardized methodology in balance and stability assessments, such as differences in task duration (from 10 to 120 s), the number of trials (from three to nine repetitions), and sampling rates (from 10 to 100 Hz). In this regard, the measurement protocol of the present study was selected to be in line with that commonly used in the literature.

The application of signals processing techniques to interpret physiologically-relevant data on balance has great potential. Duarte et al. (2000) and Duarte and Zatsiorsky (2000; 2001) analyzed the temporal characteristics of GRF signals during 30 min of standing to find high ergodicity over the entire data range. GRF signal data accrued over different temporal distances (measurement duration) were highly correlated with each other, indicating that the postural control system has fractal properties. They found that a shorter measurement projection, up to a few minutes, produces a non-stationary signal and posited that this was due to low frequency noise, which could be isolated by high-pass filtering.

A number of variables have been used to quantify upright balance, where various studies have focused on using the vertical projection of the COG as an indicator of postural sway (Collins, De Luca, 1993; Duarte, Zatsiorsky, 2000; Baratto et al., 2002). The present study analyzed GRF using the autocorrelation function. Among various parameters that may be extracted from the autocorrelation function as per Pender et al. (2012), we adopted four as physiologically-meaningful measures that can distinguish postural control differences during quiet standing.

The first of the parameters we adopted was the time elapsed from the moment of initial observation, where the autocorrelation curve is equal to 1 to when a value of 0 is reached ($T_0$). A rapid decay to 0 indicates increased randomness in the motor control process of quiet standing. This reveals the presence of short-term balance disturbance in that there is weak relationship between present motor unit recruitment and the preceding and succeeding mechanical events. In turn, a slow decrease of the autocorrelation function to 0 suggests that the balance process is free of disturbance, in which postural control shows a low-frequency trend.

The second autocorrelation parameter we considered was the time from the beginning of the record to when the autocorrelation curve reached the first extremum (Tex), most commonly this occurred when there was a change in the direction of the GRF vector. This provides a measure of the periodicity or frequency of the motor control system and musculoskeletal system.

The next parameter described the derivative of the autocorrelation function ($D_{ex}$), or the magnitude of the noise of the GRF signal. In other words, this showed disturbances in the postural control system by the random activation of postural muscles that were not anticipated in the standing task.

The final parameter was the gradient strength (GS) of the autocorrelation function, or the mean decay velocity of the function from a value of +1 to the extremum. It can describe the individual frequency of the postural control system in maintaining balance. While similar to $T_{ex}$, GS defines the decay velocity as a pulsation of the individual system.

The correlation observed between $T_0$, and $T_{ex}$ appears to be quite logical, as the time to a decay of 0 is in effect an assessment of task performance by the preceding, current, and succeeding mechanical events (maintaining steady balance during quiet standing), whereas Tex is a measure of the frequency of these events. Based on Tex, the signals responsible for postural balance were revealed to have periodic nature although with large inter-individual variation. Furthermore, the very strong correlations between Dex and GS confirm that these two parameters evaluate similar properties of the postural control system in maintaining upright balance.

## Conclusions

It is difficult to clearly state which of the analyzed parameters of the autocorrelation function best characterize the GRF time series of quiet standing as each describes a different albeit important aspect of the postural control system. Nonetheless, they provide an interesting measure of assessing the response of the central nervous system for balance maintenance during standing. Furthermore, we observed strong correlation between the analyzed parameters, indicating that they evaluate similar properties of the central nervous system as a regulator of balance maintenance. The particularly strong correlation between the derivative output of the autocorrelation function ($D_{ex}$) and the gradient strength (GS) suggest that only one of these parameters warrants inclusion in future assessments of balance using the autocorrelation function.

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# Guide for Authors

Authors are encouraged to submit high quality, original works which have not appeared, nor are under consideration in other journals. Contributors are invited to submit their manuscripts electronically to e-mail: joanna.latka@usz.edu.pl. Central European Journal of Sport Sciences and Medicine considers for publication manuscripts in the categories of Original Research, Review Article and Short Communication. The manuscripts should be in one of the following sub-disciplines: exercise physiology and biology, sports nutrition, sports science, biomechanics, coaching and training, sports medicine, sports injury and rehabilitation, physical activity and health, public health, physical education and health promotion as well as methodology of sport and history of physical culture and sport. Manuscripts with an interdisciplinary perspective with specific applications to sport and exercise and its interaction with health will also be considered. Papers are published only in English.

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