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CONTENT

OBSAH

PHYSICAL ACTIVITY AND SEDENTARY BEHAVIOR IN 14–15 YEAR OLD STUDENTS WITH REGARD TO LOCATION OF SCHOOL

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Submitted in May, 2009

Decline in physical activity and the increased number of overweight and obese children are alarming. These factors can influence, together with the passive role of schools in lifestyle education and unhealthy urban planning, the future lifestyle of adolescents and adults.

The main objective of this study was to analyze the physical activity and sedentary behaviors of adolescents aged 14–15 with regard to the size of the community where adolescents go to school.

The short version of the "IPAQ" questionnaire was used to collect data in this study. The research was conducted in three selected regions of the Czech Republic. In each region, 3 schools were randomly selected. The research was carried out with all pupils of the ninth grade (aged 14–15) of selected schools. For data analysis we used basic statistical characteristics and binary logistic regression (SPSS).

Based on the findings from the questionnaire, we have found that girls were significantly more likely to be sitting than boys. Children living in a middle-sized to large sized community, and living in an apartment, are significantly more likely to be sitting.

Boys are still less "sedentary" than girls. Respondents who meet PA recommendations are also sitting more, usually based on the time needed for rest. The results of our study show that small communities offer better conditions to their inhabitants to be more physically active, however the differences between small and large locations are not that extensive.

Keywords: Questionnaire, school, environment, sedentary behavior, physical activity recommendation.

INTRODUCTION

A decline in physical activity and the increased number of overweight and obese children are apparent according to research. These factors influence the future lifestyle of adolescents and adults (McGuinness, 2006; Pate et al., 2002; Sallis, Prochaska, & Taylor, 2000; Richmond, Hayward, Gahagan, Field, & Heisler, 2006). A better understanding of the correlates of physical activity (further only PA) and a sedentary lifestyle is needed to reduce sedentary behavior (Epstein, Raja, Gold, Paluch, Pak, & Roemmich, 2006; Norman, Schmid, Sallis, Calfas, & Patrick, 2005; Simon, Wagner, DiVita, Rauscher, Klein-Platat, Arveiler, Schweitzer, & Triby, 2004; Van der Horst, Paw, Twisk, & Van der Mechelen, 2007). Among factors determining PA, eating and lifestyle habits, in adolescents the major ones are environment and a variety of locations (Badland & Schofield, 2006; McGuinness, 2006; Nelson, Gordon-Larsen, Song, & Popkin, 2006; Sallis & Glanz, 2006). The built environment in smaller communities enhances easier safer walking to schools, work, shops and services and allows people to socialize (de Bruijn, Kremers, Lensvelt-Mulders, de Vries, van Mechelen, & Brug, 2006; Kerr, Rosenberg, Sallis, Saelens, Frank, & Conway, 2006). Larger cities have more barriers in a built up environment to support a healthy lifestyle (high speed roads, long distances, more unsafe neighborhoods, etc.) and residents' PA integrated into daily activities is diminished (Epstein, Raja, Gold, Paluch, Pak, & Roemmich, 2006; Frank, Kerr, Chapman, & Sallis, 2007; McGuinness, 2006). Children spend a lot of time sitting in school, watching TV, using computers, and playing games; therefore they have less time to be physically active. Competition between PA and inactivity shows that PA is losing the race. The environment can be a possible factor that influences sedentary habits in adolescents (Jago, Baranowski, & Baranowski, 2006; Mota, Gomes, Almeida, Ribeiro, & Santos, 2007). Schools should play an important role in establishing healthy lifestyle habits in adolescents, but adoption of a more "active environment" in schools still has barriers. Along with parental care, these factors contribute to personality development and lifestyle habits in adolescents.

The main objective of this study was to analyze the physical activity and sedentary behavior of adolescents aged 14–15 with regard to the size of the community where adolescents go to school.

MATERIALS AND METHODS

The standardized short version of the "International Physical Activity Questionnaire" IPAQ (Craig et al., 2003) translated into Czech was used to assess PA levels. The results from the questionnaire were processed in compliance with the guidelines by "IPAQ Research Committee" (www.ipaq.ki.se). Objective data about PA were measured by using ActiGraph accelerometers and selected results are presented in this study. This study was participated in by 140 boys and 162 girls aged 14–15.The data were collected in Winter 2006.

The research was conducted in three selected regions of the Czech Republic. In each region, 3 schools were randomly selected that matched these criteria: 1. a school in a town over 100.000 inhabitants (large city), 2. a school in a town with 10.000–30.000 inhabitants (middle sized community), 3. a school in a town with less than 10.000 inhabitants (small community). The research was carried out with all pupils of ninth grade (aged 14–15) of selected schools. For data analysis we used basic statistical characteristics and binary logistic regression (SPSS). Odds ratio calculations were adjusted by age, gender, BMI, location and participation in an organized PA (the last group in each category was the reference group in each binary logistic regression).

RESULTS

Based on the findings concerning PA characteristics in questionnaires, we have found that girls were significantly more likely to be sitting than boys. BMI and participation in any organized or unorganized PA (TABLE 1) did not influence time spent sitting neither in girls nor in boys. There was a difference found in time spent sitting according to the size of the community. Both girls and boys living in communities with more 10.000–30.000 residents were significantly more likely to be sitting than those living in a small community (less than 10.000 inhabitants) or in a large city.

An interesting finding was that those students who met the recommended level of PA based on walking were significantly more likely to be sitting than those who did not meet these criteria. In accordance with our assumption, students living in an apartment were significantly more likely to be sitting than those living in a house.

Most students met the criteria for the category "highly active"; however the level of PA is slightly decreasing. The amount of PA (expressed in steps from accelerometers) during weekend days (boys – 9254 steps/school day, 6353 steps/weekend day; girls – 9124 steps/school day, 6671 steps/weekend day) shows decrease in comparison with recommended level (Frömel, Novosad, & Svozil, 1999). Students do not meet the criteria on school days, either.

TABLE 1
The influence of the PA and other factors on sedentary behavior in students (n = 302) aged 14–15

	n	%	OR	CI
Gender				
Boys	140	46.3		
Girls	162	53.7	1.72*	1.03–2.87
BMI (kg/m^2)				
< 25	78	25.8		
25–29.99	207	68.5	1.38	.78–2.46
≥ 30	17	5.6	1.93	.58–6.42
Walking (30 min./5 days)				
Minimally active	86	28.5		
Moderate active	97	32.1	2.06*	1.09–3.88
HEPA active	80	26.5	2.12*	1.09–4.13
Highly active	39	12.9	1.57	.68–3.65
Vigorous PA (20 min./3 days)				
Meet the recommendation	165	54.6		
Did not meet the recommendation	137	45.4	.59	.34–1.02
Housing				
Single family house	54	17.9		
Multiple family house	75	24.8	1.40	.66–2.98
Apartment	131	43.4	2.45*	1.10–5.46
Town house	31	10.3	1.56	.55–4.44
Other	11	3.6	1.31	.33–5.20
Location (in thousands)				
> 100	64	21.2		
30–100	43	14.2	.28**	.12–.70
1–29.9	83	27.5	.35**	.16–.75
< 1	103	34.1	.50	.21–1.16
Did not answer	9	3.0	.69	.15–3.27
Participating in organized PA				
0–1 per week	124	41.1		
2 times per week	81	26.8	1.02	.52–2.00
> 2 times per week	97	32.1	1.57	.81–3.06
Participating in any PA				
No	41	13.6		
Yes	261	86.4	.90	.40–2.05

Legend:
OR – odds ratio
CI – confidence interval
* $p < .05$
** $p < .01$

DISCUSSION

Students aged 14–15 in this study still meet the recommended level of PA to maintain their health. Based on the monitoring in the randomly selected schools, this study shows that young people, especially girls, who showed more time spent sitting during a week long monitoring of lifestyle habits than boys, do not get enough exercise. We expect that this is caused mainly by the school system and type of curricula implemented and the environment where the students live. It was proven that girls are less active than boys (Frömel, Novosad, & Svozil, 1999) and if there is not a physical education (further only PE) class or other organized PA we can expect girls tend to sit more.

Students are sitting most of the time they spend at school. The only chance to be physically active is to participate in PE classes. A school environment does not usually allow students to be active on school playgrounds or in yards during breaks. This poses a challenge to school principals and PE teachers to create an active environment at schools. It is apparent that smaller schools are more likely to adopt these systems of PA promotion, but the evidence is rare. Teachers should apply more interdisciplinary teaching approaches which would help to avoid sedentary behavior. However, not only school but also parents should adopt more active lifestyle habits in general since they are major figures who determine the direction and understanding of lifestyle in their children.

Students who met the recommended level of PA based on walking were more likely to be sitting. This might be caused by a number of factors. One of them could be the overestimation of data presented in the questionnaire. Another possibility is that people who are more physically active need more time for resting, especially if they have more vigorous activities.

The difference found in time spent sitting according to the size of the community shows that the environment might significantly influence lifestyle and thus PA habits. There were differences between adolescents living in a small community and those living in large cities. In small communities both girls and boys were walking to school, in large cities they were transported to school by car or by means of public transportation. This was due to environmental conditions in each community. In a small community, where there are not such large distances between school and residence, there is usually less traffic on the streets, and so students were more often encouraged to walk or bike to school without safety restrictions. Middle sized communities and especially large cities have longer distances between school and students' homes, thus adolescents have to commute. Few of them are able or willing to bike or walk to school. These are usually students living close to school. The traffic on the road is much busier than in small communities especially during rush hours, biking to school is thus dangerous and walking usually too time consuming. Similar results were found for the adult population (Frömel, Mitáš, & Kerr, 2009) whereas people in small communities were more likely to meet recommended levels of PA.

Lifestyle patterns and behavioral habits adopted in adolescence may overlap into adulthood. However the evidence of that adherence is not that often explained (Bergman, Grjibovski, Hagstromer, Bauman, & Sjöström, 2008). But the sedentary behavior in children and adolescents should be prevented anyway, because PA can reduce risk factors for chronic diseases (U.S. Department of Health and Human Services, 2000).

There are several limitations of this study that have to be identified. The questionnaire does not ask about the structure of inactivity, therefore we only identify the amount of time when respondents are inactive. The questionnaire was standardized for the age group 15–69, however not all students reached the age of 15 during the data sampling. Students were monitored for one week and wore accelerometers, too. This could be a motivational factor that might have caused an increase in their total PA. The school environment was not specifically monitored. An additional study will be needed to determine other factors influencing sedentary behaviors within the lifestyle of adolescents.

CONCLUSIONS

Sedentary behavior and the decline of PA are trends that are rapidly increasing throughout the whole society. Boys are still less "sedentary" than girls, however, the current school system promotes long time sitting for 4 or more hours a day. This form of schooling, along with a sedentary lifestyle and inactivity (watching TV, playing computer games, etc.), causes the decrease of PA in adolescents. More studies on understanding the correlates of sedentary behavior are needed. This could help to promote intervention on PA that should reduce the negative impact of sedentary behavior on health. Adherence to PA or sedentary behavior from childhood to adulthood requires more relevant research, too.

Respondents who meet PA recommendations are also sitting more, usually based on the time needed for rest.

Overweight, obesity and other diseases related to an unhealthy lifestyle are rapidly growing. The environmental factors play a significant role, too. The results of our study show that small communities offer better conditions to their inhabitants to be more physically active, however the differences between small and large locations are not that extensive. The findings of this study and other similar studies should be applied in interventional changes in school programs enhancing PA and healthy lifestyle in students in their common life and by urban planners to promote more active environments.

ACKNOWLEDGEMENT

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POHYBOVÁ AKTIVITA A SEDAVÝ ZPŮSOB ŽIVOTA 14–15LETÝCH STUDENŮ S OHLEDEM NA SÍDLO ŠKOLY
(Souhrn anglického textu)

Pokles pohybové aktivity a zvyšování počtu dětí s nadváhou a obézních je alarmující. Tyto faktory, společně s pasivní rolí škol ve vzdělávání směrem ke zdravému životnímu stylu a „nezdravým" územním plánováním, mohou ovlivnit budoucí životní styl dospívajících a dospělých obyvatel.

Hlavním cílem této studie bylo analyzovat pohybovou aktivitu a sedavý způsob života dospívajících ve věku 14–15 s ohledem na velikost obce, kde dospívající docházejí do školy.

Pro sběr dat byla použita krátká verze dotazníku „IPAQ". Výzkum byl realizován ve třech vybraných regionech České republiky. V každém regionu byly náhodně vybrány 3 školy. Výzkumu se zúčastnili žáci devátých tříd (ve věku 14–15) z vybraných škol. Pro analýzu dat jsme použili základní statistické charakteristiky a binární logistickou regresi (SPSS).

Na základě výsledků z dotazníků jsme zjistili, že dívky vykazovaly podstatně častěji než chlapci delší dobu sezení. Děti, které žijí v malých a velkých sídlech a žijí v bytě, častěji tráví čas sezením.

Chlapci mají méně „sedavý" způsob života než dívky. Studenti, kteří plní zdravotní doporučení pro pohybovou aktivitu, vykazují také delší dobu strávenou sezením. Zpravidla se jedná o čas, kdy potřebují odpočinek. Výsledky studie ukazují, že malá sídla nabízejí svým obyvatelům lepší podmínky pro pohybovou aktivitu, ale rozdíly mezi malými a velkými sídly nejsou tak velké.

Klíčová slova: dotazník, škola, prostředí, sedavý způsob života, doporučení pro pohybovou aktivitu.

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LEISURE TIME, OCCUPATIONAL, DOMESTIC, AND COMMUTING PHYSICAL ACTIVITY OF INHABITANTS OF THE CZECH REPUBLIC AGED 55–69: INFLUENCE OF SOCIO-DEMOGRAPHIC AND ENVIRONMENTAL FACTORS

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The assessment of multiple domains of physical activity is considered to be necessary for global physical activity surveillance and might be useful for the recognition of the effects of physical activity on health.

The aims of this study were twofold: firstly to analyze moderate physical activity and walking within the leisure time, domestic, occupational and transport related domains of the inhabitants of the Czech Republic aged 55–69, and secondly, to investigate the socio-demographic and environmental factors which can influence meeting physical activity recommendations in leisure time, domestic, occupational and transport related domains.

The long version of the International Physical Activity Questionnaire (IPAQ) was used to assess physical activity in 320 randomly selected inhabitants of the Czech Republic aged 55–69. They also answered additional questions on socio-demographic and environmental factors.

Meeting moderate physical activity recommendations was significantly associated with elementary education, the age group 55–59 (compared to the age group 65–69), living in a house and non smoking whereas the likelihood of meeting the walking recommendation was connected only with having an occupation. Different socio-demographic and environmental factors were associated with moderate physical activity and walking within different domains.

These factors should be taken into consideration, particularly when creating a successful PA promotion strategy tailored to Czech national specifics.

Keywords: Physical activity, older people, socio-demographic and environmental factors, IPAQ, lifestyle domains.

INTRODUCTION

Physical inactivity is an important risk factor of chronic diseases worldwide, although there are substantial variations across countries (Guthold et al., 2008). Therefore increasing overall physical activity is a health priority in many nations (World Health Organization, 2002). Although the Czech Republic belongs among countries with the most prevalent high physical activity (Bauman et al., 2009), the Czech epidemiological study of adults (Frömel, Mitáš, & Kerr, 2008) showing 60% of males and around 40% of females being overweight or obese is alarming.

The assessment of multiple domains of physical activity is considered to be necessary for global physical activity surveillance (Bauman et al., 2009) and might be useful for the recognition of the effects of physical activity on health (Abu-Omar & Rütten, 2008). An analysis of physical activity within different lifestyle domains can be also relevant during periods of life transitions when they could lead to changes in physical activities, mainly on a daily basis. The age between 55–69, which is examined in this study can be considered to be a period of preretirement and retirement including the life transition from work to retirement.

The results of the study investigating meeting moderate and vigorous physical activity and walking guidelines in adults aged 24–64 in the Czech Republic (Frömel, Mitáš, & Kerr, 2008) suggest that only meeting vigorous physical activity requirements is inversely related to age. Hence, further examination of moderate physical activity and walking in late adulthood of the inhabitants of the Czech Republic might be important.

Since studies investigating physical activity within multiple lifestyle domains and emphasizing preretirement and retirement periods are missing in the Czech Republic, the aims of this study were therefore twofold. Firstly, to analyze moderate physical activity and walking within the leisure time, domestic, occupational and transport related domains in the inhabitants of the Czech Republic aged 55–69, and secondly, to investigate the socio-demographic and environmental factors which can influence meeting physical activity recommendations within leisure time, domestic, occupational and transport related physical activities.

METHODS

Participants and Setting

This study was participated in by 320 participants (173 male and 147 female) aged 55–69. The sample included adults and older adults from all 14 regions of the Czech Republic. A systematic random sampling from the Czech national address point database was used to identify the participants. Residents of every tenth house in housing areas or every tenth apartment in apartment block areas in a selected location were visited. If the resident at the selected address refused to participate, the inhabitants in the next house (apartment) were approached. All inhabitants who agreed to participate provided written consent and received a questionnaire to complete.

Measurements

Physical activity

The self administrative version of the "International Physical Activity Questionnaire" IPAQ (Craig et al., 2003) was used to assess physical activity levels. The Czech version was translated from English and complied with standardized translating guidelines, including back translation into English (www.ipaq.ki.se). The IPAQ long version investigated walking in free domains: work related (paid jobs, farming, and voluntary jobs), leisure time (recreational and sport activities) and the active transportation domain; and moderate PA and vigorous PA in three life domains: work related (paid jobs, farming, and voluntary jobs), house and gardening work (outside and inside the home), and the leisure time domain (recreational and sport activities). Physical activity was measured in frequency (days) and duration (in minutes; at least 10 minutes at a time) as a level of PA in the past seven days (www.ipaq.ki.se).

Socio-demographic and environmental variables

Participants also provided socio-demographic information on their age, gender, family status, number of years of completed schooling, employment, material conditions (owning a bike, a car, and a weekend house), dog ownership, and smoking, and environmental information on location (size of town where respondents lived) and type of residence. Body mass indexes of all respondents were obtained, too, calculated from subjectively recorded data (weight in kg and height in cm). Detailed characteristic of the participants according to these variables are shown in TABLE 1.

Data analysis

The results of physical activity were processed according to the guidelines of the "IPAQ Research Committee" www.ipaq.ki.se). Physical activity was translated into MET-min./week. Moderate and vigorous physical activity and walking were quantified by the amount of time spent in each activity and then summed up according to the intensity of the physical activity.

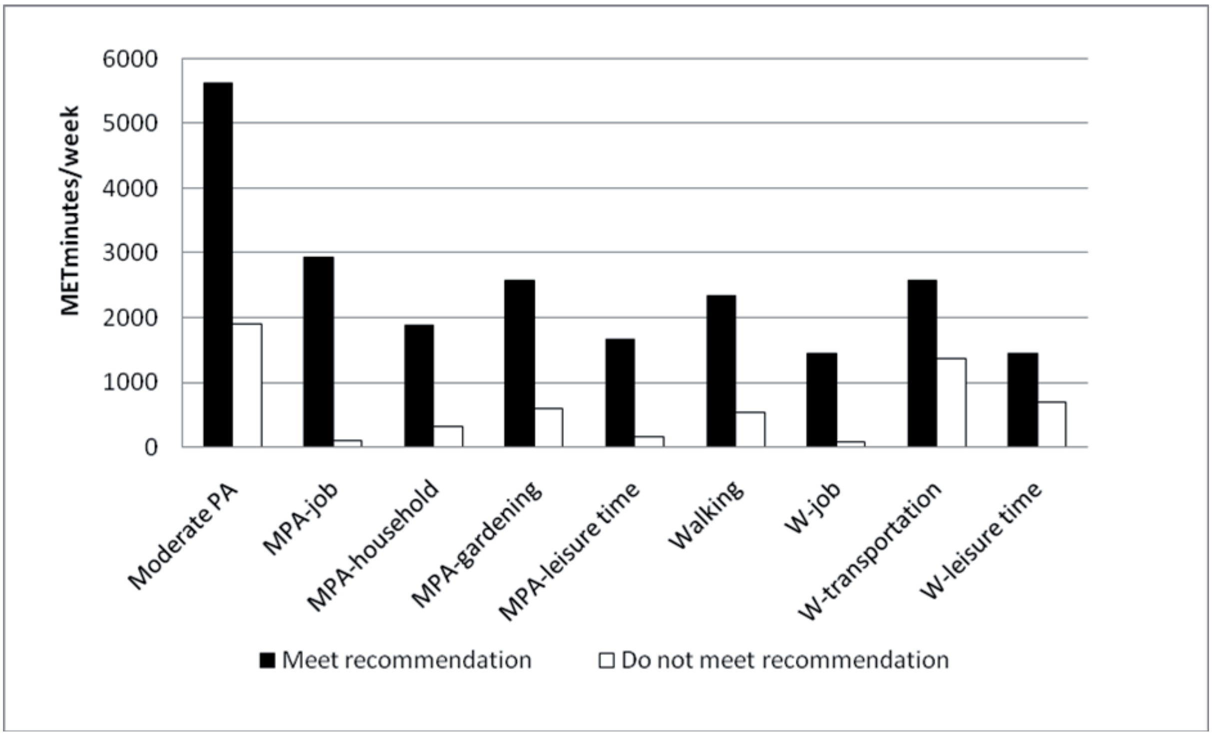
Software SPSS Statistics, version 17.0 (SPSS Inc., Chicago, USA) was used to statistically process the data. Descriptive statistics (mean and standard deviation) were calculated for each variable. Binary logistical regression (forward stepwise method) was used for dichotomous outcomes: reaching recommendations for moderate physical activity within different domains and for walking within different domains as dependent vari-

TABLE 1

Characteristic of the respondents according to socio-demographic and environmental factors

Characteristics of participants							
		n	**%**			**n**	**%**
Gender	male	173	54.1	**Education**	Elementary	87	27.2
	female	147	45.9		Secondary	177	55.3
Age	55–59	165	51.5		University	56	17.5
	60–64	86	26.9	**Smoking**	No smoker	237	74.1
	65–69	69	21.6		Smoker	83	25.9
Residence	House	174	54.4	**Family status**	Alone	39	12.2
	Block	146	45.6		In family	179	55.9
Employment	No	162	50.6		In family with children	102	31.9
	Yes	158	49.4	**Dog**	No owning	192	60.0
Location	> 100	63	19.7		Owning	128	40.0
	30–100	98	30.6	**Bike**	No	96	30.0
(thousands)	1–29.9	111	34.7		Yes	224	70.0
	< 1	48	15.0	**Car**	No	95	29.7
BMI	> 25	82	25.6		Yes	225	70.3
	< 25	238	74.4	**Cottage**	No	201	62.8
					Yes	119	37.2

Fig. 1
Difference in MET-minutes per week between respondents who meet and do not meet recommendations in different domains of moderate physical activity and walking



Legend:
MPA – moderate physical activity
W – walking

ables. For moderate physical activity and walking cut offs, the U. S. Healthy People 2010 guidelines, recommending 30 minutes five times a week were used. Binary logistical regression was not applied in the case of vigorous physical activity domains, since over 80% of the participants did not accomplish the recommendation for vigorous physical activity.

The independent variables were entered into the model in binary logistical regression – forward stepwise method, including age (split into three groups 55–59, 60–64, 65–69), gender, BMI (< 25, ≥ 25), family status (alone, in family, family with children), completed education (elementary school, secondary school, university), employment status (employed, unemployed), smoking (smoker, non smoker), dog ownership and ownership of a bike (yes, no), car (yes, no) and cottage (yes, no), residential status (house or flat in large block of flats) and location (large city – more than 100,000 inhabitants, small city – 30,000 to 99,999 inhabitants, medium town – 1,000–29,999 inhabitants and location with less than 1,000 inhabitants). The first group in each category was the referent group in each binary logistical regression analysis.

TABLE 2
Meeting moderate PA and walking guidelines within four life domains

			Walking		**Moderate PA**	
			n	**%**	**n**	**%**
Work		Men	45	26.0	32	18.5
		Women	28	19.0	16	10.9
		Total	73	22.8	48	15.0
Active transportation		Men	69	39.9		
		Women	58	39.5		
		Total	127	39.7		
Domestic and garden domain	**Household**	Men			21	12.1
		Women			50	34.0
		Total			71	22.2
	Gardening and yard work	Men			40	23.1
		Women			44	29.9
		Total			84	26.3
Leisure time		Men	28	16.2	6	3.5
		Women	28	19.0	4	2.7
		Total	56	17.5	10	3.1

TABLE 3
The socio-demographic and environmental factors significantly influencing the recommended values of moderate physical activity within different domains

Meet moderate PA recommendation (30 minutes 5 times a week)				
	n	**%**	**OR**	**CI**
Age				
55–59	95	56.5	Ref.	
60–64	42	25.0	.59	.34–1.03
65–69	31	18.5	.51*	.28–.94
Education				
Elementary	55	32.7	Ref.	
Secondary	92	54.8	.52*	.30–.90
University	21	12.5	.27*	.13–.56
Residence				
House	104	61.9	Ref.	
Block	64	38.1	.58*	.36–.92
Smoking				
No smoker	134	79.8	Ref	
Smoker	34	20.2	.50*	.29–.84

Meet moderate PA recommendation within household activities				
	n	**%**	**OR**	**CI**
Gender				
Male	21	12.1	Ref.	
Female	50	34.0	4.27*	2.33–7.84
Family Status				
Alone	6	15.4	Ref.	
In family	44	24.6	3.56*	1.3–9.75
In family with children	21	20.6	3.68*	1.23–11.06
Location (thousands)				
> 100	11	17.5	Ref.	
30–100	18	18.4	.87	.45–2.59
1–29.9	36	32.4	.05	.99–5.1
< 1	6	12.5	.55	.23–2.22
Bike				
No	30	31.3	Ref	
Yes	41	18.3	.45*	.24–.82

Meet moderate PA recommendation within gardening activities				
	n	**%**	**OR**	**CI**
Education				
Elementary	28	33.3	Ref.	
Secondary	49	58.3	.75*	.42–1.34
University	7	8.3	.27*	.11–.69
Residence				
House	60	71.7	Ref.	
Block	24	28.6	.41*	.23–.71
Smoking				
No smoker	72	85.7	Ref	
Smoker	12	14.3	.38*	.19–.75

Meet moderate PA recommendation within job				
	n	**%**	**OR**	**CI**
Employment				
No	4	2.5	Ref.	
Yes	44	27.8	20.55*	7.05–59.9
Education				
Elementary	13	14.9	Ref.	
Secondary	30	16.9	.84	.38–1.86
University	5	8.9	.20*	.06–.63

Legend:
OR – odds ratio
CI – confidential interval
*p < .05

RESULTS

From the total sample, 52.5% of respondents (151 respondents) accomplished the recommended minimum for moderate physical activity and 54.4% of respondents (174 respondents) met the recommended values for walking. After dividing moderate PA and walking into four domains it was shown (TABLE 2) that almost 40% of respondents met the walking recommendation within the active transportation domain, 23% during working hours and 17.5% during their leisure time. Furthermore, the highest percentage of respondents accomplished the fulfillment of moderate PA guidelines within the framework of domestic and garden PA, 15% of respondents within the confines of their jobs and only 3% met the recommendation during their leisure time.

TABLE 3 shows that the respondents were more likely to be moderately active if they were 55–59 years old (compared to 65–69 years old), had completed elementary education (compared to people who had completed secondary and/or university education), lived in houses and were not smokers. To be elementary educated (compared to having a secondary and/or university education), to live in a house and be a nonsmoker were associated with meeting moderate physical activity guidelines within the realm of gardening and yard activities. Different significant factors were found in the analysis of household activities. Females, people living in a family or in a family with children, in cities with more than 100 thousand inhabitants and not owning a bike were more likely to meet the recommended values of moderate PA within the household domain. The likelihood of meeting moderate PA guidelines while on the job was associated with employment (an expected factor) and elementary education (as compared to university education). Due to the low sample, to analyze meeting PA guidelines in leisure time, logistical regression could not be used.

TABLE 4
The socio-demographic and environmental factors significantly influencing the recommended values of walking and walking in leisure time

Meet walking recommendation (30 minutes 5 times a week)				
	n	%	OR	CI
Employment				
No	76	43.7	Ref.	
Yes	98	56.3	1.85*	1.19–2.89
Meet walking recommendation in leisure time (30 minutes 5 times a week)				
	n	%	OR	CI
Education				
Elementary	12	13.8	Ref.	
Secondary	40	22.6	1.83	.90–3.69
University	4	7.1	.48	.15–1.57

Legend:
OR – odds ratio
CI – confidential interval
*p < .05

Fig. 2
Percentage of respondents who met guidelines for moderate PA in various numbers of domains

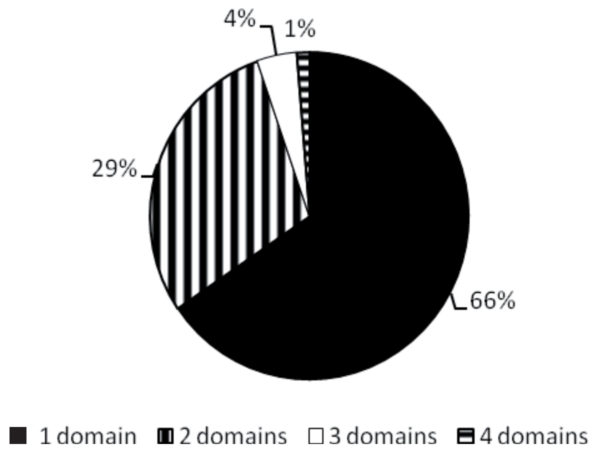


Fig. 3
Percentage of respondents who met guidelines for walking in various numbers of domains

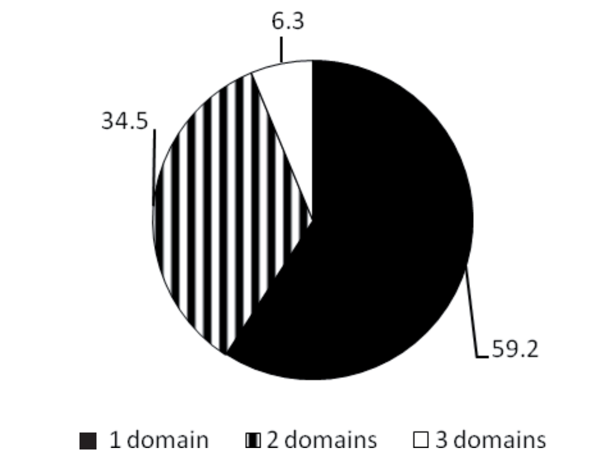


TABLE 4 presents factors that are significant while meeting the walking recommendation. Employed people were more likely to meet the weekly guidelines for walking. Furthermore, secondarily educated people were more likely to accomplish walking guidelines in their leisure time. No significant factors associated with meeting the recommended values for walking within the work and active transportation domains were found.

Differences in the domains of moderate physical activity and walking between respondents who met and did not meet recommendations are presented in Fig. 1.

Moderate physical activity consists of four domains (occupational, domestic, garden, leisure time) and Fig. 2 describes the percentage of respondents who met recommendations for moderate PA in a different number of domains. Most people accomplished it only in one domain (65.5%) and only 2 participants (1.3%) in all four domains. Walking consists of three domains (occupational, transport related, leisure time) and Fig. 3 shows that 59.2% of respondents met guidelines only in one domain and 6.3% of respondents (n = 11) in all three domains.

DISCUSSION

In this study, moderate physical activity and walking within different lifestyle domains and their relationship to socio-demographic and environmental factors were investigated. Results show the domain related effects on meeting physical activity recommendations. Furthermore, differences in factors influencing physical activity within particular domains indicate the legitimacy of domain specific studies, particularly when successful national promotion strategy should be conducted.

In recent years, the link between health indicators and leisure time physical activity, particularly walking, has been supported in studies in developed (Abu-Omar & Rütten, 2008) as well as developing (Hallal et al., 2005) countries. In this study, the BMI factor was not significantly associated with either moderate physical activity nor with walking in all domains. However, considering the importance of leisure time physical activity, the fact that only 3.1 of respondents reached the recommended value for moderate physical activity and 17.5% for walking might be of particular interest to the Czech health promotion strategy. On the other hand, over 50% of the sample met the walking recommendation and also a comparative international study confirms that the Czech Republic belongs among countries with substantial rates of physical activity, having 30% of their overall physical activity consisting of walking (Bauman et al., 2009).

The results of this study revealed a diversity of factors significantly influencing reaching moderate physical activity in gardening and household activities. Whereas significant factors related to moderate PA within the realms of garden and yard work are similar to the factors influencing overall moderate PA, the factors significantly associated with moderate PA within household activities differing from the first ones completely. It is an important finding since both household and gardening activities are always within the housework domain.

Education seems to be a significant factor of different domains and also in overall moderate physical activity and walking. This relationship is clear from previous studies (Ball et al., 2007), however the results vary (Bergman et al., 2008; Brown et al., 2005; Giles-Corti & Donovan, 2002). In this study, people with a lower education level were less likely to meet the recommendation within the realm of leisure time walking, but were more likely to reach recommended values within overall moderate physical activity and moderate physical activity within one's job and while gardening. This is in agreement with a study done by Fogelman, Bloch and Kahan (2004) who also found that people with fewer years of education engaged in more physical activity at work.

Based on results from this study, age was the significant factor related to moderate physical activity, where participants aged 65–69 were less likely to reach recommendations compared to participants aged 55–59. The inverse relationship between age and physical activity and on the other hand, the linear relationship between age and physical inactivity was confirmed across all European countries in a 51 country survey (Guthold et al., 2008) and in people with and without disabilities (Brown et al., 2005). However, in this study, age was not found to be a significant factor for moderate physical activity within the realm of gardening as well as for walking. These findings indicate that gardening and yard work might be a way of how to increase the daily portion of moderate physical activity regardless of age. Furthermore, the results confirm that walking could be the most appropriate activity for adults and older people, one they can benefit from and which has a great potential in PA promotion (Masurier et al., 2008).

Considering the age of the participants (55–69) and the period of preretirement and retirement, the factor of employment is crucial. In this study, being employed was associated with the likelihood of meeting walking guidelines. However, this factor was not significant in either the active transportation domain nor in leisure time walking. It suggests that walking within working hours appreciably contributes to daily walking. The study of Slingerland et al. (2007) demonstrates a decline in physical activity from work related transportation in association with retirement, which is not substituted for with any sport or non sport leisure time activity. Nevertheless, a number of studies have confirmed an increase of physical activity as a result of having more free time in the retirement period (Brown et al., 2005; Mein et al., 2005; Shepard, 1998).

Strengths of the study are its detailed characteristics and the analysis of domain related physical activity but there also some limitations. Although using a randomly selected sample, the multilevel modeling might be more valuable if we had used a larger sample. Furthermore, an analysis of vigorous physical activity related domains would bring more complex results. Another limitation is found in the measurement techniques used (Bauman et al., 2009).

CONCLUSION

Domain related effects on meeting moderate physical activity and walking were examined in this study. A diversity of factors significantly influencing meeting recommendations was found between moderate physical activity and walking and among particular domains within the moderate physical activity category. These findings should be taken into consideration, particularly when successful promotion strategies are to be conducted and tailored to national specifics.

ACKNOWLEDGEMENT

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POHYBOVÁ AKTIVITA OBYVATEL ČESKÉ REPUBLIKY VE VĚKU 55–69 LET PROVÁDĚNÁ V RÁMCI VOLNÉHO ČASU, ZAMĚSTNÁNÍ, V DOMÁCNOSTI A PŘI PŘESUNECH: VLIV SOCIO-DEMOGRAFICKÝCH A ENVIRONMENTÁLNÍCH FAKTORŮ

(Souhrn anglického textu)

Výzkum pohybové aktivity z hlediska odlišných oblastí života se jeví jako přínosný pro celosvětové komparační studie a pomáhá detailněji zjišťovat efekt pohybové aktivity na zdraví člověka.

Cíle této studie byly dva: za prvé analyzovat středně zatěžující pohybovou aktivitu a chůzi v rámci pohybových aktivit prováděných ve volném čase, v domácnosti, v zaměstnání a při přesunech u obyvatel České republiky ve věku 55–69 let a za druhé zjistit, které socio-demografické a environmentální faktory mohou mít vliv na plnění doporučení k pohybové aktivitě prováděné ve volném čase, v domácnosti, v zaměstnání a při přesunech.

Dlouhá verze mezinárodního dotazníku k pohybové aktivitě (IPAQ) byla využita pro zjištění pohybové aktivity u 320 náhodně vybraných obyvatel České republiky ve věku 55–69 let. Respondenti také zodpověděli doplňkové otázky vztahující se k socio-demografickým a environmentálním faktorům.

Plnění doporučení k středně zatěžující pohybové aktivitě bylo spojeno se základním vzděláním, věkem 55–59 let (při srovnání s věkem 65–69), bydlením v rodinném domku a nekuřáctvím, zatímco významným faktorem pro plnění doporučení k chůzi byl pouze faktor zaměstnání. Odlišné socio-demografické a environmentální faktory významně ovlivňují plnění doporučení k pohybové aktivitě při zkoumání pohybové aktivity ve volném čase, v domácnosti, v zaměstnání a při přesunech

Tato zjištění je potřeba brát v úvahu, zejména pokud by měla být, s ohledem na česká specifika, vytvořena úspěšná strategie na podporu pohybové aktivity u lidí předdůchodového a důchodového věku.

Klíčová slova: pohybová aktivita, starší lidé, socio-demografické a environmentální faktory, IPAQ, domény životního stylu.

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THE EVALUATION OF BODY COMPOSITION IN RELATION TO PHYSICAL ACTIVITY IN 56–73 YEAR OLD WOMEN: A PILOT STUDY

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Lack of physical activity is associated with an increase in the prevalence of overweight and obesity. Preventing excessive weight gain is a public health priority.

The aim of this study was to analyze the relationship between body composition and the level of physical activity in 56–73 year old women.

We divided the sample into individual subgroups according to recommendations concerning moderate physical activity and the number of steps made on average per day. Body composition was measured by means of multifrequency bioelectrical impedance analysis (InBody 720) and the accelerometer ActiGraph GT1M was used to monitor physical activity.

The BMI mean values were in the zone of overweight in all the measured subgroups with the exception of the women who met the recommendation relating to average steps made per day, where the BMI mean value (24.93 kg/m^2) was within the zone of normal range. The positive effect of physical activity was shown especially in the changes of body fat amount. The absolute and relative body fat proportion and the BFMI was higher ($p < .05$; $p < .01$) in the inactive women than in the active ones and its proportion decreased in correlation with the intensity of physical activity ($r_p = -0.40$; $p < .05$) and the number of steps per day ($r_p = -0.50$; $p < .05$). Concerning the distribution of body fat mass, we found that in all subgroups fat is deposited in the central part of the body. In both cases the level of very high risk was reached (WHR > 0.90). The average values of visceral fat were above the safe limit (100 cm^2) in all measured subgroups, however, its proportion was significantly lower ($p < .05$) in the active women. Based on the analysis of basic body parts it was found out that the proportion of soft lean mass in the right and left upper limb and on the trunk is higher ($p < .05$; $p < .01$) in active women than in inactive women.

The above mentioned results support the assertion of the positive effect of physical activity on human health. Regarding the body composition, physical activity results in a reduction of body fat, excessive levels of which cause a great deal of public health problems worldwide.

Keywords: Healthy aging, InBody 720, body fat mass, moderate physical activity, walking, ActiGraph.

INTRODUCTION

Aging is a complex process that is determined by genetic factors and modified by environmental factors. From the ontogenetic perspective, senescence is considered to be an important fundamental point. Since ageing is associated with an increasing risk of chronic disease, disability and cognitive decline, a sharp rise in the need for medical and social services and associated costs is to be expected (Schuit, 2006). A basic attribute of aging is physical activity decline and the adoption of sedentary lifestyle. In developed countries, physical inactivity is regarded as one of the main causes of total mortality and morbidity (Blair & Brodney, 1999; Leitzmann et al., 2007).

From the somatometric point of view, the effect of physical activity is evaluated mainly in relation to the change in ratio of body mass fractions – reduction of body fat mass and an increase in muscle tissue (Riegerová & Přidalová, 1996), thus the decrease of physical activity considerably affects the changes of body composition that are seen as an adequate indicator of body functional state (Guo, Zeller, Chumlea, & Siervogel, 1999). The reduction of active energy expenditure that is disproportionally lower than energy intake results in body weight increase and potential obesity advancement.

The Body Mass Index (BMI) is a basic indicator enabling us to classify obesity and associated risks. When the BMI value exceedes 30 kg/m^2, the person is regarded to be obese. Some authors (Kalvach, Zadák, Jirák, Zavázalová, & Sucharda, 2004; Kyle, Genton, Gremion, Slosman, & Richard, 2004a; Kyle, Morabia, Schutz, & Pichard, 2004b; Schutz, Kyle, & Pichard, 2002) however, view the evaluation of obesity by means of BMI as inadequate because this index does not allow for involving the variability and changes in the proportions of Fat Free Mass (FFM) and Body Fat Mass (BFM).

The relation of FFM to body height is presented by the FFMI (Fat Free Mass Index), which is also used for the basic evaluation of sarcopenia.

The age related decline of FFMI is lower in physically active individuals than in sedentary lifestyle individuals (Kyle et al., 2004a). According to Heyward and Wagner (2004) the optimal percentage of body fat in the male population older than 55 is 10–16%, respectively 25–35% in women. In the case of BFMI (Body Fat Mass Index), that shows the relation of the absolute proportion of body fat to body height. The normal range is 1.8–5.1 kg/m^2 for men and 3.9–8.1 kg/m^2 for women (Kyle et al., 2004a). To evaluate the type of obesity concerning the distribution of body fat, the WHR (Waist Hip Ratio) can be used. It indicates abdominal obesity based on the ratio of the waist and hip circumferential parameters. The limit of the moderate risk ratio in its relative value is 0.76 for women (60–69 years) and 0.91 for men of the same age (Bray & Gray, 1988). Clasey et al. (1999) considers WHR to be adequate for the evaluation of abdominal obesity, however the value of visceral fat appears to be even more predictive of some of the adverse health consequences of obesity.

In the field of the treatment and prevention of obesity in the senior population, the most explicit results were obtained by increasing physical activity (Shephard, 1997). The frequency, intensity and duration of physical load need an individual approach that must be in accordance with the individual's biological age. Aerobic exercises, including walking, are thought to be the basis in order to maintain the functional efficiency of seniors, to reduce their risk for cardiovascular disease (Mazzeo et al., 1998) and total cholesterol concentration (Ready, Drinkwater, Ducas, Fitzpatrick, Brereton, & Oades, 1995). There is growing evidence that 10 000 steps/day is an amount of physical activity that is associated with indicators of good health and persons accumulating this amount of steps per day are classified as active (Tudor-Locke & Bassett, 2004). Concerning the intensity of physical activity, it is generally recommended for the adult and senior population to perform moderate physical activity at least 150 minutes a week or vigorous physical activity at least 75 minutes a week, eventually to combine both intensities. To multiply the effects of physical activity on human health, it is recommended to increase moderate physical activity to above 300 minutes or vigorous physical activity above 150 minutes a week, eventually to suitably combine these (U. S. Department of Health and Human Services, 2008).

Investigating the level of physical activity and its impact on weight and body composition changes is necessary for health promotion strategies. However, the selection of physical activity and body composition assessment tools is crucial considering the study population and overall research settings (Gabriel et al., 2009). Some studies dealing with physical activity have assessed body composition using the methods of standard anthropometry (Rana, Li, Manson, & Hu, 2007; Stevens et al., 2007.) or the bioelectrical impedance method (50 kHz) (Kyle et al., 2004a, 2004b). As regards physical activity measurement, some studies have assessed it subjectively via self reported physical activity questionnaires (Hughes, Frontera, Roubenoff, Evans, & Singh, 2002; Kyle, Melzer, Kayser, Picard-Kossovsky, Gremion, & Pichard, 2006). However, subject to the age group for whom physical activity levels are being measured, along with other factors, contrasting results about the usefulness of such questionnaires have been reported. For older people, questionnaires may not be entirely satisfactory (e.g. Jørstad-Stein et al., 2005), as their reliability may be questionable (Tudor-Locke & Myers, 2001), although some questionnaires are moderately correlated with objective motion sensor measures of physical activity (pedometer and accelerometer counts) (Gabriel et al., 2009; Harris, Owen, Victor, Adams, Ekelund, & Cook, 2009). Only a few studies monitored physical activity in relation to body composition objectively, e.g. Thompson, Rakow and Perdue (2004) and Tudor-Locke, Ainsworth, Whitt, Thompson, Addy and Jones (2001), who used pedometers. To our knowledge, no study has employed accelerometers for physical activity assessment along with the multifrequency bioelectrical impedance method for body composition assessment to find out the relationship between physical activity level, walking behaviour and body composition variables.

AIM

In order to bridge this gap in literature, the aim of our study was to analyse the relationship between body composition and (1) the level of physical activity and (2) the daily number of steps in 56–73 years old women.

METHODS

Study sample

The study sample consisted of 43 women. They voluntarily participated in the study after they provided their written consent. The study was approved by the Ethical Committee of the Faculty of Physical Culture at Palacký University in Olomouc. The average age of the participants was 63.89 years (SD = 4.22). They were recruited by offering them free physical activity programmes within the University of Third Age at the Faculty of Physical Culture of Palacký University in Olomouc and the University of Technology in Brno.

Assessment of body composition

Body composition was diagnosed by the InBody 720 (1–1 000 kHz; a multifrequency bioelectrical impedance method) device that differentiates body weight into 3 components – total body water (intracellular and extra cellular), dry mass (proteins and minerals) and body fat. That technology employs 8 contact electrodes (2 are positioned on the palm and on the thumb, another 2 are on the front part of the foot and on the foot's heel) that enable us to analyse 5 basic body parts (the left and right upper limb, trunk, and left and right lower limb) independently from each other. The measurement was performed under laboratory conditions according to user manual instructions (Biospace, 2008).

The basic anthropometrical characteristics were determined with an accuracy of 0.5 cm for body height and 0.1 cm for body weight. The relative risk of health problems is judged by means of BMI, FFMI and BFMI. To evaluate abdominal obesity, we use the WHR (Waist Hip Ratio), Visceral Fat Area (VFA) and abdominal circumference. The classification of FFMI and BFMI is based on the norms as stated by Kyle et al. (2004b). The evaluation of VFA is described in the user manual (Biospace, 2008), which defines this parameter as the area of transversal cut in the abdominal zone (L_4–L_5). The correlation between the Computer Tomography and InBody 720 is set at $r = 0.92$.

Assessment of physical activity

To find out the volume, the intensity of physical activity per week and the average number of steps, we used the ActiGraph GT1M accelerometer, which, for the monitoring of physical activity in adults for 7 days, is considered reliable (Trost, McIver, & Pate, 2005). It was shown by McClain, Sisson and Tudor-Locke (2007) that the interinstrumental reliability of the ActiGraph accelerometer in adults regarding common life is 0.97 for counts and 0.99 for steps. Each participant agreed with the measurements and was acquainted with how to operate the accelerometer. To analyse the relationship between body composition and physical activity, the sample was divided into subgroups according to the classification of the U. S. Department of Health and Human Services (2008) and the number of steps made on an average per one day (TABLE 1, 2).

TABLE 1

Number of participants in individual subgroups according to number of minutes spent on moderate physical activity

	Subgroup	Intensity PA (3–6 METs)	n
Insufficiently active	SUB1A	< 150 min/week	6
Active	SUB1B	150–300 min/ week	16
Highly active	SUB1C	> 300 min/ week	21

Legend:
Classification according to the U. S. Department of Health and Human Services (2008).

TABLE 2

Number of participants in individual subgroups according to number of steps taken on average per day

	Subgroup	Steps/day	n
Not meeting recommendation	SUB2A	< 10 000	21
Meeting recommendation	SUB2B	> 10 000	22

Statistical analysis

The obtained data were adequately processed by Lookin' Body 3.0, ActiPA 2006 software (Chytil, 2006) and Statistica 7 software. To test the average differences between the individual subgroups, we used Fisher's LSD post-hoc after one factor analysis of variance (ANOVA) and the Shapiro-Wilk W test was used in testing for normality before each analysis. Cohen's coefficient *d* (Cohen, 1988) was calculated for the determination of effect size between two variables. The values of 0.2, 0.5 and 0.8 were interpreted according to the small, medium and large ranges of Cohen's standard. The strength of the relationship between physical activity characteristics and body composition variables was quantified by means of Pearson's correlation coefficient (r_p). Statistical significance was set at $p < .05$ or $p < .01$.

RESULTS AND DISCUSSION

Making 10 000 steps everyday means an energy expenditure of 300–400 kcal (depending on walking speed and somatic parameters), whereas 30 minutes of moderate physical activity amounts to 150 kcal (Tudor-Locke & Bassett, 2004). As far as weekly energy expenditure is concerned, it is more effective to take 10 000 steps a day than to attain the criteria of 150–300 minutes of moderate physical activity a week. This statement corresponds with the results presented in TABLE 3 and 4.

When we divided our sample according to the intensity of the physical activity, we could see that only those women performing more than 300 minutes of moderate physical activity attained the criterion of taking 10 000 steps a day. The women attaining the general recommendations for adults and older adults (at least 150 min/week) took only 8 430 steps/day. Different results were obtained when evaluating the number of steps taken in one day (TABLE 4). Even the test subjects that do not perform the generally recommended number of steps per one day (< 10 000/day) attained the recommendation of having 150 minutes of medium intensity physical activity (3–6 METs) a week. This statement corresponds with research results of Payn et al. (2008).

When evaluating the effect of physical activity on body composition, it is necessary to view every classification with regard to its sensitivity. Elia (2001) describes the declination of total energy expenditure as a result of natural involution. This declination is, on average, 165 kcal per decade in women and 103 kcal in men. It is mainly caused by increasing physical inactivity and reduction of basal metabolism. This trend is initiated by natural involution changes but there is also an important effect of external factors. It is evident that adhering to the above mentioned recommendations helps in keeping the energy balance and it prevents the growth of undesirable body fat mass.

According to the U. S. Department of Health and Human Services (2008), at least 150 minutes of moderate physical activity a week is recommended to maintain physical and mental health (for adults and older adults). Only 6 participants (14%) did not meet this recommendation, on the other hand 49% subjects reached more than 300 min/week (TABLE 3). European research points out that approximately 60% of people older than 65 year do not perform any moderate physical activity (European Commission, 2003). Thus participants seem to be very active according to European findings.

TABLE 3 presents the selected anthropometrical characteristics in the study sample divided into subgroups according to moderate physical activity. In SUB1A are the women who did not meet the guidelines or physical activity (insufficiently active – less than 150 minutes of moderate activity a week), in SUB1B are

TABLE 3
Selected anthropometrical characteristics in relation to meeting moderate physical activity recommendations

		< 150 min/week insufficiently active SUB1A (n = 6)		**150–300 min/week active SUB1B (n = 16)**		**> 300 min/week highly active SUB1C (n = 21)**	
		Mean	**SD**	**Mean**	**SD**	**Mean**	**SD**
Age		63.00	4.08	63.88	4.34	64.14	4.12
Body height (cm)		164.92	7.13	164.91	4.30	164.62	5.79
Body weight (kg)	†	76.16	10.00	72.26	13.19	68.70	7.73
Intracellular water (l)		21.32	2.75	21.06	2.36	21.05	1.36
Extracellular water (l)		13.38	1.77	13.36	1.62	13.31	0.88
Proteins (kg)		9.22	1.20	9.10	1.02	9.10	0.58
Minerals (kg)		3.44	0.50	3.35	0.40	3.34	0.23
Body fat (kg)	*, †	28.82	5.51	25.39	8.54	21.92	6.23
Percentage body fat (%)	*, †	37.69	4.21	34.12	6.50	31.40	5.54
Fat free mass (kg)		47.35	6.18	46.87	5.37	46.78	3.00
FFMI (kg/m^2)		17.36	1.51	17.20	1.56	17.29	1.12
BFMI (kg/m^2)	†	10.64	2.16	9.30	3.06	8.14	2.52
BMI (kg/m^2)		28.00	3.21	26.51	4.43	25.43	3.32
WHR		0.98	0.04	0.96	0.04	0.96	0.04
Bone minerals (kg)		2.85	0.41	2.78	0.33	2.77	0.19
Cell mass (kg)		30.54	3.98	30.15	3.39	30.14	1.94
Visceral fat (cm^2)	*, †	149.88	21.10	130.03	31.13	123.50	24.69
Abdominal circumference (cm)	†	104.13	9.03	95.74	13.55	94.64	8.60
Steps (per day)	**, †	6 373	1 566	8 430	1 681	12 515	2 738
Moderate physical activity (min/week)	**, †	120	39	230	40	442	113

Legend:
Differences were analysed by Fisher's LSD post-hoc after one factor ANOVA. The differences between SUB1A vs. SUB1B and SUB1B vs. SUB1C were significant only in physical activity variables (* $p < .05$, ** $p < .01$), whereas the differences between SUB1A vs. SUB1C was also significant (* $p < .05$, ** $p < .01$) in body composition variables. Large range of Cohen's coefficients († $d < 0.80$) were obtained only between SUB1A vs. SUB1C.

the women who met the general guidelines or adults and older adults (active – at least 150 min/week) and in SUB1C are the highly active women whose volume of moderate physical activity is more than that set forth in the general guidelines (they accomplished more than 300 min of moderate physical activity a week). The average body height was comparable in all subgroups and the higher was the physical activity the lower was the body weight (r_p = –0.29). Although the differences in body weight were insignificant, based on ANOVA (Fisher's LSD post-hoc), between insufficiently active and highly active women, the effect size was found to be 0.92. Following Cohen's guidelines, this should be interpreted as a large effect.

BMI and BFMI mean values showed that all the measured groups are overweight. The differences between the insufficiently active women (SUB1A) and physically active ones (SUB1B and SUB1C) were insignificant, whereas the effect size was, for BMI, in the medium (d = 0.78) and for BFMI in the large range (d = 1.02) of Cohen's standard between insufficiently active and highly active women. This is in agreement with the results of Kyle et al. (2004a) who described higher values of BFMI in the inactive senior population comparing it to the active one. A significantly lower proportion of body fat was found in SUB1C compared to SUB1A, where the body fat difference was 6.9 kg (p < .05 by Fisher's LSD post-hoc; d = 1.13), i.e. 6.29% (p < .05 by Fisher's LSD post-hoc; d = 1.19) in relative values. The mean value of visceral fat proportion was significantly lower in the highly active (p < .05 by Fisher's LSD post-hoc; d = 1.10) than in insufficiently active women. A significant difference in abdominal circumference between insufficiently active and highly active women was confirmed by the large effect of effect size (d = 1.09). Inverse linear correlation was found between moderate physical activity and the absolute (r_p = –0.40; p < .05) and relative (r_p = –0.43; p < .05) proportion of body fat, BFMI (r_p = –0.40; p < .05) and visceral fat area (r_p = –0.36; p < .05). FFMI mean values

TABLE 4
Selected anthropometrical characteristics in relation to the number of steps per day

		< 10 000 steps/day not meeting recommendation SUB2A (n = 21)		**> 10 000 steps/day meeting recommendation SUB2B (n = 22)**	
		Mean	**SD**	**Mean**	**SD**
Age		64.05	4.02	63.73	4.39
Body height (cm)		165.48	5.06	164.09	5.84
Body weight (kg)	*, †	75.31	10.35	67.01	9.40
Intracellular water (l)		21.45	2.26	20.75	1.68
Extracellular water (l)		13.59	1.51	13.10	1.09
Proteins (kg)		9.27	0.97	8.96	0.72
Minerals (kg)		3.45	0.38	3.27	0.30
Body fat (kg)	**, †	27.57	6.50	20.93	6.92
Percentage body fat (%)	**, †	36.22	4.64	30.50	6.13
Fat free mass (kg)		47.75	5.08	46.08	3.75
FFMI (kg/m²)		17.42	1.45	17.12	1.25
BFMI (kg/m²)	**, †	10.09	2.44	7.81	2.72
BMI (kg/m²)	*	27.51	3.59	24.93	3.68
WHR		0.97	0.04	0.96	0.04
Bone minerals (kg)		2.85	0.31	2.72	0.24
Cell mass (kg)		30.72	3.24	29.70	2.40
Visceral fat (cm²)	*, †	140.52	24.87	119.20	27.27
Abdominal circumference (cm)	*	100.12	10.93	92.80	10.29
Steps (per day)	**, †	7 498	1 431	12 658	2 509
Moderate physical activity (min/week)	**, †	208	79	424	127

Legend:
Differences were analysed by Fisher's LSD post-hoc after one factor ANOVA between SUB2A and SUB2B (* p < .05, ** p < .01). Cohen's coefficient was calculated for determination of effect sizes between two variables († d < 0.80).

did not show the characteristics of sarcopenia because they were above the upper limit of normal range in all subgroups. We found similar conclusions regarding the cell mass (BCM). In case of FFMI and BCM, the differences between the highly active and insufficiently active subgroup, and active and insufficiently active subgroup were insignificant.

TABLE 4 enables us to judge the differences between the women who did not meet the recommendation (SUB2A) and women who met the recommendation (SUB2B). This classification results from the recommendations made by by Tudor-Locke and Bassett (2004). Taking over 10 000 steps everyday brings lots of health benefits, amongst others the reduction of body fat. Tudor-Locke et al. (2001) found the correlation between the number of steps taken per day and the percentual proportion of body fat ($r_p = -0.27$) a BMI ($r_p = -0.30$). A similar trend was observed in our study, however, the connections between these parameters are much closer (Fig. 1). In the case of percentage body fat, the correlation coefficient is –0.52 ($p < .05$) and –0.38 ($p < .05$) in the case of BMI.

The absolute proportion of body fat mass was significantly lower ($p < .05$ by Fisher's LSD post-hoc; $d = 0.84$) in the women who met the recommendation in comparison to women who did not meet the recommendation. The same trend was found concerning the BFMI ($p < .05$ by Fisher's LSD post-hoc; $d = 0.88$). According to Kyle et al. (2004a) classification, the mean value of the BFMI was high in the women who did not meet the recommendation (BFMI = 10.09 kg/m^2), whereas in women who met the recommendation it was within the normal range (BFMI = 7.81 kg/m^2). Mean values of the WHR were in all measured subgroups in the zone of very high risk (WHR > 0.90) and values were going down with increasing physical activity. This trend is confirmed in the study of Hu, Tuomilehto, Silventoinen, Barengo and Jousilahti (2004) where they found significant differences ($p < .001$) in the WHR between physically active and inactive individuals. Furthermore, it is evident from the study that the physically active population was, on average, younger, had lower BMI, waist and hip circumference, diastolic blood pressure and a higher level of HDL cholesterol than the population with a lower volume of physical activity. In general we can state that the rising of WHR is not only affected by age, as is shown by the results of Jones, Hunt, Brown and Norgan (1986) or Gába, Riegerová and Přidalová (2008), but also by the volume of physical activity. The central distribution of body fat mass is also connected to the average values of the visceral fat area and abdominal circumference and unlike in WHR, the differences are significant ($p < .05$ by Fisher's LSD post-hoc). Based on these results, we can state that physical activity might lower the risk related to the central distribution of body fat mass in which high levels are connected to an increase in total mortality and morbidity (Elia, 2001; Spirduso, Francis, & Macese, 200).

Soft lean mass (SLM) is an active body mass, which is defined as a fat free mass without bone minerals. Its proportion in the individual body parts is shown in TABLE 5. The percentual SLM is expressed in relation to body weight, which enables us to evaluate the differences in body constitution in the monitored groups. The absolute amount of the SLM is higher in the insufficiently active and women who did not meet the recommendation with the exception of lower limbs, however the situation is different in relative amounts. On the basis of the higher body weight of the inactive women (SUB1A and SUB2A), the percentual amount of the SLM in the individual body parts is lower than in the active women (SUB1B, SUB1C and SUB2B). We found statistically significant differences in the left and right upper limb ($p < .01$ by means of Fisher's LSD post-hoc) and the trunk ($p < .05$ by means of Fisher's LSD post-hoc) between the active and highly active.

Fig. 1
Correlation of the percentage of body fat ($r_p = -0.52$; $p < .05$) a BMI ($r_p = -0.38$; $p < .05$) with number of steps made per day

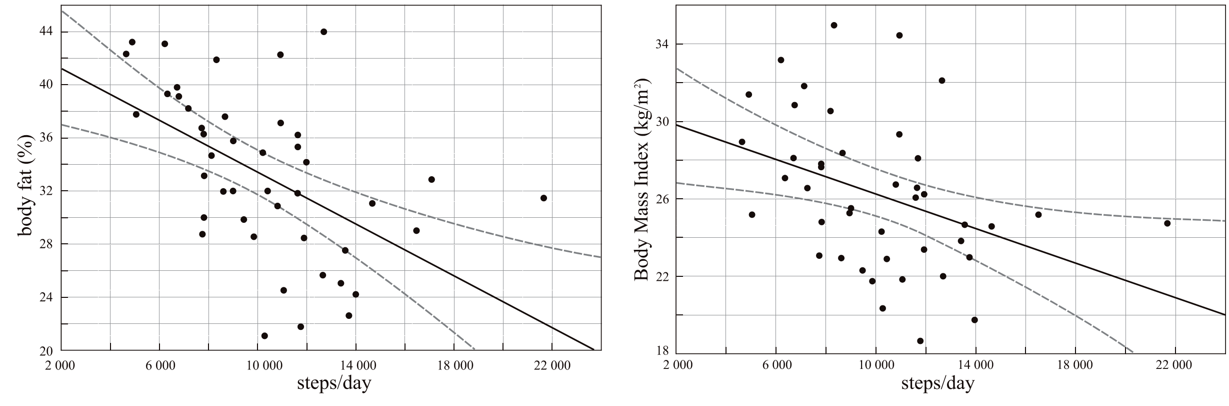

TABLE 5
Segmental analysis of soft lean mass (kg)

	SUB1A n = 6		SUB1B n = 16		SUB1C n = 21		SUB2A n = 21		SUB2B n = 22	
	Mean	**% weight**	**Mean**	**% weight**	**Mean**	**% weight**	**Mean**	**% weight**	**Mean**	**% weight**
RA (kg)	2.57	3.37	2.41	3.34 **	2.47	3.60	2.51	3.33 **	2.42	3.61
LA (kg)	2.52	3.31	2.38	3.29 **	2.43	3.54	2.48	3.29 **	2.37	3.54
TR (kg)	21.63	28.40 *	20.70	28.65 *	20.91	30.44	21.32	28.31 **	20.57	30.70
RL (kg)	7.00	9.19	7.28	10.07	6.98	10.16	7.30	9.69	6.90	10.30
LL (kg)	7.00	9.19	7.23	10.01	6.98	10.16	7.30	9.69	6.86	10.24

Legend:
RA – right arm
LA – left arm
TR – trunk
RL – right leg
LL – left leg
Differences between subgroups were analysed by Fisher's LSD post-hoc after one factor ANOVA – SUB1A vs. SUB1C, SUB1B vs. SUB1C (* $p < .05$, ** $p < .01$); SUB2A vs. SUB2B (** $p < .01$).

The same conclusions were found when we compared the subgroups on the basis of the number of steps taken on average per day. Concerning the evaluation of SLM changes, the most stable are the lower limbs. Further, we concentrated on the evaluation of muscle mass proportion on the limbs regarding laterality. When we compared the selected body parts (RA vs. LA, RL vs. LL), we found factually significant differences between the left and right upper limb. The mean value of the SLM was higher in the right upper limb in all cases, which most likely illustrates its side dominance.

CONCLUSIONS

Results of the presented study support the positive effect of physical activity on body composition, particularly on body fat mass. The more moderate physical activity or number of steps on average a day the more significant changes we observed in body fat mass quantity, in absolute and relative values and we observed distinct changes in the BMFI values. The differences in changes in the visceral fat area in the subgroups appear to be very substantial; similarly we found different values in abdominal circumference and the WHR. The quantity of fat free mass, FFMI and body cell mass did not substantially differ within the subgroups because the fat free fractions are much less affected by this type of physical activity. The mean values of intracellular and extracellular water correspond with these findings. In the women with the highest volume of physical activity, their BMFI values dropped to the safe zone level, which is regarded as a very major effect.

Since this study was conducted as a pilot study in women and concerning the small sample size, future studies investigating the relationship between the body composition and the level of physical activity in female and male population are needed to confirm these findings. Moreover, as the study sample was identified as predominantly active, the follow up research should focus on the sedentary population. It should also be noted, that other factors affecting body composition and physical activity (e.g. dietary, disease or smoking status) were not observed. In spite of these limitations, the presented study is beneficial to follow up research on body composition and in the physical activity research area in the elderly population, particularly in the Czech Republic.

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HODNOCENÍ TĚLESNÉHO SLOŽENÍ VE VZTAHU K POHYBOVÉ AKTIVITĚ U ŽEN VE VĚKU 56–73 LET: PILOTNÍ STUDIE

(Souhrn anglického textu)

Nedostatek pohybové aktivity je spojován se vzrůstajícím výskytem nadváhy a obezity. Z tohoto důvodu se v oblasti veřejného zdraví stává prevence nadváhy a obezity prioritou.

Primárním cílem prezentované studie bylo analyzovat vztah mezi tělesným složením a úrovní pohybové aktivity u žen ve věku 56–73 let.

Sledovaný soubor jsme rozdělili na dílčí podsoubory dle doporučení vztahujících se ke středně zatěžující pohybové aktivitě a počtu kroků vykonaných v průměru za den. Diagnostika tělesného složení byla realizována s využitím multifrekvenční bioimpedanční metody (InBody 720) a pro monitoring pohybové aktivity bylo využito akcelerometru ActiGraph GT1M.

Průměrné hodnoty BMI byly u všech sledovaných podsouborů lokalizovány v pásmu nadváhy s výjimkou žen, které plnily obecná doporučení vztahující se k množství kroků vykonaných v průměru za den. U tohoto podsouboru byla průměrná hodnota BMI (24,93 kg/m^2) lokalizována v pásmu optimální hmotnosti. Pozitivní vliv pohybové aktivity na složení těla se projevil především ve změně zastoupení tukové složky. Absolutní i relativní zastoupení tělesného tuku a BFMI byl u inaktivních žen vyšší než u žen aktivních ($p < 0,05$; $p < 0,01$) a jeho množství klesalo v závislosti na intenzitě pohybové aktivity ($r_p = -0,40$; $p < 0,05$) a průměrném počtu kroků vykonaných za den ($r_p = -0,50$; $p < 0,05$). Z hlediska distribuce tukové tkáně bylo prokázáno její centrální ukládání, a to jak u žen aktivních, tak u žen inaktivních. V obou případech jsme zaznamenali překročení hranice vysoké rizikovosti (WHR > 0,90). Průměrné hodnoty viscerálního tuku se u všech sledovaných podsouborů nacházely nad zdravotně bezpečnou hranicí (100 cm^2), avšak jeho množství bylo signifikantně nižší u aktivních žen ($p < 0,05$). Na základě analýzy základních tělesných segmentů bylo zjištěno, že u aktivních žen je zastoupení SLM na pravé a levé horní končetině a na trupu vyšší ($p < 0,05$; $p < 0,01$) než u žen inaktivních.

Výše zmíněné výsledky podporují tvrzení o pozitivním vlivu pohybové aktivity na zdraví člověka. U tělesného složení se tento vliv projevuje především v redukci tělesného tuku, jehož nadbytek v organismu způsobuje v celosvětovém měřítku velké množství problémů.

Klíčová slova: zdravé stárnutí, InBody 720, tělesný tuk, středně zatěžující pohybová aktivita, chůze, ActiGraph.

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THE ADMINISTRATION OF THE RORSCHACH INKBLOT METHOD AND CHANGES IN AUTONOMIC NERVOUS SYSTEM ACTIVITY

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The administration of some psychological methods can be a temporary source of stress and evoke in some patients a pathophysiological reaction with a negative health outcome. The aim of the study was to find out whether the administration of the Rorschach Inkblot Method (RIM) can change the autonomic nervous system (ANS) activity in terms of shifting the sympathovagal balance towards sympathetic activity. The RIM test was applied to 39 healthy females (22.8 ± 2.4 years). ANS activity was measured by the spectral analysis of heart rate variability (SA HRV) before, during, and after the RIM test. The same algorithm as in the previous procedure was employed in 30 healthy females (21.41 ± 1.7 years), however the Stroop color word test (SCWD), a very powerful stressor with a marked impact on ANS activity, instead of the RIM, was administered. Five relative parameters of SA HRV were used: percentages of VLF (very low frequency), LF (low frequency) and HF (high frequency) components (from the spectral power total) and VLF/HF and LF/HF ratios. Changes in VLF/HF and LF/HF during the RIM and SCWT tests were used to compare the tests. During the RIM administration, a significant decrease in spectral power in HF (%), a significant increase in VLF (%) and LF (%), and a significant increase in LF/HF and VLF/HF ratios have been shown. No significant differences in VLF/HF (markers of stressful situations) among the RIM and the SCWT were found. The administration of the RIM can act as a powerful stressor and causes a significant decrease in parasympathetic activity and the shift of sympathovagal balance towards sympathetic activity. Administration of RIM and SCWT tests can produce stress of comparable intensity, with a similar impact on ANS activity.

Keywords: Rorschach test, psychological stress, heart rate variability, spectral analysis, vagal activity, sympathetic activity, sympathovagal balance.

INTRODUCTION

If we try to understand human beings in well being and in sickness, we must approach each individual with respect to multiple interacting factors (Engel, 1977; Ruiselová & Prokopčáková, 2005), in order to take into account his/her special needs (Štěrbová, 2003). At the same time we can see that the approaches of some researchers in different areas of human sciences tend to be simplified, more or less preferring only certain aspects of human existence and avoiding others. In many studies in psychology, researchers base their findings solely on interviews, observations or questionnaires while avoiding physiological aspects of personality. At the same time it is unquestionable that detailed information about physiological changes under certain conditions (e.g. under stress, during psychological assessment or relaxation training) can significantly improve our understanding of human existence or some psychosomatic disorders. The autonomic nervous system (ANS) plays a very important role in complex stress response. Many approaches have been developed to measure ANS activity; some of which can be applied in the practice of clinical psychology. Apart from the traditional methods of ANS assessment (e.g. pupilometry, evaluation of serum catecholamines or changes in heart rate (HR) or blood pressure in standardized situations – Ewing, Martyn, Young, & Clarke, 1985) we can also find relatively new ways of doing psychophysiological assessment. One of these ways is the spectral analysis (SA) of heart rate variability (HRV) (Aubert & Ramaekers, 1999; Task Force, 1996). A growing number of studies focus on the analysis of the influence of experimentally induced stress (or the administration of psychological assessment methods) on selected aspects of human immune response and other physiological functions. Del Rio and colleagues (1998) found an increased level of plasmatic adrenaline among females in menopause during the administration of the Stroop color word test and Lindqvist, Kahan, Melcher and Hjemdahl (1993) used SCWT to study cardiovascular and sympathoadrenal response among people with primary hypertension. From the review of relevant literature we can conclude that researchers use, as experimental stressors, mostly performance tests such as: (a) the Stroop test; (b) mirror drawing; (c) mental arithmetic; or (d) various memory tasks.

One of the methods that is instrumental towards an elicitation of experimental stress is the RIM. RIM is one of the most common psychological tests used for the analysis of the personalities of respondents. It is a projective technique, using the projection of thoughts and personality traits to 10 unknown mottles (objects of strange shapes). The ways in which respondents select and emphasize specific aspects of shapes reflects personal interests, tendencies, experiences and needs. Svoboda (1999) argues that the RIM is a unique test because of its sensitivity to detect a respondent's personality in its full complexity. Only a limited number of studies focus on the changes of physiological parameters during the RIM. Keltikangas-Järvinen, Kettunen, Ravaja and Näätänen (1999) examined the relationship of temperament dimensions, serving as markers for behavioral activation and inhibition systems, with autonomic stress reactivity in 35 middle aged males. They found that the temperament activation of the skin was positively related to the task induced changes in respiratory sinus arrhythmia (RSA) amplitude, but unrelated to HR reactivity; on the other hand, temperament inhibition was positively associated with HR reactivity. In another study, Kettunen and colleagues (1998) studied electro-dermal activity (EDA), HR, and subjective and behavioral arousal during the administration of the RIM in 37 middle aged men. The authors found that EDA phases and HR accelerations were synchronized and they suggested that an intraindividual analysis of physiological time series data can extend our understanding of the individual differences in the ANS functions. Kettunen, Ravaja, Näätänen and Keltikangas-Järvinen (2000) analyzed the relationship of RSA to the coactivation of autonomic and facially expressive responses in 37 adult men during the administration of the RIM. They concluded that spontaneous autonomic and expressive responses tend to be parallel in time and that the changes in RSA were positively related to coupled autonomic expressive reactions. Masling, Price, Goldband and Katkin (1981) monitored the EDA in male subjects with high (orals) and low numbers (non orals) of oral dependent RIM responses. They found that orals showed in the presence of associates a lesser electrodermal increase than orals sitting alone or non orals either alone or with their associates.

It seems to be clear that the administration of psychological methods can be a temporary source of stress and potentially influence results. Cherrington, Moser and Lennie (2002) stated that for persons with acute cardiac disease, the administration of psychological instruments might be psychologically stressful and have two unintended negative effects: (a) if patients experience acute stress merely as a result of reading and completing the instruments, they can score spuriously high; (b) psychological stress may evoke (e.g. in patients with acute cardiac disease) a physiological reaction with a negative health outcome. The authors stated that, in the relevant literature, there is a gap in studies about the influence of the administration of psychological methods to those patients with acute myocardial infarction. According to the authors, the administration of psychological methods amplifies that physiological reactivity, which one would expect regarding the changes in specific parameters. The activation of the hypothalamic pituitary adrenal axis would lead to an increased level of cortisol in the saliva, to an increase in HR and a decrease in HRV. However, there were no significant differences, e.g. in salivary cortisol, HR or blood pressure between the measurements prior to the administration of several questionnaires and 30 minutes afterwards. The authors concluded that the administration of psychological instruments used in the mentioned study did not cause any stress reaction. A limitation of this study is the small sample size and the fact that respondents used drugs affecting their ANS activity (β blockers).

Many authors (Aubert & Ramaekers, 1999; Šiška, 2002b; Tonhajzerová, Javorka, & Petrášková, 2000; Tonhajzerová, 2008) claim that the changes in some parameters of SA HRV can be related to the level of arousal from experiencing a stressful situation. We believe that the assessment with the help of the RIM represents a specific interpersonal situation, in which many factors can play an important role (being challenged by a new task, an opportunity for a creative approach to reality, fear of the unknown, an unpleasant confrontation with less structured material, etc.). We can also state that in many cases the assessed person shows clear outer signs of stress. The purpose of the study was to evaluate the level of psychological stress during the administration of the Rorchach inkblot method (RIM) and the Stroop color word test (SCWT). The first aim of our study was to evaluate the level of stress during RIM administration on the basis of changes in ANS activity as assessed by SA HRV (part 1). The second aim was to compare the changes in SA HRV during RIM with the changes during the administration of a known and significant experimental stressor (part 2). For this purpose we used the SCWT, which was in many studies recognized as a very powerful stressor with a marked impact on ANS activity (Becker et al., 1996; Fauvel et al., 1996; Grillot et al., 1995; Manuck, Olsson, Hjemdahl, & Rehnqvist, 1992; Šiška, 2002a). The authors hypothesize that RIM administration excites the sympathoadrenal system and that the actions of the both psychological tests act as similar stressors.

METHOD

Participants

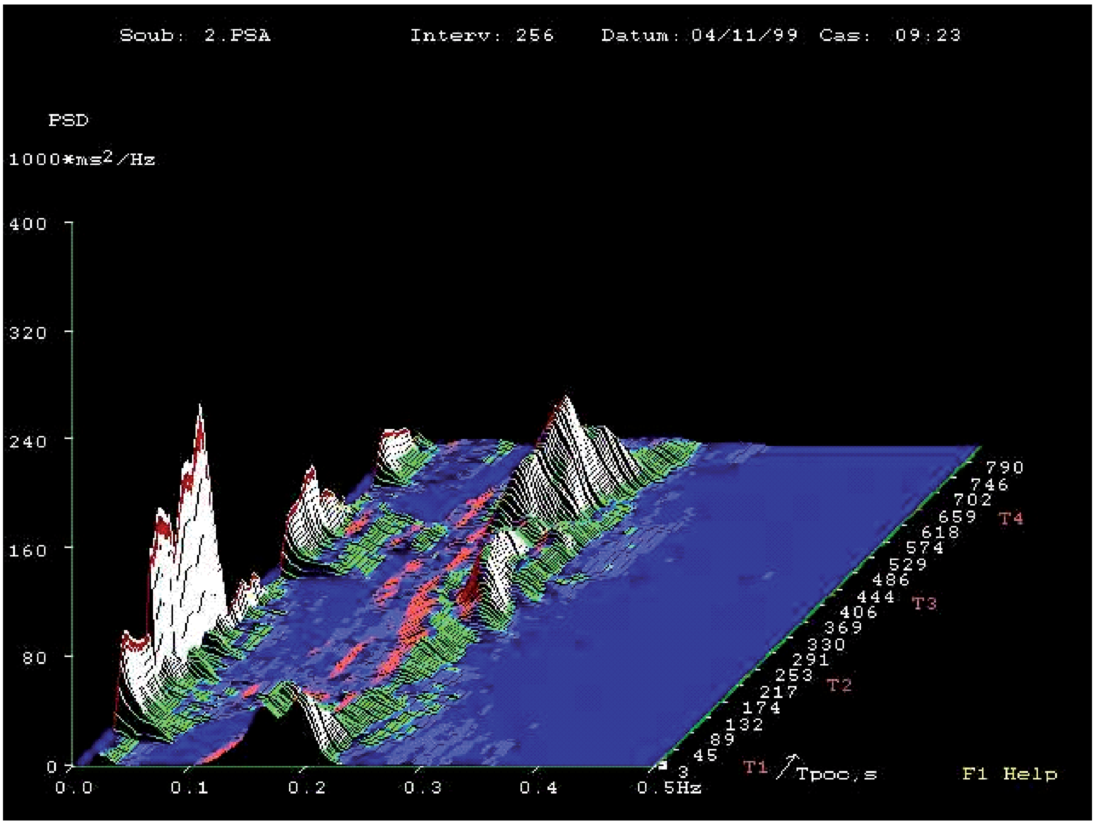
Participants in part 1 (the administration of the RIM) were 39 healthy females with an average age of 22.8 ± 2.4 years. During the experiment none of them used any substances which could affect ANS activity (e.g. β blockers). The conditions of the experiment were strictly standardized. All measures were done from 8 a.m. till 11 a.m. in a quiet room with a constant temperature. Participants were also asked to abstain from greater physical activity within 24 hrs prior to the testing. They were asked to eat only a light breakfast and not to smoke or drink coffee in the morning on the testing day. Participants in part 2 (the administration of the SCWT) were 30 healthy females with an average age of 21.41 ± 1.7 years. The conditions of the examination were the same as in Part 1 (a quiet room, no β blockers, etc.).

Measure

SA HRV represents a non invasive method which can be used to get important information about specific efferent regulatory influences of the parasympathetic (and partly also sympathetic) nervous systems and about the interaction of psychological and physiological processes. Its basic principle is based on information about a series of so called R-R intervals (intervals between consecutive heartbeats) which is transformed into the spectral power of range from 0.02 to 0.40 Hz. Their short term analysis (minimally 5 minutes and 300 heartbeat periods) allows the differentiation of three spectral components:

1. VLF (very low frequency) – range 0.02–0.05 Hz;
2. LF (low frequency) – range 0.05–0.15 Hz with a mean frequency of approximately 0.10 Hz;
3. HF (high frequency) – range 0.15–0.40 Hz with a mean around a respiratory frequency of 0.25–0.30 Hz (Fig. 1).

Fig. 1
Three dimensional graph of power spectral density acquired by means of VariaPulseTF3 System in different intervals



Legend:
T1– before test
T2 – during test
T3 – after test (all the intervals in sitting position)
T4 – standing position

Spectral power within the HF range is related to the efferent activity of the parasympathetic nervous system vagal activity (Aubert & Ramaekers, 1999; Berntson et al., 1997; Task Force, 1996). One of its main components (a frequency of approx. 0.25–0.30 Hz) is represented by the above mentioned RSA, which is seen as the non invasive index of the parasympathetic control of HR. The LF component (called Mayer's pressure wave) is considered by some authors (e.g. Pagani et al., 1991) to be an indicator of the sympathetic modulation of HR; others, however, suppose a certain level of vagal activity here as well and it seems that supporters of this opinion are in the majority today (Task Force, 1996). The LF component is influenced mostly by baroreceptor activity and corresponds with slow changes in blood pressure variability. Spectral power in the VLF component represents a relatively unclear phenomenon, which is usually related to the thermoregulatory sympathetic activity of the vascular system, the level of circulating catecholamines, and to the oscillations of the renin-angiotensin system (Berntson et al., 1997).

In order to assess the relation between the sympathetic and parasympathetic modulation of HR in more details, the LF/HF ratio was proposed, and is used as an indicator of sympathetic activity or its predominance (index of so called sympathovagal balance); some authors, however, deny its general applicability and/or suggest using it only under certain conditions (Eckberg, 1997). The ratio VLF/HF can be seen as one of the markers of the experiencing of stressful situations (Šiška, 2002a; Tonhajzerová, Javorka, & Petrášková, 2000). Therefore, the VLF/HF ratio, together with the LF/HF ratio, was used in this study. For the continuous registration of R-R intervals we used the VariaPulseTF3 System, which was developed by the group of researchers at the Faculty of Physical Culture, Palacký University, Olomouc, Czech Republic. This system allows measurements and the telemetric transfer of signals typical for the full length of R-R intervals (in milliseconds) of the ECG recording (Salinger et al., 1998). The obtained data are stored in a PC and analyzed with special software, which allows for the measuring of R-R intervals, filtration of artifacts or arrhythmias, the calculation of the frequency spectrum with the use of Fast Fourier Transformation, statistical analysis and saving the data (Salinger et al., 1994). Breathing frequency, which can markedly influence the spectral power distribution wasn't measured for technical reasons; this is one of the limits of the study. On the other hand, breathing frequency accelerates during stress. Therefore, it is hardly likely that the results of our study could be influenced by the breathing frequency $<$ 0.15 Hz, which means less than 9 breaths per minute.

Stroop colour word test

The Stroop color word test (SCWT) is a psychological test of our mental (attentional) vitality and flexibility. The task takes advantage of our ability to read words more quickly and automatically than we can name colors. When implementing the classic form of the SCWT, the subject is initially required to read words representing the names of some basic colors, then he/she tries to quickly name the colors of, for example, small rectangles and at the end he/she goes through the so called subtest of interference (Šiška, 2002b). The subtest of interference is based on the assumption that looking at the name of a color which is other than what the actual color is (e.g. the word red is written in green), the subject strongly tends to read the name instead of saying the color in which the word is written (which is what the instruction requires). The cognitive mechanism involved in this task is called directed attention, you have to manage your attention, inhibit or stop one response in order to say or do something else. When reading quickly, the person gets into a conflict filled stressful situation because the answer is influenced by the learned reaction (in this case by the tendency to read words, not to name the colors).

Rorschach inkblot test

The Rorschach inkblot test is a psychological test in which subject's perceptions of inkblots (ambiguous images) are recorded and then analyzed using psychological interpretation. The tester and subject typically sit next to each other at a table, with the tester slightly behind the subject. This is to facilitate a "relaxed but controlled atmosphere". There are ten official inkblots, each printed on a separate white card, approximately 18 × 24 cm in size. Each of the blots has near perfect bilateral symmetry. Five inkblots are of black ink, two are of black and red ink ant three are multicolored, on a white background. After the test subject has seen and responded to all of the inkblots (free association phase), the tester then presents them again one at a time in a set sequence for the subject to study: the subject is asked to note where he sees what he originally saw and what makes it look like that (inquiry phase). The subject is usually asked to hold the cards and may rotate them. The general goal of the test is to provide data about cognition and personality variables such as motivation, response tendencies, cognitive operations, affectivity, and personal/interpersonal perceptions. The underlying assumption is that an individual will class external stimuli based on person specific perceptual sets, and including needs, base motives, conflicts, and that this clustering process is representative of the process used in real life situations (Klopfer & Davidson, 1962).

Procedure

Part 1 (RIM)

Each participant was informed about the study and its objectives and then was asked to sign an informed consent form. After the taking of a brief interview, the participants were asked to sit quietly. Subsequently, the RIM was administered and the participant's responses were recorded. After responding to the last card, the participant was asked to sit quietly again. During all of these phases, HR was recorded by means of VariaPulseTF3 to obtain the required numbers of R-R intervals for the short term recordings of SA HRV (about a 5 minute long measurement period in each interval). So we obtained three recordings from all participants: pre-test (prior to the RIM), test (the first 5 minutes of the RIM administration), and post-test (after the RIM). For the assessment of the above mentioned recordings we used SA HRV. We were interested in finding any statistically significant differences in the relative spectral power of each component (%) – VLF (% VLF), LF (% LF), and HF (% HF), and in the VLF/HF and LF/HF ratios.

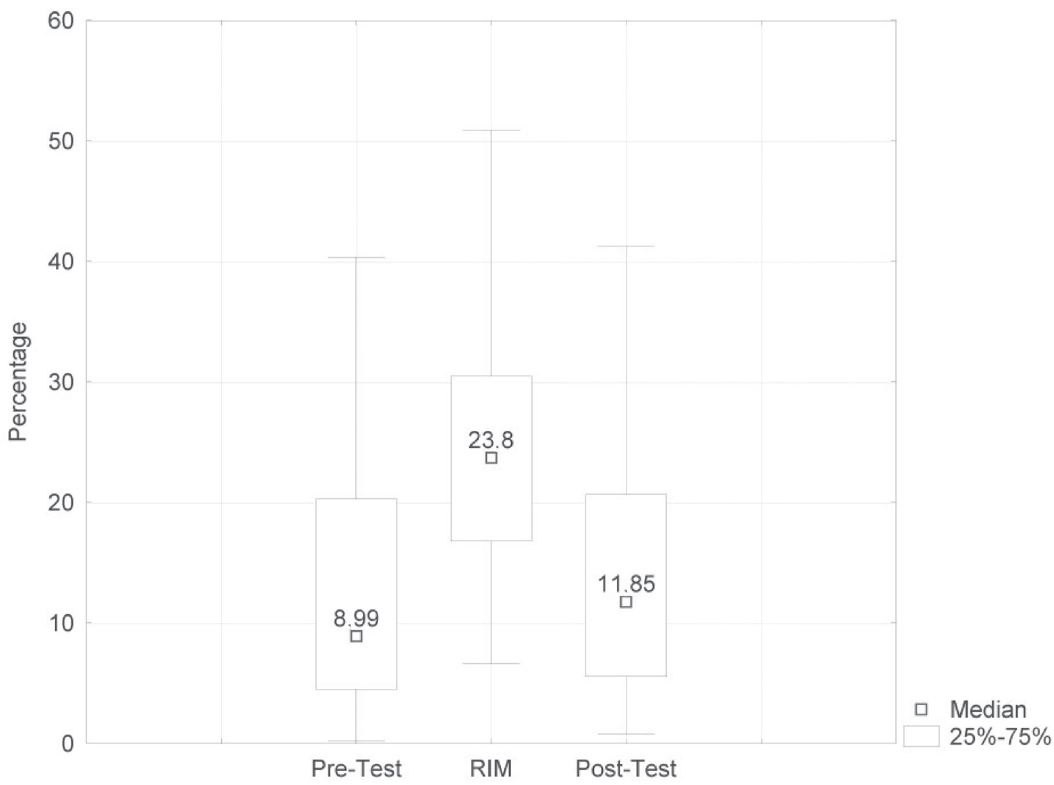
Part 2 (SCWT)

We used the same procedure (algorithm) as in part 1, however the Stroop color word test, instead of the RIM, was repeatedly administered. So we obtained three recordings from all participants: pre-test (prior to SCWT), test (5 minutes of SCWT administration), and post-test (after SCWT). The values of the VLF/HF and LF/HF were compared between the RIM and SCWT. The first parameter is considered to be a marker of stressful conditions and the second is seen as an index of the so called sympathovagal balance (see above).

Statistics

Basic statistical analysis showed that the distribution of values of most monitored variables was noticeably asymmetrical. For comparison of changes in selected parameters of SA HRV (part 1) we decided to use only non parametric statistics, specifically Friedman ANOVA for repeated measures. The differences between particular situations (pre-test: test, test: post-test, and pre-test: post-test) were evaluated with the help of a mul-

Fig. 2
Differences in relative powers of VLF



tiple comparison method (by means of the Wilcoxon matched pairs test and the Bonferroni adjustment). This is accomplished by dividing the pre-set α level (0.05) by the number of tests being performed (in our case 0.05: 3 = 0.0166). Any test that results in a p-value of less than 0.0166 would be considered to be statistically significant. For the comparison of possible differences between the administrations of SCWT (part 2) and RIM (part 1) we used the Mann-Whitney test. All statistical calculations were done with the use of the software STATISTICA®.

RESULTS

Part 1

During the RIM administration (in comparison with pre-test and post-test, Fig. 2–6) we found a decrease in % HF (pre-test vs. test: $Z = 5.01$, $p < 0.01$, test vs. post-test: $Z = 5.22$; $p < 0.01$),an increase in % VLF (pre-test vs. test: $Z = 4.09$, $p < 0.01$, test vs. post-test: $Z = 4.10$; $p < 0.01$), and % LF (pre-test vs. test: $Z = 3.54$, $p < 0.01$, test vs. post-test: $Z = 3.92$, $p < 0.01$), and an increase in LF/HF ratio (Ppe-test vs. test: $Z = 4.507$; $p < 0.01$, test vs. post-test ($Z = 4.73$; $p < 0.01$) and VLF/HF ratio (pre-test vs. test: $Z = 5.01$, $p < 0.01$, test vs. post-test: $Z = 5.39$, $p < 0.01$).

After the administration of the RIM we found a relatively fast return of the monitored parameters of SA HRV to the initial levels, and no significant differences between the post-test and the pre-test: % VLF ($Z = 0.89$, $p = 0.37$), % LF ($Z = 0.49$, $p < 0.01$), % HF ($Z = 0.25$, $p = 0.80$), VLF/HF ($Z = 0.11$, $p = 0.91$), and LF/HF ($Z = 1.02$, $p = 0.318$).

Part 2

Among the values of VLF/HF at particular intervals of the examination (pre-test, test a post-test) we found no significant differences between the RIM and the SCWT (pre-test: $Z = 0.73$, $p = 0.47$; test: $Z = -1.46$, $p = 0.14$; post-test: $Z = 1.19$, $p = 0.23$). The LF/HF ratio showed out a non significant difference in the pre-test ($Z = 1.17$, $p = 0.24$), but the differences in the two following phases were significant (test: $Z = -2.46$, $p = 0.01$; post-test: $Z = 2.26$, $p = 0.02$, Fig. 7 and 8).

Fig. 3
Differences in relative powers of VLF

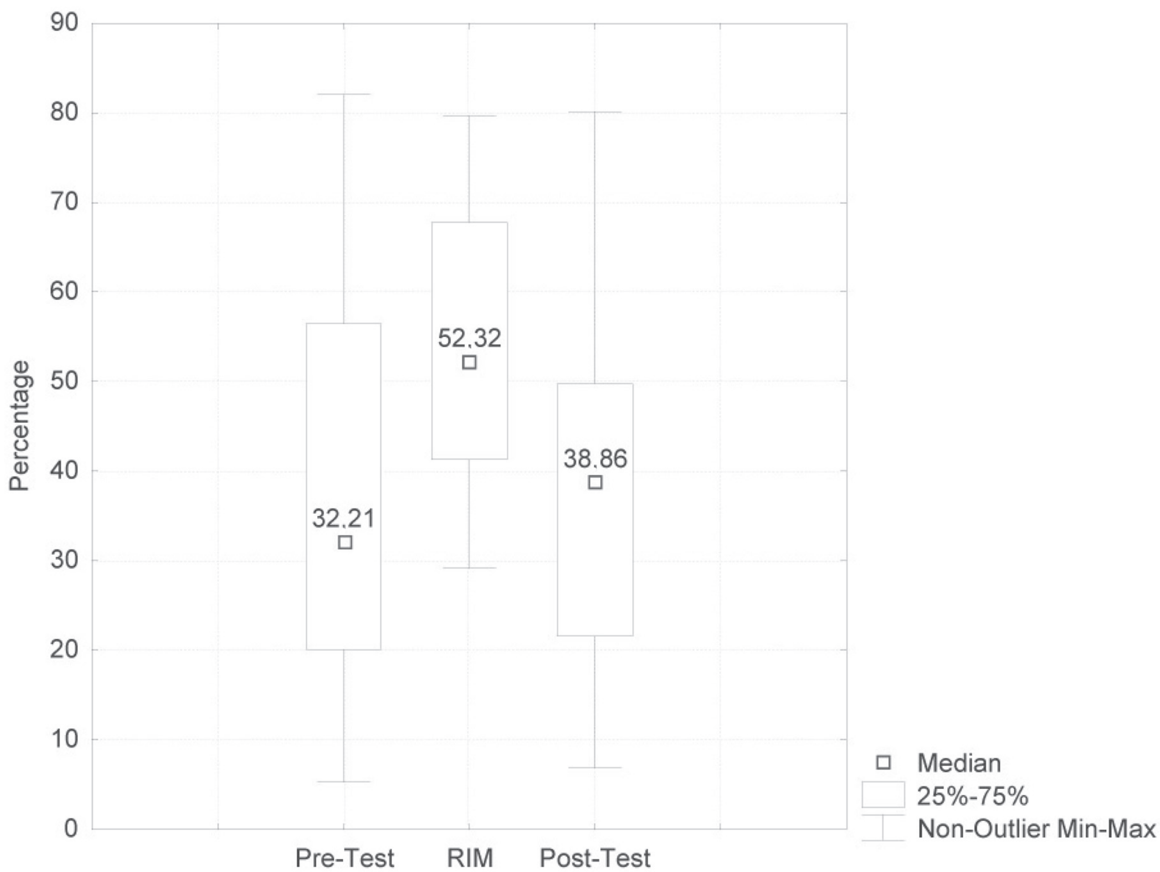


Fig. 4
Differences in relative powers of HF

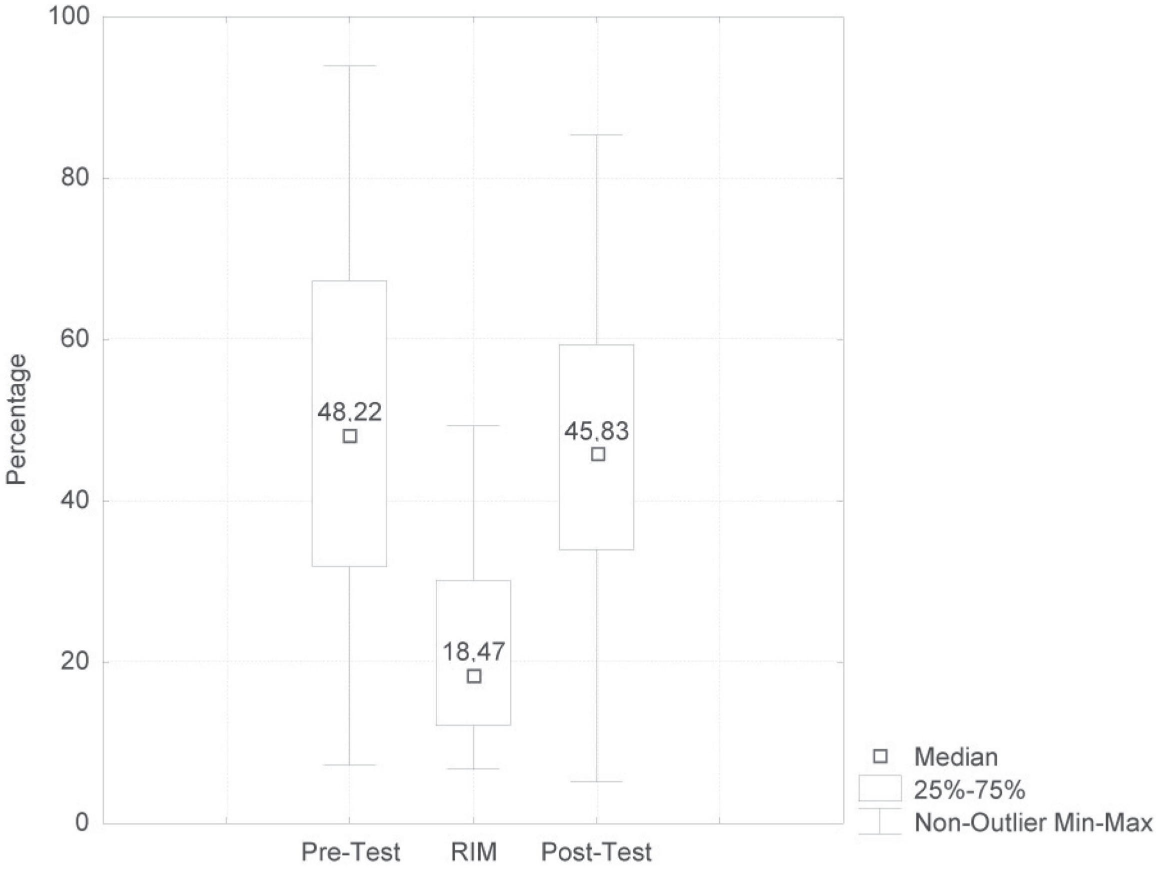


Fig. 5
Differences in VLF/HF

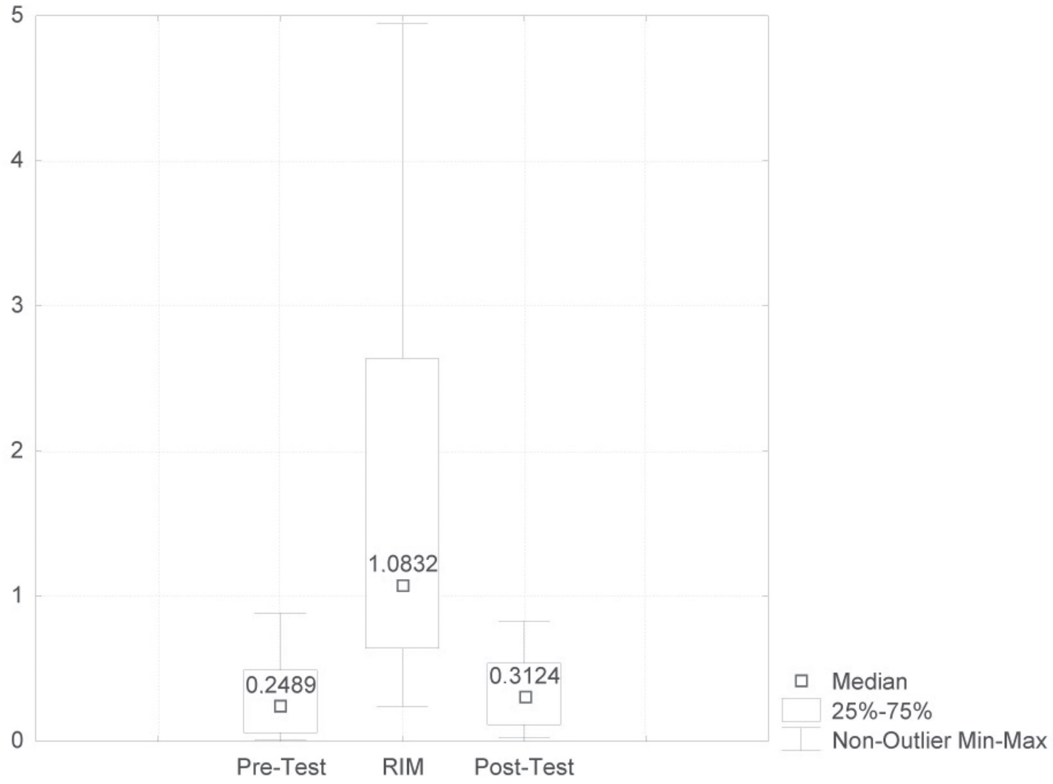


Fig. 6
Differences in LF/HF

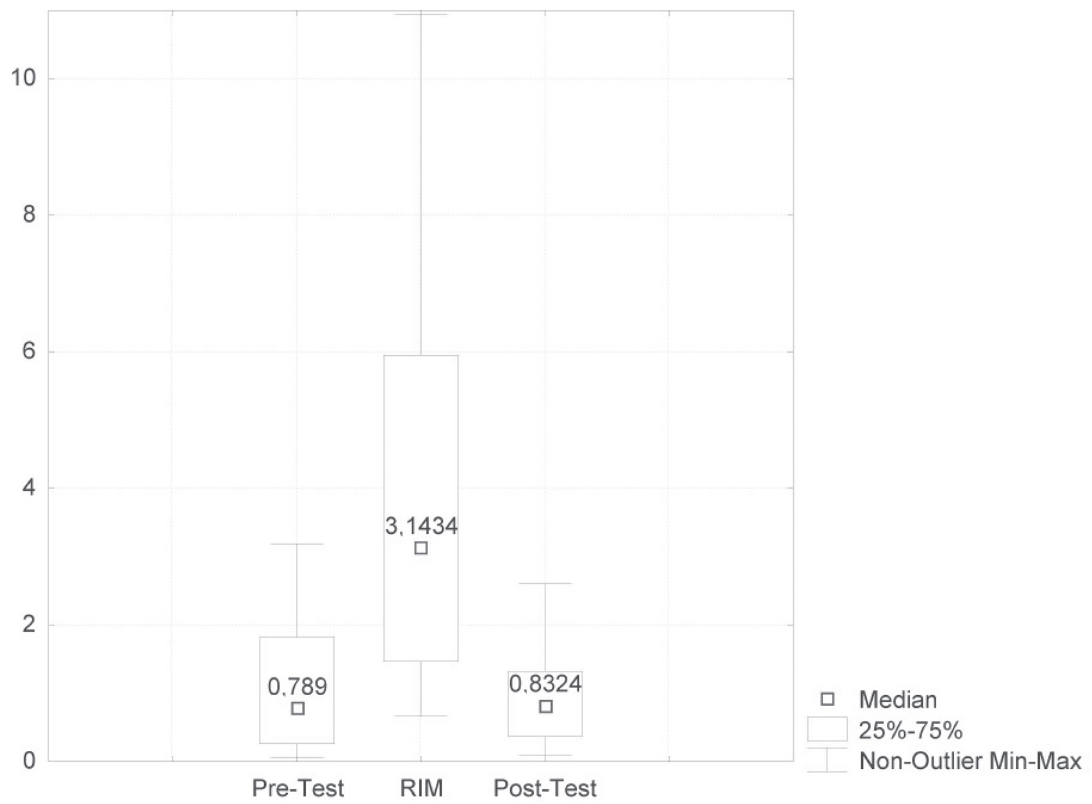


Fig. 7
Differences in LF/HF

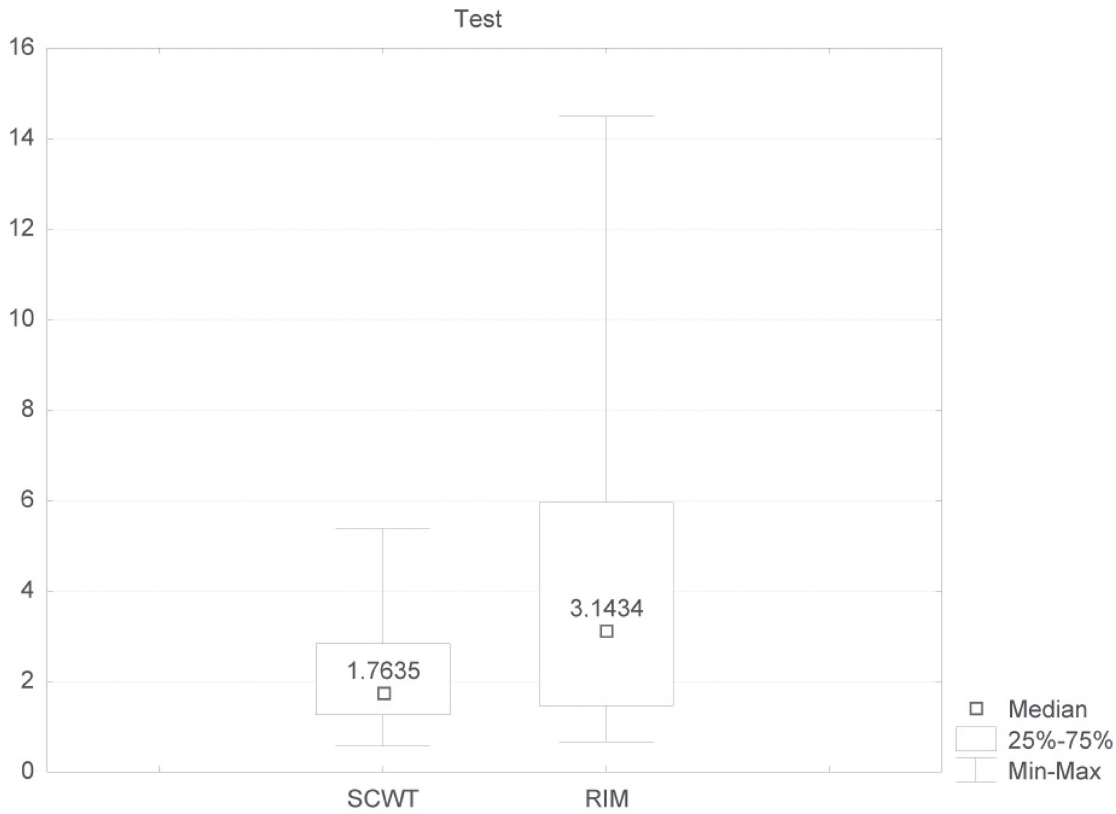
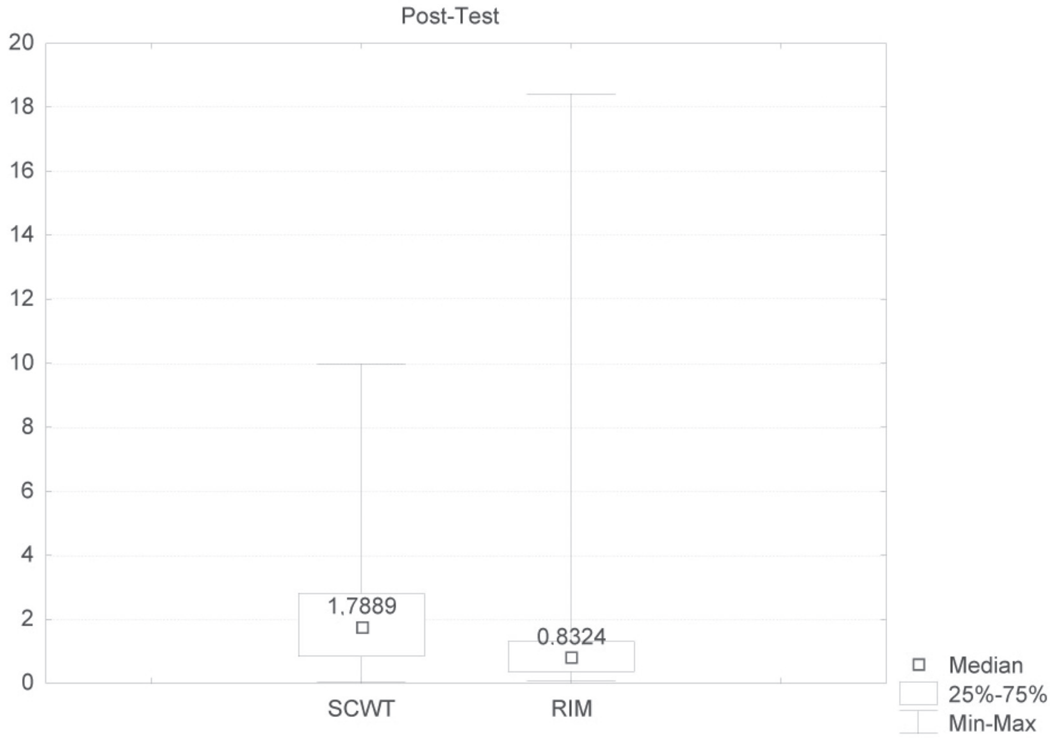


Fig. 8
Differences in LF/HF



DISCUSSION

Human existence is complex and everything interacts with everything else. In the professional area there is a consensus that for maintaining homeostasis the ANS is one of the most important factors. According to McEwen and Stellar (1994) it is better to use term alostasis as we should not ignore the variability of physiological processes in their dependence on outside influences. ANS is structurally and functionally intended to manage relationships between inner and outer conditions and to coordinate somatic processes with the aim of assuring adaptive reaction to changing life conditions. The functions of ANS depends on the tuning of physiological and behavioral responses, which are coordinated centrally and peripherally (Hamill, 1996). At the same time it is supposed that practically every mental or physical activity has its reflection in changes in ANS activity.

It is evident that the administration of the RIM (at least in the first minutes after beginning) can act as a powerful stressor, which causes a clear decrease in parasympathetic activity and a shift of sympathovagal balance towards sympathetic activity (a decrease in HF % and an increase in VLF %, LF %, LF/HF and VLF/HF). The results of many studies (Aubert & Ramaekers, 1999; Berntson et al., 1997; Grillot et al., 1995; Hoshikawa & Yamamoto, 1997; Task Force, 1996; Tonhajzerová, 2008) show that similar changes in the autonomic efferent activity are typical for stressful situations. Everyday clinical experience supports these findings. For example, we can see that for some persons the administration of the RIM represents a stressful situation, which can be reflected in non verbal expressions (increased motor instability, tremor, blushing, etc.) as well as in open verbal statements (they complain about their eyes hurting from the cards; they are not for "such things"; they judge tables as non sense daubs and refuse to share their associations in order to escape from stressful situation). The level of experienced stress can – in our opinion – potentially affect the productivity and spontaneity of respondents (e.g. the problem of so called low R). It can also lead to the activation of censorship, to lower willingness to share some interpretations or to use certain determinants, etc. This, in the final analysis, determines the quality of responses and, naturally, the reliability of our diagnostic judgment. We should keep this fact in mind when interpreting Rorschach protocols and we should try to create a testing environment, which can lower the stress, anxiety and tension of our patients/clients and lead to more valid results.

From the comparison of changes in selected parameters of SA HRV in particular phases of examination (with respect to psychological methods used, i.e. the RIM and the SCWT) we can see that in the VLF/HF ratio there were no significant differences, whereas the LF/HF ratio during the administration of the RIM (Test phase) was even significantly higher than during the SCWT. In the post-test phase, the situation was inverse – the LF/HF after the SCWT was significantly higher than the LF/HF after the RIM. On the basis of the obtained results, we conclude that the administration of both methods can produce stress of comparable intensity, with a similar impact to the autonomic modulation of heart activity. The difference in the post-test phase is difficult to explain (different types of stress?) and requires further research.

In our study we used the SA HRV method for the evaluation of changes in the autonomic modulation of HR, which is judged by many authors as being a reliable and sensitive indicator of the actual, current functional state of the ANS. At the same time, we would like to bring attention to the fact that the clinical use of SA HRV preceded full understanding of all its physiological correlates and, solely on its basis, we cannot evaluate the state of sympathetic and parasympathetic activity under varying conditions (Malik & Camm, 1993). As this method is relatively accessible and non invasive, it has been used in many areas and by many researchers, but some of the results of published studies seem to be somewhat contradictory. It is therefore important to state that this method is sensitive to many influences, which we do not fully understand yet (Aubert & Ramaekers, 1999; Task Force, 1996). A generally accepted opinion is that measuring the dynamics of changes in SA HRV parameters under varying natural and experimental conditions deepens our understanding of the psycho-physiological foundations of this method and thus increases the opportunities for its adequate application in clinical practice (Berntson et al., 1997; Fagard, Pardaens, & Staessen, 1999; Task Force, 1996). The above mentioned facts lead to a certain degree of caution in the interpretation of the results of our study. Another limitation is the low sample size or the reduction of the sample only to females, which lowers its ecological validity and shows the need to further study this phenomenon.

CONCLUSION

We would like to emphasize that SA HRV appears to be a very suitable method for the evaluation of the psychophysiological reactions of persons under different conditions, as it provides a very sensitive and fast evaluation of changes in the cardiovascular system (specifically periodic changes in HR), which are strongly determined also by the current functional state of the ANS. Our results confirmed the hypothesis that RIM administration induces a significant decrease in parasympathetic activity and shifts sympathovagal balance towards sympathetic activity. The administration of the RIM and SCWT tests could produce stress of comparable intensity, with a similar impact on ANS activity. The next step in our research could be focused on searching for the relationship between selected indicators of RIM and the dynamics of changes of SA HRV parameters. The combination of personality assessment with the use of the RIM together with the evaluation of changes in psychophysiological parameters (e.g. autonomic modulation of heart activity) can, in our opinion, lead to a more profound understanding of the human complex stress response, of the etiology and pathogenesis of certain psychosomatic disorders, to broaden opportunities for the identification of persons with a high to pathological reactivity to stress, to help with the planning of appropriate therapeutic procedures or in the evaluation of the effect of relaxation techniques in persons with more serious psychosomatic problems, etc.

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APLIKACE RORSCHACHOVY METODY A ZMĚNY V AKTIVITĚ AUTONOMNÍHO NERVOVÉHO SYSTÉMU

(Souhrn anglického textu)

Použití některých psychologických metod může přechodně působit jako zdroj stresu a u některých pacientů vyvolat patofyziologické reakce s negativním dopadem na zdraví. Cílem této studie bylo zjistit, zda aplikace Rorschachovy metody (Rorschach Inkblot Method – RIM) může ovlivnit aktivitu autonomního nervového systému (ANS) ve smyslu posunu autonomní rovnováhy směrem k sympatiku. Test RIM byl aplikován u 39 zdravých žen (22,8 ± 2,4 roku). Aktivita ANS byla hodnocena pomocí spektrální analýzy variability srdeční frekvence (SA HRV) před testem RIM, v jeho průběhu a po jeho ukončení. Stejný postup byl zachován i v souboru 30 zdravých žen (21,41 ± 1,7 roku), avšak test RIM byl zaměněn za Stroopův test (Stroop color word test – SCWT), který se používá jako uznávaný zátěžový faktor ovlivňující významně aktivitu ANS. Pro hodnocení aktivity ANS bylo použito pět relativních ukazatelů SA HRV: percentuální podíl komponent VLF, LF a HF na celkovém spektrálním výkonu a poměry mezi komponentami (VLF/HF a LF/HF). Tyto poměry byly použity pro porovnání změn aktivity ANS, ke kterým došlo při použití obou psychologických testů (RIM a SWCT). Během aplikace testu RIM došlo k významnému poklesu spektrálního výkonu HF (%), významnému vzestupu VLF a LF (%) a významnému vzestupu poměrů VLF/HF a LF/HF. Mezi testy RIM a SCWT nebyly shledány žádné rozdíly v dynamice VLF/HF (ukazatel stresu). Aplikace testu RIM může vyvolat silnou stresovou reakci spojenou s významným poklesem vagové aktivity a posunem autonomní rovnováhy směrem k sympatiku. Aplikace testů RIM a SCWT může vyvolat stres podobné intenzity a s podobným dopadem na aktivitu ANS.

Klíčová slova: Rorschachův test, psychologický stres, variabilita srdeční frekvence, spektrální analýza, aktivita vagu, aktivita sympatiku, sympatovagová rovnováha.

PhDr. Emil Šiška, Ph.D. †

In memory of our dear colleague, first author of this article, dr. Emil Šiška, the great professional, sincere person and good friend to us. Despote of several years elapsed from the implementation of the experiment, coauthors preserved original design and results of experiment and the major part of the test which was mostly a matter of the first author. Only some interpretations of the results were changed so that corresponds to current knowledge.

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THE INFLUENCE OF THE LEADER ON THE MOVEMENT OF THE HORSE IN WALKING DURING REPEATED HIPPOTHERAPY SESSIONS

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The movement of a walking horse is utilized as a tool for a therapeutic effect in hippotherapy. The movement impulses of the horse's back are influenced by the movement action of its limbs, morphology, speed of walk, etc.

The aim of the study was to evaluate the influence of the leader on a horse's movement while walking during repeated hippotherapy treatment sessions.

Three dimensional (3D) videography was used for the assessment of the movements of a horse (selected points on the limbs and back) and a human being (reaction to the horse's movement). The study was done with the repeated measurements (n = 6) of the movement of horses (n = 2) and riders (n = 12) during five weeks of hippotherapy intervention (9 sessions in total) by the different leaders (n = 6) of the horses.

There are differences in the range of movement of selected points on the limbs and back of the horse while leading it as done by different leaders ($p < 0.05$, $p < 0.01$). The changes in the kinematics of the horse's limbs are transmitted to the horseback movements of horse H1 only within a limited range. The range of the differences on the limbs and back for horse H2 is similar. The movement responses of healthy riders show differences in the lower part of the spine ($p < 0.05$); in the upper part of the spine the differences are minimal. The horse leader is one of the key factors for adhering to the desired medical effect, which is established on the basis of the intervention of physiotherapy throughout hippotherapy.

As there are a number of factors which could have a negative effect on the movement of the horse (weather, disturbing influences of the environment, low quality surface), the activities of the horse leader in keeping the relevant direction and speed of the horse's movement are decisive factors. This study emphasises the significance of the role of the horse leader in therapy and puts stress on his/her level of professionalism, fitness, motivation and performance.

Keywords: Hippotherapy, leader of a horse, 3D videography, movement response of the rider.

INTRODUCTION

Locomotion of horses

Each gait of a horse has a characteristic sequence of the stepping of the individual limbs onto the ground, which determines the amount of contact of the limbs with the ground and the rhythm and speed of the movement (Pilliner, Elmhurst, & Davies, 2004).

The walking of a horse is a four period gait (four limb contacts). The speed of the movement is at an average of 100 $m \cdot min^{-1}$ (6 $km \cdot h^{-1}$). The ideal situation involves all four limb contacts being in equal periods from each other. This rhythm is described as regular or square (Clayton, 2004). The collective acting of the dorsal and ventral muscles of the horse's torso is very important for the fluency of the rhythm (Nicholson, 2006). The manner of the horse's step is furthermore projected into the three dimensional movement of the horse's back, which becomes the unique balance area for therapy.

The quantitative parameters of the mechanics of the horse's movement are the length of step, speed of movement and step frequency. Dušek et al. (1999) suggests that the more the horse is able to increase its speed through prolonging the length of a step and not through increasing the step frequency, the better it is equipped and disposed to movement.

Hippotherapy – the horse as a variable

A horse trainer takes part in choosing the horse for the purposes of hippotherapy. He or she evaluates the horse as a whole, in collaboration with individual parts, the muscles and the mechanics of movement. A physiotherapist evaluates the horse's height, the width of the back, the length of step along with its softness and fluency. It is necessary to choose the horse with regards to a specific group of patients (Hermannová, 2002). Horses which seem suitable by anatomical appearance, but are unable to become free in movement due to some health problems, should not be considered for therapy (Benetinová, 2000; Hermannová in Kulichová et al., 1995).

We can divide horses into the inhibitive or stimulative categories for the purposes of hippotherapy on the basis of the biomechanical parameters of movement components in the oscillating of the horse's back. The stimulative category mostly occurs in the bigger intensity of the vertical component of the back movement.

The movement dialogue between a person and a horse in hippotherapy

A person and a horse are two independent biological systems with their own wills. The movement "activator" in hippotherapy is the horse and the task of the person (patient) is to adjust to these movements for the collective acting of movements to occur (Wheeler, 2003). The locomotion impulses of the dorsal muscles of the horse's back during walking are three dimensional and are transferred to the rider with a frequency of 90–110 impulses per minute (Tauffkirchen, 2000).

The surrounding elements of both systems most often lead to movement transfer – the pelvis of the patient in the classic therapeutic position in sitting and the horse's back. The mobilisation of individual movement segments of the spine occurs during this transfer, thus leading to the removal of articulatory hyper mobility and, simultaneously, to the eccentric training of the short mono segmental (autochthonic) muscles (Véle, 1997; Rothaupt, Laser, & Ziegler, 1998).

Personal safeguarding of the process of hippotherapy

Hippotherapy is a method of treatment using horses for the purpose of physiotherapy intervention. The patient's doctor must send clients for such treatment. The members of the therapeutical team are the physiotherapist with a special education, a trainer and a horse leader (not always one person), and a helper who ensures the safety of the client on the horse. Due to the degree of progress of the patient with the physical handicap, from 2 to 4 people are necessary to care for one patient.

In practice it is necessary to have the possibility to work gradually with the horse, which the therapist uses through a leader. This mostly involves changing the length of the horse's step and its speed. The therapist modifies the movement behaviour of the animal with the intention of achieving the desired effect within the framework of therapeutical units. This is carried out on the basis of the gradual evaluation of the patient's reactions.

Each leader, just like the horse, is an individual whose movement moves through the horse to the rider. Therefore, it is suitable to use specially trained leaders to lead the horse during hippotherapy to achieve the desired effect (Dvořáková, Janura, Svoboda, & Pavelková, 2004).

The purpose of the study was to find the influence of the leader on the manner of carrying out the movement of the horse in hippotherapy and to determine how these changes affect the reactions of the movement system of the rider.

SUBJECTS AND METHODS

The measurements were taken in cooperation with the equestrian club Théta Chválkovice in Olomouc, where hippotherapy has been taking place for more than 10 years. The study was focused on following the changes in the movement of some selected parameters in the limbs and on the horseback in the repeated performance of hippotherapy for a period of five weeks (nine therapeutical units with a frequency of twice per week). The measurements took place on a large asphalt ring, where hippotherapy regularly takes place.

Characteristics of the observed group of horses

In order to minimise the movement differences, horses of the same breed (thoroughbred) with a similar bodily constitution (Fig. 1) were used in this study.

Fig. 1
Horses H1 and H2 were used for the purposes of our study

Horse H1 – gelding, age 19 years, height 165 cm, length of time in hippotherapy 8 years.

Horse H2 – mare, age 14 years, height 165 cm, length of time in hippotherapy 9 years.

The horses were in good physical condition, i.e. capable of full performance. The Ethical Board of the Faculty of Physical Culture in Olomouc gave their agreement for the use of these horses for the purpose of these studies.

Preparation of the horses

The horses were saddled with a thin mat and stomach strap (sling to stop the mat from slipping). Before they were measured, the horses were lead around outside for around 15 minutes. The bridling of the horses was carried out with a palpation identification of the anatomical structures. The application of contrasting signs was also done. The anatomy of the horse's body surface is relatively simple. Individual anatomical points are identified in relation to the total constitution and are more evident in comparison with other kinds of domestic animals (Černý, 1995). The same person carried out all the measurements of palpation.

Observing points

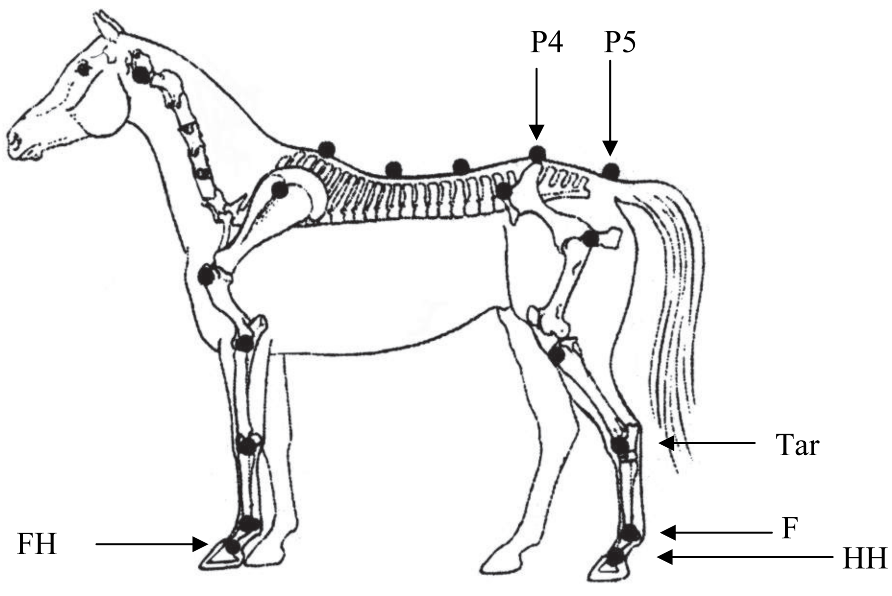
For the purpose of marking the points on the horseback, we used foam semi rounded markings of 0.04 m in diameter and yellow in colour. The labels were fixed onto the horse's skin by using double sided sticky tape. We used crosses from the strips of white sticky tape 0.12 m in length and 0.02 m in width for labelling the horse's limbs, as the labels tended to fall off. The centre of the cross was the observed point.

We used the basic set of anatomic points used for the movement analysis of horses for the purpose of our research. These are presented in the works of Holmström (2002) and Robert, Audigié, Valette, Pourcelot and Denoix (2001). We labelled 8 points on the body in order to fulfil the aims of this work (Fig. 2).

Leaders

Each horse was led by three leaders over the course of the repeated hippotherapy units. They were individuals with varying levels of experience and differing amounts of practice. Each leader, generally an active rider, was acquainted in detail with the method of carrying out these activities and knew all the factors which could negatively influence the movement of the horse. As the research took place over a period of several weeks, it was not possible to find out the concurrent number of therapy units which were carried out with all the participating leaders. This was partially due to the other work responsibilities of the leaders (TABLE 1).

Fig. 2
Observed points on the horse's body



Legend:
P4 – sacral tuber
P5 – root of the tail
F – fetlock (centre of the side projection of the fetlock joint)
Tar – tarsus (lateral edge of the trochlea tali)
FH – centre of the coronet of front hoof
HH – centre of the coronet of hind hoof

TABLE 1
Amount of analysed sequences of horse steps when led by individual rider

Horse H1		Horse H2	
Leader	Number of sequences	Leader	Number of sequences
L1	62	**L4**	98
L2	24	**L5**	68
L3	70	**L6**	24

Legend:
L1–L6 – leaders of horses H1, H2

Records of movement

A flat asphalt area of around 15 m in length was chosen for the recording. Four cameras were placed at the sides of the flat area (JVC GR – DVL9800, SONY DCR – TRV900E, frequency 25 Hz). A central line was marked in the middle of the way indicating the direction of the horse's movement. Perpendicular lines on the determined area with a distance of 2 m were indicated for better orientation when compiling the video recordings. These lines simplified the identification of the double step in synchronising the video recordings from each camera. Three pieces of synchronising equipment were installed into the recording area along with four black and white control points for further video processing.

A calibration device was recorded throughout the measurements in five chosen places. These were created through a cuboid with dimensions of 1 × 1 × 2 m. The points located in the corners of the cuboid and the edges were important for the calibration of the area necessary for the subsequent digitising of the video recordings.

Processing of video recordings and analysis of data

The acquired video sequences were divided into individual strides of the horses and synchronised. They were then processed using APAS software for 3D kinematic analysis (Ariel Dynamics Inc., Trabuco Canyon, CA, USA). The resulting coordinates of points from the synchronised recordings (DLT) were used for determining the basic kinematic parameters (length, speed, and angle).

The observed kinematic parameters on the horse's body

We evaluated the following parameters when analysing the movement of the horse:

- step duration,
- step length,
- step frequency,
- walking speed,
- the vertical displacement of the front and hind hoofs,
- the vertical displacement of the fetlock and tarsus,
- the vertical displacement of points P4 and P5.

The observed kinematic parameters on the rider's spine

We evaluated the following parameters when analysing the recordings of the rider's movements:

- the vertical displacement of point L5,
- the horizontal displacement of point L5 on a sagittal plane,
- the upper spine angle displacement (the angle defined by segments C7–Th5, Th5–Th12) on a sagittal plane,
- the lower spine angle displacement (the angle defined by segments Th5–Th12, Th12–L5) on a sagittal plane.

Statistical analysis

The acquired data was processed by the STATISTICA 6.0 programme. Basic descriptive statistics were calculated for the evaluated parameters. An analysis of variance was used for the comparison of the data derived from all lectures involving different leaders. We used the LSD post hoc test for determining the differences between individual leaders.

RESULTS AND DISCUSSION

The basic statistical values of the observed parameters are in TABLE 2.

Horse H1
Movement of the horse

There were significant differences between the individual leaders ($p < 0.01$; $p < 0.05$) in terms of the majority of the observed parameters (TABLE 3). The length of each step was between 1.69 m and 1.80 m; the speed of each step was between 1.39 $m.s^{-1}$ and 1.49 $m.s^{-1}$. The highest step speed in leading done by leader L3 was achieved through a combination of the highest length of a step and a higher frequency.

The maximal displacement for the front hoof differed by 0.019 m, whereas it is 0.012 m for the hind hoof. The differences in the lifting of the leg are also transferred to further segments of the hind limbs and the size among individual leaders decreases. In the case of leader L3, this height is at its lowest and the trajectory of the limb is at its flattest.

We found a further decrease in differences for the points on the horseback. The differences we found were statistically significant on the level $p < 0.01$ i.e. $p < 0.05$, and the absolute difference is less than 0.01 m.

Parameters of the riders

We found statistically significant differences in the body of the rider, especially for the movement of point L5 in a vertical direction. The tendency of changes is similar to those in the case of point P4 on the horse's

TABLE 2

The basic statistical characteristics of selected parameters on the bodies of the horse and rider while working with different leaders

Horse	Leader	Tstep [s]		Lstep [m]		Speed [$m.s^{-1}$]		Freq [Hz]		FH [m]		HH [m]		F [m]	
		Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
H1	L1	1.26	0.113	1.74	0.047	1.39	0.128	0.80	0.065	0.073	0.016	0.092	0.024	0.126	0.015
	L2	1.19	0.088	1.69	0.058	1.43	0.133	0.84	0.064	0.086	0.017	0.105	0.017	0.146	0.015
	L3	1.22	0.098	1.80	0.042	1.49	0.120	0.83	0.063	0.067	0.017	0.093	0.017	0.124	0.015
H2	L4	1.32	0.064	1.78	0.042	1.35	0.076	0.76	0.037	0.061	0.013	0.091	0.014	0.129	0.011
	L5	1.28	0.115	1.81	0.058	1.43	0.139	0.79	0.067	0.068	0.012	0.090	0.013	0.126	0.011
	L6	1.32	0.079	1.79	0.027	1.36	0.090	0.76	0.045	0.076	0.017	0.091	0.015	0.124	0.012

Horse	Leader	Tar [m]		P4 [m]		P5 [m]		L5y [m]		L5z [m]		A1 [°]		A2 [°]	
		Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
H1	L1	0.154	0.023	0.059	0.011	0.074	0.009	0.078	0.041	0.030	0.011	21.00	11.18	18.41	7.69
	L2	0.165	0.017	0.054	0.008	0.070	0.010	0.069	0.027	0.021	0.009	21.64	14.93	17.84	10.91
	L3	0.160	0.018	0.062	0.009	0.079	0.009	0.066	0.023	0.034	0.010	18.13	7.39	17.62	7.17
H2	L4	0.128	0.014	0.055	0.007	0.068	0.007	0.064	0.055	0.028	0.009	12.13	4.43	11.18	4.21
	L5	0.135	0.010	0.064	0.008	0.074	0.009	0.062	0.056	0.027	0.008	14.69	5.60	12.35	3.87
	L6	0.130	0.013	0.052	0.006	0.065	0.005	0.074	0.059	0.025	0.008	13.59	4.92	10.86	3.50

Legend:
Tstep – step duration
Lstep – step length
Speed – walking speed
Freq – step frequency
FH – centre of the coronet of front hoof
HH – centre of the coronet of hind hoof
F – fetlock (centre of the side projection of the fetlock joint)
Tar – tarsus (lateral edge of the trochlea tali)
P4 – sacral tuber
P5 – root of the tail
L5y – the horizontal displacement of point L5 on a sagittal plane
L5z – the vertical displacement of point L5 on a frontal plane
A1 – the angle defined by segments C7–Th5, Th5–Th12 on a sagittal plane
A2 – the angle defined by segments Th5–Th12, Th12–L5 on a sagittal plane
** – $p < 0.01$
* – $p < 0.05$
LA × LB – difference between leader A and leader B

TABLE 3

Statistically significant differences of measured parameters when horses H1 and H2 are led by different leaders

		Horse 1			Horse 2		
	Parameter	**L1 × L2**	**L1 × L3**	**L2 × L3**	**L4 × L5**	**L4 × L6**	**L5 × L6**
Body – horse	Tstep	*					
	Lstep	**	**	**	**		
	Speed		**		**		
	Freq	*			**		
	FH	**	*	**	**	**	*
	HH	**		**			
	F	**		**			
	Tar	**	*		**		
	P4	**		**	**	*	**
	P5	*	**	**	**		**
Body – rider	L5y		*				
	L5z	**	*	**			
	A1		*		*		

Legend:
Tstep – step duration
Lstep – step length
Speed – walking speed
Freq – step frequency
FH – centre of the coronet of front hoof
HH – centre of the coronet of hind hoof
F – fetlock (centre of the side projection of the fetlock joint)
Tar – tarsus (lateral edge of the trochlea tali)
P4 – sacral tuber
P5 – root of the tail
L5y – the horizontal displacement of point L5 on a sagittal plane
L5z – the vertical displacement of point L5 on a frontal plane
A1 – the angle defined by segments C7–Th5, Th5–Th12 on a sagittal plane
A2 – the angle defined by segments Th5–Th12, Th12–L5 on a sagittal plane
** – $p < 0.01$
* – $p < 0.05$
LA × LB – difference between leader A and leader B

back and the size of the differences increases to the value of 0.013 m when leaders L2 and L3 lead the horses. There are lesser differences in the segments in the upper parts of the spine. The angle displacement with the top in Th12 differs from leader to leader by less than 1°. The average value for the angle with the top in Th5 in terms of differences between leaders L2 and L3 is 3.5°. The extent of the interindividual differences between individual riders is great.

Horse H2

Movement of the horse

In the movement of the horse we found significant differences ($p < 0.01$) when the horses were led by leaders L4 and L5. The length of the step of the horse ranged between 1.28 m and 1.32 m and the walking speed between 1.35 $m.s^{-1}$ and 1.43 $m.s^{-1}$. The increase in the walking speed when the horse was led by leader L5 was caused by a combination of the longest step and the highest frequency.

The maximal displacement of the front hoof differs by 0.015 m, the differences between the individual leaders were significant ($p < 0.01$). We found differences for the points on the hind limb, which were smaller and did not exceed 0.005 m. With the exception of the difference for the tarsus displacement, when the horses were led by leaders L4 and L5, there were no significant differences between the remaining leaders on the level of $p < 0.05$.

In terms of the points on the horseback, the amount of statistically significant differences increases. For point P4 we found this difference in three different leaders. The absolute size difference is 0.012 m for point P4 and 0.009 m for point P5.

Parameters of the riders

In contrast to leading horse H1, the number of statistically significant differences is smaller. The size of the difference in leading horse H2 through leader L4 and L6 is 0.012 m for the movement of point L5 in the horizontal direction. The differences found in the movement of point L5 in the vertical direction were minimal, less than 0.005 m. The range of the movement of the angle with top in Th12 differed between individual leaders by 1.5°. The size of the difference between leaders L4 and L5 for the angle with top on Th5 was 2.56° ($p < 0.05$).

When evaluating the differences in the performance of the movement of the horse and rider in hippotherapy, a number of factors must be taken into account, sharing the influence in these changes. As the horse's movement is, to a certain degree, determined by the activity of the leader, it is necessary to judge the situation from a systematic point of view, where there is an interaction between two (three in the case of observing changes to the body of the rider) biological subsystems (Wheeler, 2003), which are both extremely complicated. It is therefore necessary to define the basic factors which influence the activity of individual subsystems and which also have a say in the quality of the measured data.

Weather and wind conditions

During the measurements, the weather changed from cold and rainy to sunny, with the temperature reaching 30° C. This was, of course, an influencing factor in the carrying out of the movement, especially in terms of the speed and length of the steps. It is possible to say that rain and cold weather lead to a tendency to spend less time in unsheltered areas. Being in a fixed area (on a course) may lead to the movement becoming faster. This is evident in the length of the steps and in the size of the absorbtion of impulses in the stepping of the front limbs (Harris, 1993). Furthermore, these changes are evident in the size of the deviations of the horse's back (Dvořáková, Janura, Vyjídáková, & Svoboda, 2004).

Influence of tiredness

It is difficult to presume that the leader is not affected by physical or psychological tiredness in his/her maximum professional approach. This may have a significant effect on the basic parameters of his/her gait (Straus, 2001). Furthermore, the relatively simple and stereotyped activities required by the leader may in turn cause tiredness.

Moreover, the work of the horse in hippotherapy is very demanding, not only due to the intensive stress put on the back by the patient, with a frequent erroneous control over his/her own posture, yet more from a psychological point of view. "Hippotherapy is not a relaxing activity for sport horses nor renting stables, nor is it an outing for old used up horses" (Casková, 2003, 7).

Errors in measurement

When comparing the measured differences, it is necessary to take the size of the measurement errors into account. In this case, it is a combination of the accuracy of the technical equipment and its influence on a living and moving entity. The error grows in the process of evaluating records, during the calibration of the space and the transformation of coordinates (Allard, Stokes, & Blanchi, 1995). If we are dealing with mistakes caused by the palpation of the bone structure, placement of markers, or movement of tissue, then this influence cannot be totally eliminated. A certain advantage in the analysis of the movement of a horse is that the anatomic points on its body are more evident in comparison with other domestic animals due to the total constitution (thin skin, thinner fascia, a smaller amount of ligament in the fat tissue) (Černý, 1995).

The above mentioned sizes of errors touch particularly on the cases where the analysis of the movement is carried out in one attempt. Our study focuses on comparing the effect of leaders, when the amount of analysed attempts for the given leader was from 24 to 98. The determination of the average values from the high amount of sequences leads to a decrease in the errors in measurement (Smith, 1993).

When evaluating the size of differences, we must also take the segment or place on the horse's body (rider) into account, for which the difference was established. In the case of horse H1, the differences in movement of the points on the horseback are smaller than the differences on the limbs. Their size, which approaches 1 cm in the vertical direction, is to be considered to be objectively important. This is also valid for the movement of points on the rider's body, as there is an increase in the differences in comparing the movement of points on the horse's back. The number of differences is smaller in terms of the movements of horse H2. The sizes of differences on the limbs and on the horse's back were similar. These changes were not transferred to the points on the rider's spine.

CONCLUSIONS

The horse leader is one of the important factors contributing to the quality of a hippotherapy course. As there are a number of factors which could have a negative effect on the movement of the horse (weather, disturbing influences of the environment, low quality surface), the activity of the horse leader in keeping to the relevant direction and speed of the horse's movement are decisive factors. These are essential conditions for adhering to the medical effect which is established on the basis of the intervention of physiotherapy throughout hippotherapy.

There are considerable differences found between different leaders when comparing the movement of points on the limbs and on the horse's back (P4, P5). These differences also have a logical significance for the vertical movement of the L5 point on the rider's spine.

This study should serve as a source of information for those engaged in this therapeutic method. It emphasises the significance of the role of the horse leader in therapy and puts stress on his/her level of professionalism, fitness, motivation and performance.

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VLIV VODIČE NA POHYB KONĚ V KROKU V OPAKOVANÝCH LEKCÍCH HIPOTERAPIE

(Souhrn anglického textu)

Pohyb koně v kroku je prostředkem k léčebnému působení hipoterapie. Pohybové impulzy hřbetu koně jsou ovlivněny mechanikou pohybu končetin, morfologií, rychlostí kroku atd. Vzhledem k tomu, že pohyb koně je do určité míry determinován činností vodiče, je nezbytné posuzovat situaci ze systémového hlediska, kde v rámci systému dochází k interakci mezi dvěma (třemi, v případě sledování změn na těle jezdce) biologickými subsystémy.

Cílem práce bylo určit vliv vodiče na pohyb koně v kroku při opakovaných jednotkách hipoterapie.

Pro hodnocení pohybu koně v kroku (vybrané body na končetinách a na hřbetu) a jezdce (reakce na pohyb koně) byla použita 3D videografická metoda. Studie byla provedena jako opakovaná měření (n = 6) pohybu koní (n = 2) a jezdců (n = 12) v průběhu pěti týdnů probíhající intervence formou hipoterapie (celkem 9 lekcí) při vedení koní s využitím různých vodičů (n = 6). Data získaná ve všech lekcích při vedení různými vodiči byla pro každého koně porovnána použitím analýzy rozptylu (program STATISTICA v 6.0). Pro určení rozdílů mezi jednotlivými vodiči jsme použili LSD post hoc test.

V rozsahu pohybu vybraných bodů na končetinách a na hřbetu koně existují významné diference při využití různých vodičů ($p < 0{,}05$, $p < 0{,}01$). Při vedení koně H1 se změny v kinematice končetin koně přenáší do pohybu hřbetu pouze v omezeném rozsahu. Pro koně H2 je rozsah diferencí v pohybu bodů na končetinách a na hřbetu koně podobný. Reakce zdravých jezdců na rozdíly v pohybu koní v horních úsecích páteře se při vedení různými vodiči vyznačuje pouze minimálními diferencemi. V oblasti bederní páteře je změna ve vertikálním posunu bodu L5 významná ($p < 0{,}05$).

Vzhledem k množství faktorů, které mohou negativně působit na pohyb koně (počasí, rušivé vlivy prostředí, nekvalitní povrch), rozhoduje aktivita vodiče o dodržení odpovídajícího směru a rychlosti pohybu koně a tím o naplnění léčebného efektu, stanoveného na základě intervence fyzioterapeuta v průběhu hipoterapie. Tato studie zdůrazňuje význam role vodiče v terapii a klade důraz na jeho profesionalitu, kondici, motivaci a standardní výkon.

Klíčová slova: hipoterapie, vodič koně, 3D videografická metoda, motorická reakce jezdce.

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ASSESSMENT OF POSTURAL STABILITY IN PATIENTS WITH A TRANSTIBIAL AMPUTATION WITH VARIOUS TIMES OF PROSTHESIS USE

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Postural confidence is an initial precondition for all activities within the activity of daily living. Subjects with lower limb amputation have, due to somatosensory loss of information from the lower limb, more difficult conditions for maintaining postural stability in comparison with healthy subjects. Early prosthetic fitting with a prosthesis (with regard to amputation level, health state, financial claims, etc.) is crucial for amputee reintegration into daily life.

The aim of this study was to assess the selected biomechanical parameters of standing stability in patients with a transtibial lower limb amputation with various times of prosthesis use. The next aim was to assess how the waiting time for the prosthesis fitting influences standing stability in different situations.

The tested group was made up of 21 patients (the average age was 64.4 ± 9.18 years) with a unilateral transtibial amputation. The reason for amputation was in the case of 12 tested patients a vascular disease, in 8 patients trauma and in one it was a tumor. The average length of prosthesis use was 156.4 ± 359.6 days. A right side transtibial amputation had been performed on 10 patients and on the left side in 11 patients. To define the basic parameters of postural stability, two force plates of the Kistler (type 9286AA) were used. Stability was tested for 30 seconds in 4 standing positions (natural bipedal stand, bipedal stand with a narrow base, natural bipedal stand with closed eyes and standing on foam). For an influence assessment of the period of prosthesis use on the level of postural stability, correlation analysis was used. The difference between each standing modification was analysed by ANOVA for repeated measurements and LSD post hoc test.

In all tested situations, the loading of the sound limb is greater compared to the prosthetic limb in patients with a transtibial amputation (from 17.8% to 22.8%). This is also valid for COP sways in a mediolateral direction and for COP movement velocity in both anteroposterior and mediolateral directions ($p < 0.01$, $p < 0.05$). We did not find differences between all the tested standing modifications (except for the natural bipedal standing position) in sways and COP velocity movements. With a prolonged period of waiting for a prosthesis fitting we can observe an enlarged asymmetry of body weight distribution between the legs and also a higher range of COP sway and velocity.

In all measurements in patients with a transtibial amputation, our results show a greater loading on the sound limb compared to the prosthetic one. Faster prosthesis fitting decreases asymmetry from body weight distribution between both of the legs. The basic goal of achieving full value life in patients after lower limb amputation is a tendency towards early prosthesis fitting.

Keywords: Balance, lower limb amputation, posturography, weight bearing symmetry.

INTRODUCTION

It is necessary to perform most activities of daily living to keep one's postural stability. Central and peripheral diseases could lead to the impairment of postural control. Postural stability is influenced by body weight distribution. In the case of side affected disorders in the area of regulation, an abnormal asymmetry of weight distribution between both legs occurs. Symmetrical standing in healthy subjects provides maximal stability (Winter et al., 1996; Winter et al., 1998). The exact relationship between body weight distribution and postural stability is not known.

For everyday stability control the participation of sensory, visual, vestibular and cognitive systems as well as the motor control system are necessary. In the case of the deficiency of some of those systems, then the human organism is forced to adapt to these conditions and to compensate this deficiency with a different system (Meyer, Oddson, & De Luca, 2004).

An example of a somatosensory information loss from a lower limb is an amputation. Subjects with a lower limb amputation have difficulties with maintaining postural stability as a consequence of biomechanical changes caused by the absence of muscles, bones and joints and altered afferent and efferent projections as results (Vlahov, Myers, & Al-Ibrahim, 1990). These patients are forced to create a new control strategy of postural stability, and, eventually, to adapt commonly used strategies (Aruin, Nicholas, & Latash, 1997; Buckley, O'Driscoll, & Bennett, 2002; Viton et al., 2000).

Despite today's huge progress in medicine and mainly in prosthetics, lower limb amputation remains a big physical and psychological encumberment for a patient. The ratio of transfemoral and transtibial amputations incidents has been changing within the last few years. When deciding the level of amputation, in the case of the surgery of transtibial amputation, it is important to appreciate a higher risk of reamputation, a worse prognosis of wound healing, and the possibility of prolonged hospitalization. On the other hand, transtibial amputation has a significantly lower preoperative mortality compared to the transfemoral level of amputation (Bowker, 2004). Further advantages are a better rehabilitation perspective, a higher percentage of prosthesis fitted patients, lowering the cost of the prosthesis and an independent way of life with almost unlimited movement.

Most research studies, which focus on stability in subjects with lower limb amputation, are concentrated on stability control in quiet standing positions. The results of these works are not explicit. Buckley, O'Driscoll and Bennett (2002), Guerts et al. (1992), Fernie and Holliday (1978), Isakov et al. (1992), Hermodsson et al. (1994) state an increase in postural sways in subjects with lower limb amputation (short and long term prosthesis users) compared to healthy subjects. The standing stability in patients with amputations is altered in the way of postural sway increases and the stability control strategy changes as results (Viton et al., 2000). Other authors (Dornan, Fernie, & Holliday, 1978; Vittas, Larsen, & Jansen, 1986) do not confirm these increased postural sways.

In most of the studies, a one force plate is used to measure postural stability parameters. Studies, which separately analyse the prosthetic and non amputated leg, show a lowering of the load and decrease of the COP (centre of pressure) sway on the prosthetic limb (Guerts et al., 1992; Nadollek, Brauer, & Isles, 2002; Quai, Brauer, & Nitz, 2005).

Research confirms that good intact limb stability for the functional integration of an amputated subject into life is conditional (Schoppen et al., 2003).

The aim of the study was to assess the selected biomechanical parameters of standing stability in persons with transtibial amputation with various lengths of prosthesis use.

METHOD

Research group

The experimental group consists of 21 patients with a unilateral transtibial amputation (16 males, 5 females) from a Rehabilation Centre in Chuchelná. The average age of the patients was 64.4 ± 9.2 years, their average height was 174.3 ± 7.5 cm, and their average weight was 85 ± 16.3 kg, BMI 27.8 ± 4.4 kg/m². The reason for the amputation was, in 12 tested subjects, vascular disease, in 8 trauma and in one case it was a tumor. The average length of the prosthesis use was 156.4 ± 359.6 days. The average period from the surgery to the date of measuring was 247.8 ± 365.3 days. The average waiting time for prosthesis fitting was 210.2 ± 315.5 days. Right side transtibial amputation was performed on 10 patients and 11 had left side amputations. All tested subjects had, at the time of measurement, an activity level of 1 to 3 (evaluated by prosthetists). Patients with any health complications (wound, infection, etc.) were excluded.

Methods

To determine the basic biomechanical parameters of the postural stability in the observed subjects, two force plates Kistler (type 9286AA, Kistler Instrumente AG, Winterthur, Switzerland), with a scanning frequency of 200 Hz were used.

The process and organisation of measuring

The task of the observed subjects was to stand with each limb on one force plate, to adopt the required position and to keep this position for 30 seconds with the aim of minimizing body sways. During the recording of data, the tested subjects had their shoes on. Their stability was tested in four different modifications – a natural bipedal stand with opened eyes, a bipedal stand with a narrow base, a natural bipedal stand with closed eyes and standing on foam with a width of 5 cm. The patients were tested without any supporting devices.

Measured parameters and data analysis

For our study purposes from real values of vertical ground reaction force on the affected (P) and non affected (S) lower limb, the relative size of each leg loading (%) was derived in respect of the total force in a vertical direction. The assessment of stability was carried out with the use of a standard deviation of the COP position in both a mediolateral (Sway X) and an anteroposterior direction (Sway Y) and the COP velocity movement in both a mediolateral (Vx) and an anteroposterior direction (Vy). The measured data was analysed with the help of the software Bioware (version 3.2.6.104, Kistler Group, Winterthur, Switzerland) and was statistically analysed with the help of STATISTICA (version 6.0, StatSoft, Inc., Tulsa, Oklahoma, USA). For evaluating the relationship between the prosthesis use influence period and the lower limb loading, we used regression analysis. For influence assessment of the period of using a prosthesis on the level of postural stability, correlation analysis (Pearson's coefficient, Spearman's coefficient) was used. The difference between each standing modification was analysed by means of the analysis of variability for repeated measurement and the LSD post hoc test.

For documentation and better orientation, the whole process of measuring was recorded on a video camera. The results from the force plates were completed by taking information from medical documentation provided on the basis of an agreement with the tested subjects.

RESULTS

Lower leg loading and postural stability parameters

The average values of the observed parameters indicate the difference in lower leg loading and the process of COP movement deviations in both limbs in patients with transtibial amputation and are presented in TABLE 1. We found significant differences ($p < 0.01$, $p < 0.05$) between the sound and prosthetic leg for most measured parameters in each standing modification. The size of COP deviation in a mediolateral direction is greater on the affected limb and is valid for both parts of the COP velocity movement.

TABLE 1
Values of the observed parameters for assessing lower limb loading and the level of postural stability

	1		2		3		4		Difference
	Mean	**SD**	**Mean**	**SD**	**Mean**	**SD**	**Mean**	**SD**	**S × P**
Sway X S	0.702	0.204	0.735	0.232	0.702	0.210	0.675	0.234	1*, 3**, 4**
Sway X P	0.946	0.498	0.956	0.371	0.991	0.532	0.897	0.490	
Sway Y S	1.463	0.431	1.479	0.444	1.664	0.438	1.405	0.444	DNF
Sway Y P	1.477	0.579	1.324	0.375	1.546	0.843	1.590	1.052	
Vx S	1.420	0.605	1.424	0.597	1.395	0.589	1.398	0.694	1*, 2*, 3**
Vx P	2.046	1.173	2.023	0.846	2.081	1.252	1.888	0.972	
Vy S	2.035	0.861	1.849	0.863	1.896	0.879	1.881	0.927	1*, 3**, 4**
Vy P	2.886	1.468	2.496	1.115	3.000	2.099	3.262	3.034	
V S	2.735	1.120	2.575	1.136	2.597	1.133	2.583	1.230	1*, 3**, 4**
V P	3.906	1.969	3.553	1.489	4.022	2.612	4.159	3.135	
Loading %	17.8	17.6	17.8	19.3	21.8	20.8	21.0	20.3	

Legend of TABLE 1, 2, 4:
Sway X – COP movement deviation in a mediolateral [cm]
Sway Y – COP movement deviation in an anteroposterior direction [cm]
Vx – COP velocity movement in a mediolateral direction [$m.s^{-1}$]
Vy – COP velocity movement in an anteroposterior direction [$m.s^{-1}$]
V – total COP velocity movement [$m.s^{-1}$]
Waiting period – time interval between amputation surgery and prosthesis fitting
Amp period – time interval between amputation surgery and our measurement
Fitting period – time interval between prosthesis fitting and our measurement
Loading % – difference between the relative loading on the sound and on the prosthetic limb [%]
S – sound limb
P – prosthetic limb
S × P – significant difference between the sound and the prosthetic limb
S – sound leg
P – prosthetic leg
1 – natural stand
2 – stand with a narrow base
3 – a natural stand with closed eyes
4 – a natural stand on foam
italics – a statistically significant difference $p < 0.05$
bold – a statistically significant difference $p < 0.01$

TABLE 2
Values of correlation coefficients describing relations between time period intervals and parameters in the level of postural stability

Limb		Sound					Prosthetic					Loading %
Parameter	**Stand**	**Sway X**	**Sway Y**	**Vx**	**Vy**	**V**	**Sway X**	**Sway Y**	**Vx**	**Vy**	**V**	
Waiting period	**1**	−0.19	−0.44	−0.11	−0.18	−0.15	*0.59*	**0.68**	*0.57*	*0.59*	**0.62**	**0.72**
	2	−0.43	*−0.55*	−0.38	−0.47	−0.44	0.39	0.27	0.39	0.26	0.32	*0.49*
	3	0.08	−0.01	0.11	0.09	0.11	**0.61**	*0.57*	*0.60*	*0.52*	*0.56*	*0.56*
	4	0.03	−0.22	0.07	−0.02	0.02	**0.61**	**0.76**	0.48	**0.63**	**0.66**	**0.70**
Amp period	**1**	0.05	*−0.46*	0.18	0.01	0.08	0.43	0.43	0.42	0.12	0.25	0.29
	2	−0.42	**−0.56**	−0.36	−0.40	−0.38	0.07	−0.02	0.05	−0.03	0.01	0.42
	3	−0.07	−0.29	−0.02	−0.17	−0.12	0.35	0.31	0.28	0.16	0.18	0.43
	4	−0.13	−0.35	−0.07	−0.11	−0.10	0.09	0.27	0.11	0.08	0.10	0.38
Fitting period	**1**	0.36	−0.03	*0.47*	0.28	0.35	**0.61**	*0.52*	**0.61**	0.38	*0.50*	0.25
	2	0.31	−0.12	0.45	0.33	0.36	0.25	0.30	0.30	0.32	0.32	0.10
	3	0.23	−0.11	0.25	0.38	0.37	0.27	0.27	0.29	0.37	0.38	0.17
	4	0.46	−0.02	0.44	0.20	0.33	0.13	0.23	0.25	0.27	0.27	−0.01

While comparing the observed parameters during various standing modifications (natural stand, stand with a narrow base, natural stand with closed eyes, natural stand on foam) we did not find any statistically significant differences ($p < 0.05$) in patients with a transtibial amputation for lower legs loading and for postural stability parameters on the sound and even on the prosthetic limb.

The influence of time period intervals bordered by amputation surgery, prosthesis fitting and the date of measurement on postural stability level

The dependence between the measured parameters and the time period intervals bordered by amputation surgery, prosthesis fitting and posturographic measurement expressed by values of correlation coefficients are shown in TABLE 2.

The time period between the amputation and prosthesis fitting significantly correlates for all types of natural stands with the parameters characterized by COP movement on the prosthetic limb and also with a loading difference between the sound and prosthetic limb.

Patients fitted with prostheses later have a greater COP sway with a faster COP velocity on the prosthetic limb and a greater asymmetry of body weight distribution between the lower legs (TABLE 3). The relationship between the time period of waiting for prosthesis fitting and an asymmetry of loading expressed by linear regression is shown in Fig. 1. The asymmetry of body weight distribution between both legs increases with an extending waiting time period.

We found a statistically significant dependence ($p < 0.01$, $p < 0.05$) on the time period between the time of prosthesis fitting and the date of measurement with the parameters of incident COP movement in a natural standing position. The differences in COP velocity movements and COP deviations increase with a longer period after prosthesis fitting.

TABLE 3
Values of regression coefficients and coefficients of the determination describing the relationship between the waiting period for the prosthesis fitting and the difference in lower legs loading

Stand	b	a	r^2
1	−0.023	0.002	0.519
2	0.000	0.002	0.241
3	0.018	0.002	0.315
4	−0.016	0.002	0.495

Legend:
a, b – quadratic regression coefficient
r^2 – coefficient of determination
1 – natural stand
2 – stand with a narrow base
3 – natural stand with closed eyes
4 – natural stand on foam

Dependence between the parameters characterized by COP sway and COP velocity movement

Parameters characterized by COP movement correlate to the prosthetic limb with COP velocity movement (except for standing on foam) and also with the difference between sound and prosthetic limb loading ($p < 0.01$). The tendency is similar to the sound limb, but only for COP movement in a mediolateral direction (TABLE 4).

Fig. 1
A graphical representation of linear regression describing the relationship between a waiting period for the prosthesis fitting and the difference in lower legs loading

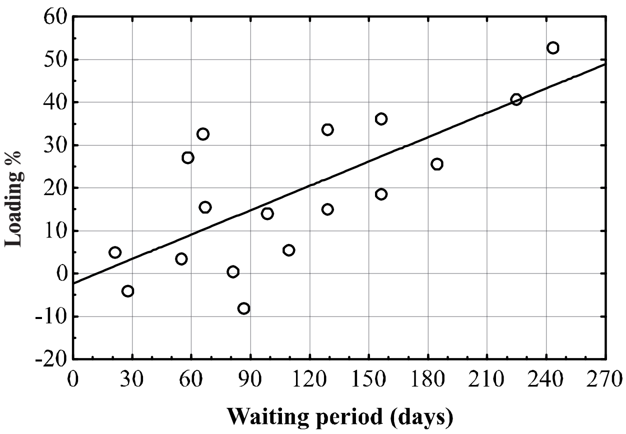

TABLE 4
Values of correlation coefficients describing relationships amongst the size of parameters characterizing a level of postural stability and its velocity changes

Limb	Parameter	Stand	Vx	Vy	V	Loading %
Sound	Sway X	1	**0.91**	**0.71**	**0.81**	−0.26
		2	**0.95**	**0.88**	**0.92**	−0.49
		3	**0.96**	**0.89**	**0.95**	−0.20
		4	**0.93**	**0.87**	**0.94**	−0.13
	Sway Y	1	0.06	0.22	0.16	−0.20
		2	*0.50*	**0.65**	*0.60*	−0.43
		3	0.25	0.24	0.25	−0.10
		4	0.17	*0.51*	0.40	−0.15
Prosthetic	Sway X	1	**0.99**	**0.79**	**0.90**	**0.71**
		2	**0.98**	**0.88**	**0.95**	**0.73**
		3	**0.98**	**0.92**	**0.95**	**0.67**
		4	**0.92**	0.34	0.47	**0.67**
	Sway Y	1	**0.88**	**0.94**	**0.96**	**0.78**
		2	**0.83**	**0.96**	**0.93**	**0.64**
		3	**0.90**	**0.98**	**0.97**	*0.58*
		4	*0.54*	**0.95**	**0.96**	**0.60**

DISCUSSION

Asymmetry of body weight distribution in patients with lower leg amputation

The results of our study show that measuring a group of patients with transtibial amputation while standing in different modifications applies a heavier load to the non affected limb (17.8–21.8%). The boundary value of physiological asymmetry in loading of the limbs is 10% (Véle, 1995). For the elderly, the mean limb load asymmetry while standing with eyes open was 7% (Blaszczyk et al., 2000).

While the advantage of increased healthy lower limb loading is better at control stability, the disadvantage remains the frequent overload and consequential joints arthrosis of this limb (Burke, Roman, & Wright, 1978; Nadollek, Brauer, & Isles, 2002).

Asymmetrical lower limb loading can be explained by listing the following reasons – decreased ankle movement, pain of the stump, discomfort caused by a hard prosthesis socket, etc. (Nadollek, Brauer, & Isles, 2002; Summers, Morrison, & Cochrane, 1988).

Postural stability decreases with the growing asymmetry of body weight distribution. This theory is confirmed by the results of some studies (Blaszczyk et al., 2000; Genthon & Rougier, 2005).

It is necessary to appreciate that this general hypothesis, when we count on a higher stability in biomechanical system symmetry, is not completely valid. The asymmetry while standing upright should be considered to be a part of functional asymmetry, which combines the anatomical human body asymmetry, and also restrictions, which appear together with the pathology and the body's ageing. The lower limbs' asymmetrical loading can, in older subjects, represent a compensatory mechanism of postural stability control (Blaszczyk et al., 2000).

Standing stability in patients after lower limb amputation

The research confirms that the good stability in the intact limb is conditional for the functional involvement of an amputated subject into life (Schoppen et al., 2003).

The standing stability in patients with a lower limb amputation is altered with the result of higher postural sways and changes of control stability strategy thus implied (Viton et al., 2000).

In our work, we learnt that there was an increase in postural deviations in subjects with transtibial amputation in comparison with the control group. Hermodsson et al. (1994) also confirms the increase of postural deviations after lower limb amputation (both short term and long term prosthesis users). Other studies, on the other hand, did not show any difference in healthy subjects (Vittas, Larsen, & Jansen, 1986; Dornan, Fernie, & Holliday, 1978).

Vittas, Larsen and Jansen (1986) came to the conclusions that patients with transtibial amputation have lowered postural sways compared to healthy subjects. However, only one force plate was used for measurement in this study. Studies, which separately analyse the prosthetic and non amputated lower limb, point towards a loading decrease and a decrease in COP deviations on the prosthetic lower limb (Guerts et al., 1992; Nadollek, Brauer, & Isles, 2002; Quai, Brauer, & Nitz, 2005).

Rogers, Hedman and Pai (1993) state that an improvement of bipedal standing stability would mean an improvement of locomotion stability. However, the measuring of static balance does not necessarily characterize the balance during motional activities as a movement from bipedal to monopedal standing or to walking (Mouchnino et al., 1992).

Influence of the waiting time for prosthesis fitting

The time the patient spends waiting for the prosthesis fitting shows itself to be key factor in our research for the symmetrical weight distribution between both lower limbs. It influenced parameters describing COP movement as well as the velocity of the COP movement on the prosthetic lower limb. With the longer waiting time for prosthesis fitting, the asymmetry of body weight distribution increases. The asymmetry of body weight distribution in healthy older subjects is linked with the enlargement of postural sway in an A/P direction (Blaszczyk et al., 2000; Marigold & Eng, 2006).

This fact was also verified in our study about patients with lower limb amputation. With a longer waiting time, the range of COP moves in an A/P direction, both on the healthy and prosthetic lower limb.

Influence of the time of prosthesis use

The duration of prosthesis use had a significant impact on the results of the measurement on a prosthetic limb in a natural bipedal stand. COP movement grows with the length of time the patient has the prosthesis available and the velocity grows and the extent of COP movement increases.

We can explain these facts by the tendency to involve a prosthetic limb more to the postural control of stability and resulting increase of COP movement velocity and COP deviations sways. Patients find confidence in the prosthesis use and begin to rely on it more.

The next question is why we can see this tendency only in the natural stand. This standing position can be less difficult for patients and therefore he/she involves the prosthetic limb in, while in other more difficult standing modifications he or she relies more on the sound limb.

Influence of sight

We did not find any statistical influence of sight and proprioception in the measured parameters of postural stability. These were surprising findings because, according to many studies, whereby disabling the sight control in subjects with amputation increases and COP sway on average in both legs, it manages to increase the non amputated lower limb loading (Guerts et al., 1992; Hermodsson et al., 1994; Isakov et al., 1992; Nadollek, Brauer, & Isles, 2002; Quai, Brauer, & Nitz, 2005). Vrieling et al. (2008) supposes that the influence of visual control intensifies, as a compensation mechanism of somatosensory deficit in patients, after lower limb amputation. In healthy subjects with disabilities of visual control, this difference in the loading of lower limbs was not found (Gauthier-Gagnon et al., 1986), or, respectively, only a very small difference (Guerts et al., 1992; Hermodsson et al., 1994; Isakov et al., 1992).

The loss of information from missing proprioreceptors of the foot is partly substituted for by an information transfer from the skin receptors, subcutis and also from receptors located in the muscles, ligaments and joints of the residual limb (Isakov et al., 1992).

One of the possible reasons could be the fact, that the skin on the stump becomes more sensitive to pressure at the point of stump and socket contact, which would make the control of the prosthesis easier. The adaptation could be caused also by expansion of afferent input on the intact lower limb. This idea has not been confirmed (Kavounoudias et al., 2005).

Limits of the study

With respect to the fact that we made the effort to simulate everyday life situations as much as possible, at most we did not come to the standardization of the standing position from the point of anteroposterior foot placement. It is necessary to appreciate that the tested persons, often just a few days after prosthesis fitting, are put up to solve difficult situations in keeping postural stability. For this reason we aimed to standardize the standing position only in the frontal plane. Earlier studies show that the foot position in healthy subjects is closer than for subjects with lower limb amputation (Fernie & Holliday, 1978) and that the dependence on visual control is lower for subjects with amputations in the case of a larger supporting base (Gauthier-Gagnon et al., 1986).

We unearthed another limit in that the patients couldn't be observed on a long term basis. Repetitions of measurements in these patients, which would lead to a data gain of changes in lower limb loading and postural stability, are, however, at this time, impossible.

CONCLUSIONS

1. In all types of standing, the modifications to the loading on the sound limb were greater than on the amputated one in persons with a transtibial amputation.
2. The size of the COP sway in the mediolateral direction is greater for the prosthetic limb in all standing modifications. This is valid for the COP velocity movement in both anteroposterior and mediolateral directions.

3. The size of the COP movement sway on the sound limb significantly correlates with the COP velocity movement in all types of standing positions.
4. We did not find any significant differences between each type of standing position (except natural stance) in a range of sway movements and COP velocity movements.
5. With a prolonged time period between surgery and prosthetic fitting, the asymmetry of loading between the amputated and the non amputated leg is bigger. We can find greater degrees of sway and the velocity of COP movement.

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HODNOCENÍ POSTURÁLNÍ STABILITY PACIENTŮ S TRANSTIBIÁLNÍ AMPUTACÍ S RŮZNOU DOBOU POUŽÍVÁNÍ PROTÉZY

(Souhrn anglického textu)

Ztráta somatosenzorické informace z dolní končetiny způsobená amputací se podílí na vzniku potíží při udržení posturální stability, které zvyšují riziko pádu. Snaha o včasné vybavení protézou, při zohlednění všech působících vlivů (typ amputace, zdravotní stav pacienta, finanční náročnost apod.), je nezbytným předpokladem pro návrat osob s amputací do běžného života.

Cílem studie bylo zhodnocení vybraných biomechanických parametrů stability stoje u osob s transtibiální amputací s různou dobou používání protézy. Dále posouzení vlivu doby čekání na vybavení protetickou pomůckou na stabilitu stoje v různých situacích.

Sledovaný soubor tvořilo 21 pacientů (průměrný věk 64,4 ± 9,18 let) s jednostrannou transtibiální amputací. Příčinou amputace bylo u 12 testovaných osob cévní onemocnění, u 8 testovaných osob trauma a u 1 tumor. Průměrná délka používání protézy byla 156,4 ± 359,6 dnů. Pravostrannou transtibiální amputaci mělo 10 pacientů, 11 amputaci levostrannou. K určení základních parametrů posturální stability byly použity dvě silové plošiny Kistler (typ 9286AA). Stabilita byla testována po dobu 30 s ve 4 modifikacích stoje (přirozený bipedální stoj, bipedální stoj s úzkou bázi, přirozený bipedální stoj se zavřenýma očima a stoj na molitanu). Pro určení vlivu doby používání protézy na úroveň posturální stability jsme použili korelační analýzu. Rozdíl mezi jednotlivými modifikacemi stoje byl hodnocen analýzou rozptylu pro opakovaná měření a LSD post hoc testem.

Zatížení na zdravé končetině je u osob s transtibiální amputací ve všech typech stoje větší než na postižené končetině (rozdíl 17,8 až 21,8 % v závislosti na typu stoje). To platí také pro velikost výchylky COP v mediolaterálním směru a pro rychlost pohybu COP v anteroposteriorním a v mediolaterálním směru ($p < 0,01$, $p < 0,05$). Parametry charakterizující pohyb COP korelují ($p < 0,01$) na postižené končetině s rychlostí pohybu COP (s výjimkou stoje na molitanu, $p < 0,01$). Na zdravé končetině platí tato závislost pouze pro pohyb COP v mediolaterálním směru. Mezi jednotlivými typy stoje (s výjimkou přirozeného stoje) jsme nenalezli významné rozdíly v rozsahu a v rychlosti pohybu COP.

S rostoucí dobou, která uplyne mezi amputací a vybavením protetickou pomůckou, dochází k nárůstu asymetrie v zatížení amputované a zdravé končetiny, rozsah pohybu COP a jeho rychlost se zvětšují. Pro zmenšení pravděpodobnosti přetěžování zdravé končetiny v bipedálním stoji je nutné využít všechny možnosti pro zkrácení doby při vybavení protézou.

Klíčová slova: balance, amputace dolní končetiny, dynamografie, symetrie zatížení.

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PONTRYAGIN'S MAXIMUM PRINCIPLE AND OPTIMIZATION OF THE FLIGHT PHASE IN SKI JUMPING

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There are several factors (the initial ski jumper's body position and its changes at the transition to the flight phase, the magnitude and the direction of the velocity vector of the jumper's center of mass, the magnitude of the aerodynamic drag and lift forces, etc.), which determine the trajectory of the jumper ski system along with the total distance of the jump. The objective of this paper is to bring out a method based on Pontryagin's maximum principle, which allows us to obtain a solution of the optimization problem for flight style control with three constrained control variables – the angle of attack (α), body ski angle (β), and ski opening angle (V). The flight distance was used as the optimality criterion. The borrowed regression function was taken as the source of information about the dependence of the drag (D) and lift (L) area on control variables with tabulated regression coefficients. The trajectories of the reference and optimized jumps were compared with the K = 125 m jumping hill profile in Frenštát pod Radhoštěm (Czech Republic) and the appropriate lengths of the jumps, aerodynamic drag and lift forces, magnitudes of the ski jumper system's center of mass velocity vector and it's vertical and horizontal components were evaluated. Admissible control variables were taken at each time from the bounded set to respect the realistic posture of the ski jumper system in flight. It was found that a ski jumper should, within the bounded set of admissible control variables, minimize the angles α and β, whereas angle V should be maximized. The length increment due to optimization is 17%. For future work it is necessary to determine the dependence of the aerodynamic forces acting on the ski jumper system on the flight via regression analysis of the experimental data as well as the application of the control variables related to the ski jumper's mental and motor abilities.

Keywords: Computer simulation, ski jumper, optimal control, aerodynamic force.

INTRODUCTION

Aerodynamic drag and lift forces, the initial movement state of the flight phase of the ski jump, together with the gravitational force, determine the trajectory of the ski jumper system's center of mass along with the total distance of the jump. The mentioned forces are substantially influenced by the skier's course of posture (Jin, Shimizu, Watanuki, Kubota, & Kobayashi, 1995; Müller, Platzer, & Schmölzer, 1996; Schmölzer & Müller, 2002; Schmölzer & Müller, 2005; Virmavirta et al., 2005), the aerodynamic qualities of the ski jumper's equipment (Meile et al., 2006) and his/her somatotype (Vaverka, 1994; Schmölzer & Müller, 2005; Müller, W., Gröschl, Müller, R., & Sudi, 2006).

Computer simulations, among other things, can help to clarify the optimization strategy of the flight style. There is only one pattern of the optimal change in the angle of attack, thus affording maximal flight length (Remizov, 1984). To solve the optimization problem with one control variable, Remizov applied Pontryagin's maximum principle (Pontryagin, 1962) and computations were based on data from wind tunnel experiments (Grozin, 1971). It was shown that the angle of attack should gradually increase according to a convex function. A solution of the optimization problem of the flight phase in ski jumping demands data describing the dependency of the aerodynamic forces on angle parameters of the flight style. Seo and Murakami (2003) took one control variable (the forward leaning angle) to solve the optimization problem. Their result showed that a jumper should keep the forward leaning angle of the magnitude of 6°. As a new style named the V-style was extended in the 1990's, so far a sufficient amount of information about the contemporary range of the flight position and appropriate aerodynamic force acting on the ski jumper system and the jumper's equipment has not been found. Thus, Seo, Watanabe and Murakami (2004) made wind tunnel experiments with full size models to acquire data for sufficiently wide ranges of angles of attack, body ski angles and ski opening angles. Seo, Murakami and Yoshida (2004) solved the optimization problem by using two control variables: the body ski angle and the ski opening angle. The authors used data prepared by Seo, Watanabe and Murakami (2004).

Meile et al. (2006) investigated the aerodynamic behaviour of a ski jumper model in a reduced scale (1:√2) in a wide range of angles of attack. The experimental results were in good agreement with full scale measurements on athletes. Murakami, Hirai, Seo and Ohgi (2008) derived aerodynamic forces from the data analysis of a high speed video image of the initial flight phase. They concluded that the aerodynamic forces, which were extracted from the image, were in reasonable agreement with existing wind tunnel data for the cases of jumping flights in the quasi steady flight phase.

Hermsdorf, Hildebrand, Hofmann and Müller (2008) introduced a biomechanical multibody model for simulation in ski jumping that makes possible the evaluation of the time course of joint angles, global position and the orientation of the ski jumper.

The simple ski jumping model for the calculation of jump length was evaluated by Schindelwig and Nachbauer (2007). Wind velocity plays an important role in the agreement between the measured and calculated jump lengths.

The aim of this study is to bring out a method for obtaining a solution to the optimization problem for flight style control with three control variables (angle of attack, body ski angle, ski opening angle) and correction of the concrete flight style based on the solution of the optimization problem. Admissible control variables were taken from the bounded set to respect the realistic posture of the ski jumper system in flight. The influence of the wind was neglected.

METHODS

Formulation of the optimization problem and the methodology used in the numerical computation of the optimal flight style

A ski jumper controls, over time, flight position in order to maximize flight distance and securely finish a jump by landing and outrunning. The way to find the optimal control of flight position was a matter of solving an optimization problem. An element of the optimization problem formulation for a ski jumping flight is the mathematical modeling of the movement of the center of mass of a ski jumper system. Consider the jumper moving through still air on a vertical plane. For the simulation made here the coordinate system O_{xy} with the horizontal x axis oriented forward in the direction of the flight, the vertical y axis oriented downward and the origin blending with the center of mass of the ski jumper system above a ski jump edge have been used. A ski jumper controls body segment angles, the angle of attack and the ski opening angle.

A ski jumper system's center of mass and state of motion are determined by the coordinates x, y and velocity vector components v_x and v_y in the coordinate system O_{xy}. Thus, the vector of the state variables $\boldsymbol{s}$ takes form:

$$\boldsymbol{s} = (v_x(t), v_y(t), x(t), y(t)). \tag{1}$$

The equation of motion $m\boldsymbol{a} = \boldsymbol{F}_g + \boldsymbol{F}_D + \boldsymbol{F}_L$, where $m\boldsymbol{a}$ is the net force, is rearranged to obtain the components of the acceleration and the velocity vector

$$\begin{aligned}
\frac{dv_x}{dt} &= -\frac{\rho D(\boldsymbol{u}(t))}{2m} v_x\sqrt{v_x^2+v_y^2} + \frac{\rho L(\boldsymbol{u}(t))}{2m} v_y\sqrt{v_x^2+v_y^2} \\
\frac{dv_y}{dt} &= g - \frac{\rho D(\boldsymbol{u}(t))}{2m} v_y\sqrt{v_x^2+v_y^2} - \frac{\rho L(\boldsymbol{u}(t))}{2m} v_x\sqrt{v_x^2+v_y^2} \\
\frac{dx}{dt} &= v_x \\
\frac{dy}{dt} &= v_y
\end{aligned} \tag{2}$$

and these equations model the state of motion progress in time and take into account forces acting on the ski jumper system in the inertial system of coordinates O_{xy} – gravitation $\boldsymbol{F}_g = m\boldsymbol{g}$ (m being the mass and $\boldsymbol{g}$ the gravitational acceleration), aerodynamic drag $\boldsymbol{F}_D = \frac{1}{2}\rho C_D S_f v^2 \boldsymbol{i} = \frac{1}{2}\rho D v^2 \boldsymbol{i}$ (ρ being the air density, C_D the drag coefficient, S_f the frontal area, D the drag area, $v = \sqrt{v_x^2 + v_y^2}$ the magnitude of the velocity vector and $\boldsymbol{i}$ the unit vector in the same direction as the velocity vector) and lift forces $\boldsymbol{F}_L = \frac{1}{2}\rho C_L S_p v^2 \boldsymbol{j} = \frac{1}{2}\rho L v^2 \boldsymbol{j}$ (C_L being the lift coefficient, S_p the planform area, L the lift area and $\boldsymbol{j}$ the unit vector normal to the air stream). Express (2) as:

$$\frac{d\boldsymbol{s}}{dt} = \boldsymbol{f}(\boldsymbol{s},\boldsymbol{u}). \tag{3}$$

The acquired solution of the optimization problem has to respect the athlete's psychological and physical individuality, which are exhibited in individual flight style. That is the reason why the control vector of the system is assumed to be constrained to belong to a suggested closed and bounded set U^r in r-dimensional space. In all steps of the algorithm consider

$$\forall t \in \langle 0, T\rangle:\ \boldsymbol{u} \in U^r \subset R^r. \tag{4}$$

The flight time T corresponds to the time interval from the start of the reference jump to the instant of the landing of the jumper's model at the intersection of the flight path with a smooth curve S representing the projection of the landing area of the ski jump on a vertical plane containing the coordinate system O_{xy}. The equation of curve S is given as follows:

$$S:\ \psi(x,y)=0. \tag{5}$$

Assume for coordinates of the center of mass in the instant T that the following is valid:

$$\psi\big(x(T),y(T)\big)=0. \tag{6}$$

To solve the optimization problem, Pontryagin's maximum principle has been applied. The jumper ski system, from the dynamics point of view, can be characterised in terms of a set of first order differential equations (2) in which control variables are to be selected over time to obtain some desirable objectives in an optimal manner. Pontryagin's maximum principle consists of a set of necessary conditions, which must be satisfied by optimal solution and originate in classical calculus of variations (Pierre, 1969, 478).

The functional J is to be minimized by the appropriate selection of $\boldsymbol{u}(t)\in U^r$ at each instant

$$t\in\langle 0,T^*\rangle : J^*=\min_{\boldsymbol{u}(t)} F\big(\boldsymbol{s}(T),\boldsymbol{u}(T)\big). \tag{7}$$

Because the purpose is to maximize jump length, the functional J has the form

$$J=-x(T). \tag{8}$$

To minimize J, it is necessary to formulate a Hamiltonian that has the following general form (Víteček, 2002; Pierre, 1969; Lewis & Syrmos, 1995):

$$H(\boldsymbol{s},\boldsymbol{u},\boldsymbol{p})=\boldsymbol{p}^{\mathrm{T}}\boldsymbol{f}(\boldsymbol{s},\boldsymbol{u}), \tag{9}$$

where $\boldsymbol{p}(t)$ is the costate vector. On the basis of (2) is

$$\begin{aligned}H=&-p_1K_1(\boldsymbol{u})v_x\sqrt{v_x^2+v_y^2}+p_1K_2(\boldsymbol{u})v_y\sqrt{v_x^2+v_y^2}+p_2g-\\&-p_2K_1(\boldsymbol{u})v_y\sqrt{v_x^2+v_y^2}-p_2K_2(\boldsymbol{u})v_x\sqrt{v_x^2+v_y^2}+p_3v_x+p_4v_y,\end{aligned} \tag{10}$$

where

$$K_1\big(\boldsymbol{u}(t)\big)=\frac{\rho D}{2m}\ \text{or}\ K_2\big(\boldsymbol{u}(t)\big)=\frac{\rho L}{2m}. \tag{11}$$

According to the Pontryagin's maximum principle, the costate vector $\boldsymbol{p}$ must satisfy the system of equations canonically conjugated to the system (2)

$$\frac{\mathrm{d}\boldsymbol{p}}{\mathrm{d}t}=-\frac{\partial H}{\partial \boldsymbol{s}} \tag{12}$$

and the control vector $\boldsymbol{u}^*(t)$ which leads to the minimum of J is the vector which minimizes Hamiltonian H:

$$H^*\big(\boldsymbol{s}^*,\boldsymbol{u}^*,\boldsymbol{p}^*\big)=\min_{\boldsymbol{u}(t)\in U^r} H\big(\boldsymbol{s}^*,\boldsymbol{u},\boldsymbol{p}^*\big). \tag{13}$$

Our conjugate system for components of the costate vector is obtained on the basis of the equation (10):

$$\begin{aligned}\frac{\mathrm{d}p_1}{\mathrm{d}t}&=-\frac{\partial H}{\partial v_x}=\frac{v_xv_y}{\sqrt{v_x^2+v_y^2}}\big(p_2K_1-p_1K_2\big)-p_3+\\&+\sqrt{v_x^2+v_y^2}\big(p_1K_1+p_2K_2\big)+\frac{v_x^2}{\sqrt{v_x^2+v_y^2}}\big(p_1K_1+p_2K_2\big)\\\frac{\mathrm{d}p_2}{\mathrm{d}t}&=-\frac{\partial H}{\partial v_y}=\frac{v_xv_y}{\sqrt{v_x^2+v_y^2}}\big(p_1K_1+p_2K_2\big)-p_4+\\&+\sqrt{v_x^2+v_y^2}\big(p_2K_1-p_1K_2\big)+\frac{v_y^2}{\sqrt{v_x^2+v_y^2}}\big(p_2K_1-p_1K_2\big)\\\frac{\mathrm{d}p_3}{\mathrm{d}t}&=-\frac{\partial H}{\partial x}=0\\\frac{\mathrm{d}p_4}{\mathrm{d}t}&=-\frac{\partial H}{\partial y}=0.\end{aligned} \tag{14}$$

A corresponding boundary condition is formed (Lewis & Syrmos, 1995):

$$\left(\frac{\partial F}{\partial \boldsymbol{s}}+\frac{\partial \psi}{\partial \boldsymbol{s}}\nu-\boldsymbol{p}\right)\bigg|_T \mathrm{d}\boldsymbol{s}(T)+\left(\frac{\partial F}{\partial t}+\frac{\partial \psi}{\partial t}\nu+H\right)\bigg|_T \mathrm{d}T=0. \tag{15}$$

Based on comparing (7) and (8) $F\big(\boldsymbol{s}(T)\big)=-x(T)$, so

$$\frac{\partial F}{\partial \boldsymbol{s}}=\begin{bmatrix}0\\0\\-1\\0\end{bmatrix} \tag{16}$$

Also

$$\frac{\partial \psi}{\partial \boldsymbol{s}}=\begin{bmatrix}0\\0\\\dfrac{\partial\psi}{\partial x}\\\dfrac{\partial\psi}{\partial y}\end{bmatrix},\ \frac{\partial F}{\partial t}=0,\ \frac{\partial \psi}{\partial t}=0. \tag{17}$$

These identities (16) and (17) are substituted appropriately into the boundary condition (15):

$$-\left[p_1(T)\quad p_2(T)\quad p_3(T)-\nu\frac{\partial\psi(T)}{\partial x}+1\quad p_4(T)-\nu\frac{\partial\psi(T)}{\partial y}\right]\mathrm{d}\boldsymbol{s}(T)+H(T)\mathrm{d}T=0. \tag{18}$$

Both the final state and the final time T are free, i.e. different choices of the control vector $\boldsymbol{u}$ will result in different values for T and the final state vector $\boldsymbol{s}(T)$. Therefore, $\mathrm{d}T\neq 0$ and $\mathrm{d}\boldsymbol{s}(T)\neq 0$. Differentials $\mathrm{d}T$ and $\mathrm{d}\boldsymbol{s}(T)$ are also independent so that (15) yields the separate boundary conditions

$$\left.\left(\frac{\partial F}{\partial \boldsymbol{s}}+\frac{\partial \psi}{\partial \boldsymbol{s}}\nu-\boldsymbol{p}\right)\right|_T=0 \tag{19}$$

and

$$\left.\left(\frac{\partial F}{\partial t}+\frac{\partial \psi}{\partial t}\nu+H\right)\right|_T=0. \tag{20}$$

Using (16), (17) and (19) the final costate vector we get

$$\boldsymbol{p}(T)=\begin{bmatrix}0\\0\\\nu\dfrac{\partial\psi}{\partial x}-1\\\nu\dfrac{\partial\psi}{\partial y}\end{bmatrix} \tag{21}$$

and the Hamiltonian at time T becomes:

$$H(T)=0. \tag{22}$$

The components of the costate vector $\boldsymbol{p}(T)$ can be added to the condition (21) with respect to the Hamiltonian (10) to obtain a coefficient ν, thus

$$H(T)=p_3v_x(T)+p_4v_y(T)=\left(\nu\frac{\partial\psi}{\partial x}-1\right)v_x(T)+\nu\frac{\partial\psi}{\partial y}v_y(T)=0. \tag{23}$$

A logical consequence is:

$$\nu=\frac{v_x(T)}{v_x(T)\dfrac{\partial\psi}{\partial x}+v_y(T)\dfrac{\partial\psi}{\partial y}}. \tag{24}$$

The MATLAB® technical programming language has been used for the numerical solution of the optimization problem. This algorithm was turned into MATLAB statements:

1. The numerical solution of the Cauchy problem for the four dimensional system of nonlinear differential equations (2) with the initial condition of

$$\boldsymbol{s}_0=\left(v_{\mathrm{x}}(0),v_{\mathrm{y}}(0),x(0),y(0)\right) \tag{25}$$

respects a typical state of motion of the ski jumper system's center of mass at the start of the optimized flight. Apart from the initial condition, it is necessary to define a reference jump by tabulated functions $L = L(t)$ and $D = D(t)$ too.

2. Assessment of the flight time T, for that holds equality (6).

3. Numerical solution of the four dimensional system of nonlinear differential equations (14) with boundary conditions (21) with respect to identity (24).

4. Minimize a Hamiltonian to get an optimal time course for the control variables that facilitate the solution of the equations of motion (2) if the regression dependence of quantities L and D on control variables is known. For this purpose, it is necessary to use data from wind tunnel experiments with athletes or models of athletes positioned in accordance with real postures.

Optimization of the reference jump with three control variables

Below are the supposed aerodynamic characteristics of the model described by Seo, Watanabe and Murakami (2004) in the form of regression function

$$D=\sum_{i=0}^{4}\sum_{j=0}^{2}\sum_{k=0}^{2}a_{ijk}\alpha^i\beta^jV^k,\ L=\sum_{i=0}^{4}\sum_{j=0}^{2}\sum_{k=0}^{2}b_{ijk}\alpha^i\beta^jV^k \tag{26}$$

With the tabulated regression coefficients a_{ijk} and b_{ijk}. The control vector included three components: α, β and V. The set U^r contains at each time t the intervals in the form $\langle\alpha_0-\sigma_\alpha,\alpha_0+\sigma_\alpha\rangle$, where α_0 is a function of time describing the changing of the angle α in the reference flight (TABLE 1) and σ_α is the maximal standard deviation from the field studies made by Schmölzer and Müller (2005) – analogously for the other control variables. The values m = 65.5 kg and ρ = 1 kg·m^{-3} have been used for the all computer simulations. The initial state of motion was set to s_0 = (25.93 m·s^{-1}; 2.49 m·s^{-1}; 0 m; 0 m), because the supposed angle of the slope of the ramp was 11°, in run velocity 25.93 m·s^{-1} and take off velocity perpendicular to the ramp was 2.5 m·s^{-1} in accordance with Schmölzer and Müller (2005).

As curve S was selected an abscissa between the origin of the coordinate system O_{xy} and the position of the center of mass of the ski jumper system at the instant 5.5 s according to the equations of motion (2) solution. The trajectories of the reference and optimized jumps were compared with the K = 125 m jumping hill profile in Frenštát p. Radhoštěm (Czech Republic) and appropriate lengths of the jumps were evaluated. The projection of the jumping hill profile on the vertical plane, including the coordinate system $O_{xy,}$ was based on the measurement of the coordinates of surface points on the jumping hill by using the Leica TCR307 theodolite.

RESULTS AND DISCUSSION

The figures show the reference and optimal time dependence of the control variables (Fig. 1), aerodynamic drag and lift forces (Fig. 2), magnitude of the ski jumper system's center of mass velocity vector and it's vertical and horizontal components (Fig. 3). The optimal correction of the flight course increases the jump length from 100.7 m for the reference jump to 117.7 m – i.e. a length increment of 17% (Fig. 4). It has been

Fig. 1
Optimized and reference time variations of angles α, β and V

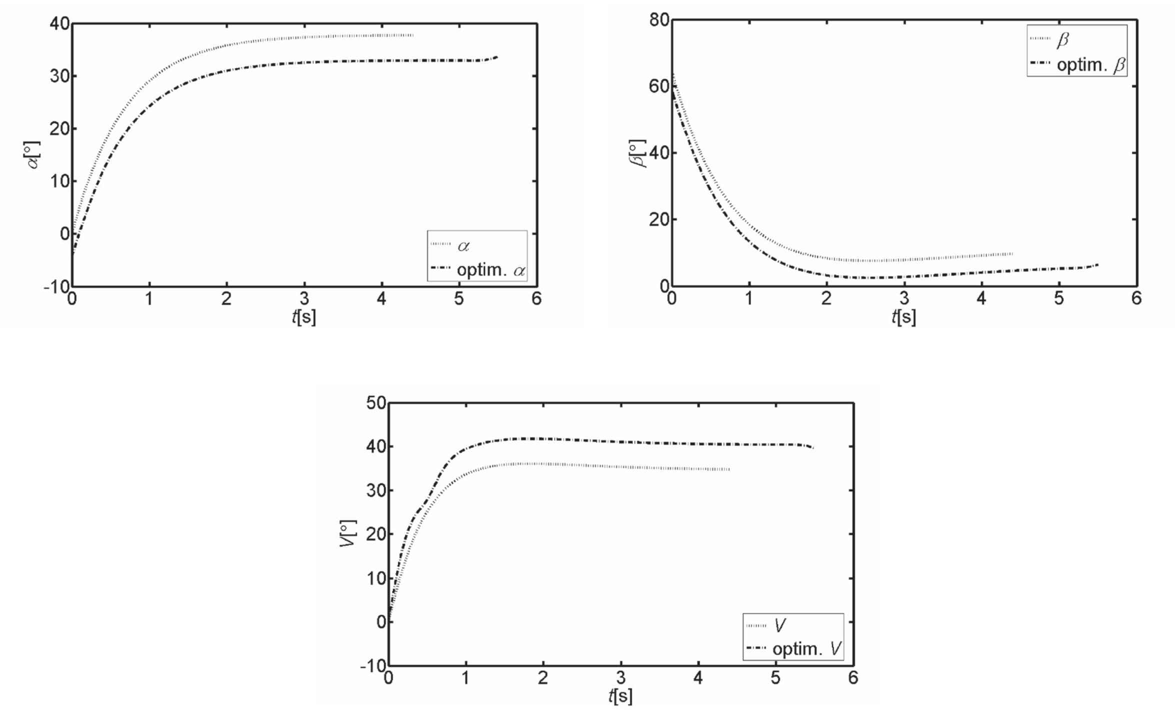


Fig. 2
Optimized and reference time variations of drag and lift forces

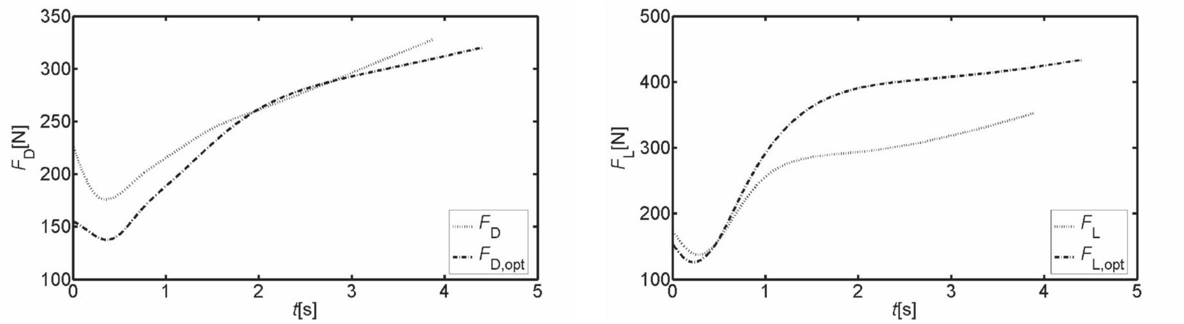


TABLE 1
The reference jump angle of attack (α), body ski angle (β) and ski opening angle (V) for model of the ski jumper at given times t. The angles correspond to the mean values found in the field. The values were selected from Schmölzer and Müller (2002)

***t* [s]**	**0**	**0.2**	**0.4**	**0.7**	**1.0**	**1.2**	**1.5**	**2.0**	**4.0**	**5.5**
α_0 [°]	0	7	14	25	30.2	32.6	34.8	36.1	37.1	36.2
β_0 [°]	63	49	43	26	16.4	13	10.4	10.3	10.8	9.3
V_0 [°]	0	13	20	31	35	35	35	35	35	35

Fig. 3
Optimized and reference time variations of the magnitude, vertical and horizontal components of the ski jumper's center of mass velocity vector

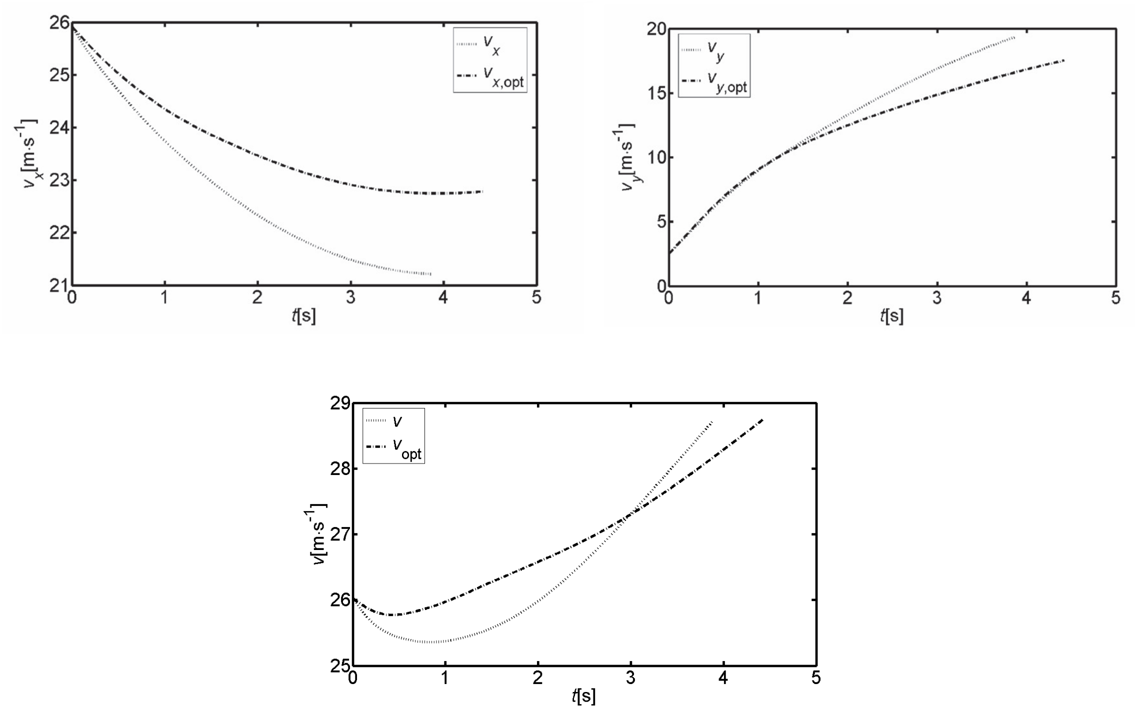
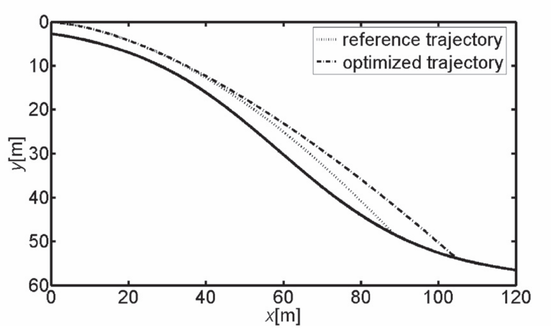


Fig. 4
Flight path for the reference and optimized jump execution in the case of Frenštát p. R. Jumping Hill (K = = 125 m)



discovered that a ski jumper should minimize angles α and β (Jošt, Kugovnik, Strojnik, & Colja, 1997; Seo, Murakami, & Yoshida, 2004; Virmavirta et al., 2005), the remaining angle V should, however, be maximized for some time in the interval from 0 s to 0.5 s, while the optimal angle V should gradually approach the upper bound of the set U^r, containing the acceptable values of angle V. As found by Seo, Murakami and Yoshida (2004), the ski opening angle should be increased in the first half of the flight, and than kept at a constant value.

In terms of aerodynamic forces, it is particularly optimal to minimize the drag force within 0.5 s, while at 2–3 s, the value of the drag approaches the value corresponding to the reference jump, later again becoming a strong requirement to minimize the drag force. The best option is to minimize the lift force up to 0.5 s and to subsequently maximize (Fig. 2). In contrast to the study of Schmölzer and Müller (2005), Fig. 2 shows a local minimum of the aerodynamic drag and lift forces.

The difference between the x-th resp. the y-th components of the velocity vector gradually increases and, for example, at the moment 3 s extends to $v_{x,\mathrm{opt}} - v_x = 1.5\ \mathrm{m \cdot s^{-1}}$ resp. $v_{y,\mathrm{opt}} - v_y = -2.5\ \mathrm{m \cdot s^{-1}}$. The relative differences in the y-th component of the velocity vector are remarkably bigger that in the x-th component. Initially it is $v_{\mathrm{opt}} > v$, afterwards $v_{\mathrm{opt}} < v$. This changeover is due to the new directive to maximize the lift with some delay, similarly as in the increasing influence of the optimization to the vertical component of the velocity vector. According to Jošt, Kugovnik, Strojnik and Colja (1997) in order for the jump to be performed successfully, it is right to maximise the resultant speed in the first part of the flight and to maximize the x-th component of the velocity vector during the entire time of the flight, unlike shown in Fig. 3, in particular in the first part of the flight.

Meile et al. (2006) stated that current computer fluid dynamics tools do not seem to be capable of simulating the aerodynamic forces acting on the ski jumper system. Thus, the experimental investigation of the aerodynamic forces remains, so far, essential.

The ways of how to achieve the optimal time course of flight position angles can distinctly differ depending on the athlete – compare the gold medallist Amman and the silver medallist Malysz (Schmölzer & Müller, 2005). This means that the reliability of the optimization studies could be improved by having data for a deeper insight into the aerodynamics of the individual athlete. There exist several strategies of how to solve the changes at the angular momentum at the early flight phase (Hildebrand, Drenk, & Müller, 2007).

CONCLUSION

The solution of the optimization problem with three control variables allowed for the correction of the reference flight style to maximize flight distance with respect to control limits on control variable values. Unambiguous directives to minimize the angle of attack and body angle relative to the skis correspond to the requirement to minimize the aerodynamic drag primarily in the first part of the flight (Fig. 1). From the viewpoint of aerodynamics, it is interesting to note that, during the flight, gaining grain aerodynamic lift in this sense that is becoming majoritarian, that is, to maximize lift demand above all by increasing the ski opening angle compared with the reference values (Fig. 1). Even in the middle part of the flight, the optimal aerodynamic drag force is slightly higher than the reference drag as can be seen in Fig. 2. In terms of kinematics, the trajectory of the ski jumper system's center of mass is straightening compared to the reference trajectory approximately at a distance 60 m from the jumping hill edge, where the difference of the height above the jumping hill exceeds 0.5 m.

If, in the future, correct work contrary to the presented study maps the flight style of the exact ski jumper, data collection might involve the following steps:

- mathematical modeling of the selected jumping hill profile, for example on the basis of topography measurement,
- the setting of admissible intervals of control variables that respect the ski jumper's mental and motor abilities,
- determination of the dependence of aerodynamic drag and lift forces acting on the ski jumper system on the flight via regression analysis of experimental data.

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PONTRJAGINŮV PRINCIP MAXIMA A OPTIMALIZACE STYLU LETU VE SKOKU NA LYŽÍCH

(Souhrn anglického textu)

Existuje několik faktorů (počáteční poloha skokana na lyžích a její změny v průběhu přechodové fáze letu, velikost a směr vektoru rychlosti pohybu těžiště skokana, velikost aerodynamické odporové a vztlakové síly apod.), které určují trajektorii soustavy skokan + lyže a tím i dosaženou délku skoku. Cílem studie je představit metodu řešení úlohy optimálního řízení letové fáze skoku na lyžích se třemi omezenými řídicími proměnnými – úhel náběhu (α), úhel trup vs. lyže (β), úhel levá lyže vs. pravá lyže (V) – na základě Pontrjaginova principu maxima. Kritériem optimality byla zvolena délka skoku. Jako zdroj informací o závislosti veličin L (lift area) a D (drag area) na řídicích proměnných byla použita převzatá regresní funkce s tabelovanými regresními koeficienty. Srovnány byly trajektorie referenčního a optimalizovaného skoku s profilem můstku K = 125 m ve Frenštátě pod Radhoštěm a stanoveny odpovídající délky skoku, aerodynamické odporové a vztlakové síly, velikosti rychlosti pohybu těžiště soustavy skokan + lyže, její vertikální a horizontální složky. Aby byly respektovány reálné polohy v letové fázi skoku, přípustné hodnoty řídicích proměnných náležely v každém okamžiku ohraničené množině. Bylo zjištěno, že skokan by měl na ohraničené množině přípustných hodnot řídicích proměnných minimalizovat úhly α a β, úhel V naopak maximalizovat. Prodloužení skoku vlivem optimalizace je 17 %. Pro možnost dalšího výzkumu je nezbytné využití regresní analýzy pro experimentální data při určení závislosti aerodynamických sil působících během letu na soustavu skokan + lyže. To platí také pro aplikaci kontrolních proměnných vztahujících se k základním fyzickým a psychickým vlastnostem skokanů na lyžích.

Klíčová slova: počítačová simulace, skokan na lyžích, optimální řízení, aerodynamické síly.

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We look forward to our further cooperation!

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