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Jízda na koloběžce: antropologicko-ergonomické zhodnocení

Diplomová práce

Ondřej Sitek

Vedoucí práce: Mgr. Martin Čuta, Ph.D.

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Scooter Riding: An Anthropological-ergonomic Evaluation

Diploma thesis

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Supervisor: Mgr. Martin Čuta, Ph.D.

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Abstract

This present diploma thesis deals with the fresh phenomenon of non-motorised scooters. Rapid increase in popularity and consequent progressive development of various scooter types resulted in the incorporation of scooters among regular means of transport, with the potential to substitute bicycles in many instances. This thesis endeavours to present a satisfactory insight into scooter problematics, both on a theoretical and practical level. The performed research strived to systematically cover the fundamental anthropological fields: anthropometry of scooter riders and kinematics of scooter riding. The anthropometry was performed on 30 scooter riders (24 males and 6 females), and the chosen dimensions were related to the scooter ergonomics. The kinematics of the scooter riding was recorded, described and analysed in 24 scooter riders (15 males and 9 females) and 27 non-scooter riders (14 males and 13 females, representing a control sample). Complementarily, the back posture of all participants was inspected and associated to the scooter riding, and finally, a questionnaire was given to the participants to supplement the retained findings. Based on anthropometric findings, several human dimensions are provided to be respected in scooter construction in order to harmonise the scooter to real human dimensions. What is more, it is proposed that the scooter producers fabricate at least two sizes of scooter models, in order to fit variable human dimensions. Based on the kinematic recordings a thorough comparison between scooter riders and non-scooter riders was performed. The comparison of body posture and back and neck ache between two samples showed significantly more impairment in non-scooter riders.

Abstrakt

Předkládaná diplomová práce pojednává o poměrně novodobém fenoménu, koloběžce. Prudký nárůst popularity koloběžek, doprovázený vývojem a rozvojem rozličných typů, vede k současnému pojetí koloběžky, tedy dopravnímu prostředku takřka rovnocennému jízdnímu kolu. Práce si klade za cíl představit uspokojivý pohled na problematiku koloběžek na teoretické i praktické úrovni. Praktická část je zaměřena na základní antropologické disciplíny: antropometrii koloběžkářů a kinematiku jízdy na koloběžce. Antropometrie byla provedena na 30 koloběžkářích (24 mužů a 6 žen), přičemž vybrané tělesné rozměry byly kladeny do souvislosti s ergonomií koloběžky. Kinematika jízdy na koloběžce byla pořízena a obecně popsána a analyzována u 24 koloběžkářů (15 mužů a 9 žen) a u 27 nekoloběžkářů (14 mužů a 12 žen, představujících kontrolní vzorek). K doplnění předchozích metod byla u všech účastníků výzkumu provedena vizuální inspekce držení těla a rovněž každý účastník vyplnil zdravotní dotazník. Na základě výsledků antropometrie představuje práce výčet i hodnoty rozměrů lidského těla, jež mají sloužit konstruktérům koloběžek při výrobě ergonomicky vhodného stroje. Práce rovněž přináší doporučení k výrobě nejméně dvou ergonomicky podložených konfekčních velikostí koloběžek. Na základě kinematického záznamu jízdy na koloběžce poskytuje práce zevrubná porovnání koloběžkářů s nekoloběžkáři. Srovnání držení těla a bolestí v zádové a krční oblasti mezi koloběžkáři a nekoloběžkáři odhalilo statisticky významně horší držení těla a častější bolesti mezi nekoloběžkáři.

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Oficiální zadání:
Koloběžka je moderní a v České Republice stále populárnější fenomén. V rámci magisterské diplomové práce se autor bude zabývat antropologií českých koloběžkářů a ergonomických vztahů člověka a koloběžky.
Teoretická část bude obsahovat uvedení do problematiky koloběhu (historie, současný ideál, rozdělení typů koloběžek, konstrukce koloběžky, závodní koloběh), popis anatomických struktur lidského těla v souvislosti s jízdou na koloběžce, dále definici antropometrických rozměrů relevantních pro ergonomické zhodnocení pozice při jízdě na koloběžce. Bude se též stručně zabývat možnostmi analýzy pohybu a jeho dopadu na struktury lidského těla.
Praktická část práce bude obsahovat antropometrické zhodnocení vzorku českých jezdců na koloběžce (vrcholových sportovců i rekreačních jezdců). Vhodné rozměry budou konfrontovány s konstrukcí běžně rozšířených koloběžek a bude zhodnocena jejich ergonomie (s případným návrhem vhodných úprav). Součástí práce bude též záznam a kinematická analýza specifického pohybu při jízdě na koloběžce.

Základní literatura:

Mlýnek, T.: Metodika jízdy na koloběžce na 1. stupni ZŠ – diplomová práce. Brno: Masarykova Univerzita, Pedagogická fakulta, 2011.

Žďárek, K.: Koloběh – současný stav: diplomová práce. Praha : Karlova Univerzita, Fakulta tělesné výchovy a sportu UK, 2005.

Malina, R. M., Bouchard, C., Bar-Or, O. (2004): *Growth, maturation and physical activity*. Human kinetics, USA.

Bláha, P. a kol. *Antropometrie československé populace od 6 do 55 let.* Praha: ÚV ČSS, 1985.

Janura, M.; Zahálka, F. Kinematická analýza pohybu člověka. 1. vyd. Olomouc: Univerzita Palackého v Olomouci, 2004.

Riegerová, Jarmila, Přidalová Miroslava, Ulbrichová Marie. *Aplikace fyzické antropologie v tělesné výchově a sportu: (příručka funkční antropologie)*. 3. vyd. Olomouc: Hanex, 2006.

Dylevský, I. *Pohybový systém a zátěž*. Praha: Grada, 1997.

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Declaration of Honour

I hereby declare on my honour that I personally prepared the present diploma thesis and that I have used no resources other than those declared in the references. All formulations and concepts adopted literally or in their essential content have been cited according to the rules for academic work.

Brno, 9 February 2016

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Ondřej Sitek

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List of Abbreviations

BS	Back Swing
ČSK	Český Svaz Koloběhu
CT	Computed Tomography
FS	Front Swing
IKSA	International Kicksled and Scooter Association
K	Kick
KFootMed	FootMed of the Kicking leg
MaxBS	Maximal Back Swing
MaxFS	Maximal Front Swing
MaxSq	Maximal Squat
MaxStr	Maximal Straightening
MR	Magnetic Resonance
NAF	Netherlandse Autoped Federatie
NSR	Non-Scooter Rider/Non-Scooter Riders
PO	Push Off
RelMaxBS	Relative Maximal Back Swing
RelMaxFS	Relative Maximal Front Swing
RelMaxSq	Relative Maximal Squat
RTG	Radioisotope Thermoelectric Generator
SFootMed	FootMed of the Standing leg
SR	Scooter Rider/Scooter Riders

List of Appendixes

The appendixes are only attached in an electronic form, both affixed on a CD and uploaded on the IS MU (Information System of the Masaryk University). The Appendixes A – I are contained in the .pdf file.

1. Introduction

In the last decade, the popularity of non-motorized vehicles called scooters increased immensely. After forty years of almost latent, however surprisingly rich history and slow development, a real scooter boom has arisen in the Czech Republic. A progressive evolution of miscellaneous scooter types has followed (see Kickbike.com; Kolobezka.com; Kostka-kolobka.eu (a); Mibo.cz (a) *et cetera*), resulting in scooters being incorporated among regular means of human transport, with a potential to substitute the bicycles in many instances (Horák, 2011, 2013, 2015; Lindner, 2010, 2011a, 2012a; Ceskykolobeh.cz; ZkusKolobku.cz). Scooter popularity will most likely grow even more. The most obvious reasons for such a claim are simple. Compared to the bicycle, the scooter is usually lighter, more versatile in a crowded city and it is much simpler in mechanics. Although slightly slower and more tiring, the scooter has more sport-like character and it is in harmony with the modern active lifestyle.

None of the references listed above represent an academic paper, but rather popularising or community websites, although some of them are very serious and erudite. Apart from three diploma theses (Žďárek, 2005; Kittlerová, 2006; Mlýnek, 2010), a scientific scooter-related literature is lacking. In the theoretical section of this thesis, I aim for a satisfactory insight into scooter problematics, with emphasis on the scooter history, construction, typology and the main scooter producers in the Czech Republic. Further on, I describe in theory both the basic scooter mechanics and the thorough biomechanical and health-affecting aspects of scooter riding as such.

Having the thesis representing one of the pioneer scooter-related studies, in the practical section I strive to systematically cover the fundamental anthropological fields: anthropometry of scooter riders and kinematics of scooter riding. The anthropometry was performed on scooter riders of both sexes and the chosen dimensions were related to the scooter ergonomics. The kinematics of scooter riding was recorded, described and analysed in scooter riders and non-scooter riders of both sexes. Complementarily, the back posture of all participants was inspected and associated to scooter riding and, finally, a questionnaire was given to the participants to supplement the retained findings.

2. Objectives

1. To provide the theoretical insight into scooter riding problematics on a national level, including the history, scooter construction and scooter racing.
2. To provide the theoretical insight into anatomical scooter-related structures relevant for an ergonomic evaluation of the scooter.
3. To describe the biomechanics of scooter riding.
4. To associate the scooter riding with the body posture.
5. To perform the anthropometry of scooter riders, to associate the relevant findings with the scooter dimensions and, if felicitous, to propose the adequate alteration.
6. To perform the kinematic recording of scooter riding and to comment and analyse the findings.

3. Terminology

To avoid any misunderstanding it is crucial to explain and define the English terminology used in the thesis.

In English there are at least four ways to denominate the non-motorised vehicle defined as scooter.

Scooter – the most frequently used, official variant and also a term which the presented thesis operates with. Etymologically the term *scooter* originates in the English verb *to scoot* which means "to go or leave somewhere quickly" (Hoad, 1993, p. 422). The origin of the verb *to scoot* is more blurred. The Oxford Dictionaries provide only a short note that the first *scoot* appearance was in the middle of 18th century, but its origin is unknown (Oxforddictionaries.com). The Online Etymology Dictionary gives one possible explanation of the word origin in the Old Norse word *skjota* which means "to shoot" (Harper, 2014).

According to an English monolingual dictionary, the *scooter* means "*a child's toy consisting of a footboard mounted on two wheels and a long steering handle, propelled by resting one foot on the footboard and pushing the other against the ground*". This meaning appeared firstly in the 19th century. The later connotations of the *scooter* refer to the motorized scooters, either road, snow or water ones (Oxforddictionaries.com) and they are not the subject-matter of the thesis.

The imperfection of the scooter definition is that contemporary scooters represent more than just the child's toy. Many scooter types and sizes exist today, varying from the child's toy to professional sportsman's equipment. Present variability of scooters is nearly comparable to the variability of bicycles. A detailed description of the scooter as well as the particular scooter types is provided further in the thesis.

Kickbike – an unofficial term. It originates in two English words *kick* and *bike*. The *kick* refers to a specific kicking movement used for propelling the scooter. The *bike* refers to a similarity of bicycle and scooter. The term *kickbike* does not occur in the English monolingual dictionary, hence it does not exist in the standard English at all (Hoad, 1993; Oxforddictionaries.com). Nevertheless, the most important Finnish scooter producer holds the name Kickbike and nowadays, as the brand is growing its global importance, an increasing trend in using this term for the scooters is obvious. Similarly, the term *kickbiking* is broadly used for a scooter riding, even by the scooter racers (Kickbike.com).

Footbike – an unofficial term. A *footbike* is a compound word consisting of a *foot,* referring to the part of human body participating in scooter propelling, and a *bike*, referring to the similarity to bicycle. Likewise as *Kickbike*, it does not occur in the English monolingual dictionary (Hoad, 1993; Oxforddictionaries.com). The term is used in the United States of America and Australia rather than in Europe; this can be observed in the different terminology which European scooter companies use for the scooters promotion in these countries (Kickbike.com; Mibospace.com).

Kick scooter – an unofficial term. The word does not occur in the English monolingual dictionary (Hoad, 1993; Oxforddictionaries.com). Etymologically, the collocation combines the word *kick*, the way of propelling the scooter, and the *scooter*. Use of the term is rather seldom.

Since the scooter does not represent the mainstream means of transport, there is an ambiguity in calling "moving on a scooter" in English.

Scooter riding – the most frequently used, linguistically correct variant. According to the Oxford dictionaries *to ride* means (besides some other meanings) "to travel on a vehicle" (Oxforddictionaries.com). Therefore, the way of travelling or moving on the scooter is riding.

Kicking – an unofficial variant, in English broadly used, especially among scooter riders (Kickbike.com; Kickfrance2013.com). As a designation of the way of moving on the scooter it does not occur in the English monolingual dictionary (Hoad, 1993, p. 252; Oxforddictionaries.com). However, the verb *to kick* can be defined as "to strike or propel forcibly with the foot" (Hoad, 1993, p. 252; Oxforddictionaries.com). Thus, the term is technically correct, because the impact of the leg pushing off the ground can be considered a kick. However, since a proper terminology is accented in the thesis the word *kicking* will not be applied.

Scootering – an unofficial term. The word does not occur in any studied English monolingual dictionary (Hoad, 1993; Oxforddictionaries.com) and it can be considered a neologism, although it is used to describe the process of riding both motorised and non-motorised scooters.

Cycling – an often used, but inaccurate term. From its definition *cycling* is “the sport or activity of riding a bicycle”. Originally, the word comes from the late Latin word *cyclus*, which comes from Greek word *kuklos* meaning “a circle” (Hoad, 1993, p. 110; Oxforddictionary.com). In the figurative meaning the circle is a wheel and since a scooter has two wheels, it can, hypothetically, be cycled. However, the contemporary definition of *cycling* does not consider this yet and a usage of the word *cycling* for riding a scooter is therefore incorrect.

4. Scooter Legislation

A juridical perspective provides another scooter characterisation. According to Road Transportation Act 361/2000 Sb. § 57, subsection 2, the scooter, when on road, is considered a bicycle. Alike the bicycle, the scooter, when on road, is obliged to ride on the right side. When on pavement, the scooter is not allowed to ride, however it can be pushed. A scooter rider is considered a cyclist and therefore is required to hold a handlebar with both hands, not allowed to hold another vehicle or to carry neither dog nor other object which can impede safe riding on the road.

Technical Competence and Technical Conditions of Traffic on a Road Order 341/2002 Sb., appendix 13, states the scooter (representing the bicycle) is obliged to carry mandatory equipment. The mandatory equipment consists of two functional brakes, bicycle bell, reflectors and both white front and red rear light when dark.

The scooter construction legislation and safety is directed by European Standard ČSN EN 14619 (2005). The standard enumerates the safety requirements for the roller sports equipment and stands for the constructors, producers, distributors and importers of this equipment. The standard specifies safety requirements, testing methods and information for the third person and the user, in order to minimize the risk of injury (Technicke-normy-csn.cz).

5. Brief History of Scooter Riding

The scooter as the means of human transport has undergone a different evolution in different regions. There is a certain independency between its evolution in Western, Central and North Europe, although all branches of scooter development have more or less been influenced by each other (Žďárek, 2005, p. 10; Ceskykolobeh.cz, 2013; Brouwer, 2014).

The very origin of two-wheeled vehicles propelled by human power in Western and Central Europe was set up by a German inventor Karl Dreis in 1818 (Cibula, 2004, p. 9). His invention called Laufmaschine (in English "running machine"), later renamed by Europeans as "draisine" after its constructor, consisted of two wooden felly wheels connected by a wooden frame. There was a handlebar attached to the front of the frame and a saddle attached to the frame in between the wheels. The Laufmaschine was propelled by a person sitting astride on a saddle, and performing swift walking-like movement with legs (Soulek & Martínek, 2000, p. 9; Herlihy, 2004, p. 24–25). In the following years, the fast and sudden popularity of this vehicle made it spread to the American continent as well. However, due to the lack of real practical usage the Laufmaschine faded into obscurity for many years, until the pedals were installed on it, leading to the birth of a bicycle in 1853 (Rychter, 1979, p. 25; Cibula, 2004, p. 11; Smithsonian.tumblr.com). Probably then, after this renaissance of two-wheeled vehicles called in general velocipedes, there was a crucial division and scooters emerged by the side of many various velocipede types such as monocycles, bicycles, dicycles, tricycles, quadricycles *et cetera.* (Herlihy, 2004, p. 26).

By the end of the 18th century, the English term scooter already exists defining the two-wheeled vehicle propelled by pushing off the ground, used mostly as a child's toy (Oxforddictionaries.com). The scooter held this toy-status during the whole 19th century up to the middle of 20th century, when, at some places of Central Europe (for example Rožnov pod Radhoštěm, the Czech Republic) the scooter ("koloběžka" in Czech, Machek, 1968, p. 305) has turned into a dry summer practicing tool for professional skiers [Mibo.cz (a)]. In 1968 the first official scooter racing competition in former Czechoslovakia took place, called Rollo league ("Rollo liga" in Czech) which, with some intermissions, operates until today (Ceskykolobeh.cz, 2013).

Implying the above mentioned, the sixties was a decade when the scooters were definitely established as a regular means of transport in the former Czechoslovakia and, albeit still marginal, definitely not only for children (Figure 1). The final step for establishing scooter riding as an official sport in the newly formed Czech Republic was the founding of the Czech scooter federation (Český svaz koloběhu) in 1994. Since then, the Czech scooter federation has been acting as an official association for organising the highest Czech competition Rollo league and promoting the scooter sport (Ceskykolobeh.cz, 2013).

Figure 1: Masaryk circuit, Brno, Czechoslovakia (Český svaz koloběhu).

In Western Europe, specifically in the Netherlands, the scooter ("autoped" in Dutch, Autoped.nl) already existed before the Second World War as the means of transport. Nevertheless, its character was not a sport-like one yet. The first real races took place in the Netherlands in the late sixties and early seventies (Brouwer, 2014, Figure 2). Another important milestone was the year 1987, when the Netherlands scooter federation

(Nederlandse Autoped Federatie, NAF) was established to take the patronage over the Dutch scooter competitions and races (Autoped.nl).

Figure 2: Race Kamperzeedijk, the Netherlands, 1982 (Brouwer's archive).

There was a certain time in both Czechoslovakia and the Netherlands when the scooter riding had been fading out, but ignited again through the seventies, eighties and nineties. There was a similar situation in Germany, Italy and France as well. Unfortunately, in France the interest for scooter riding faded out completely and France scooter riding fell silent for some years (Brouwer, 2014).

After a massive progress of the internet in the nineties, the particular scooter sport organisations started communicating with each other and the first international scooter race took place in 1997 in Finland (Brouwer, 2014).

The scooter evolution in North Europe was originally very different, although its result was convergent to the main European scooter-development branch. Due to long and tough winters with a lot of snow, there was a great tradition in sled use in North Europe (*id est* mostly in Sweden and Finland). The first sleds were pulled by the livestock (Arvonen, 2002, p. 15). Later, by the beginning of 19th century, more types of sleds had appeared, among them there was also a small light human-powered sled called kicksled (Aik.se). The very light construction consisted of two parallel runners connected through a perpendicular handlebar pole at the front ends of the runners. The rider stayed on one of the runners with a leg, while the second leg propelled the kicksled by kicking the snowy ground between the runners (Arvonen, 2002, p. 15). This type of kicksled is in use even nowadays, sometimes called kickspark instead (Figure 13, Kickbike.com). In 1985 a Finnish medicine student Hannu Vierikko started using the kicksled as a practicing tool to maintain physical condition and stamina. He found the kicksled ingenious for such a purpose and invented a special light aluminium construction for it. Looking for the similar tool for summer time, Vierikko, inspired by the above mentioned European scooters ("potkulauta" in Finnish, Suomisanakirja.fi), constructed a large scooter with 28" front and 18" rear wheel rim size. This act, followed by the founding of the Kickbike company (1994), laid the foundations of the modern scooter riding in Finland (Žďárek, 2005, p. 10).

Altogether, the main branches, Dutch, Czech, Finish and German, laid the foundations of a nowadays scooter riding tradition in whole Europe (Brouwer, 2014). The most natural way of the scooter spreading around the globe was via sport events. In 1998 IKSA (International kicksled and scooter association) was established to take patronage over particular national scooter associations (Ceskykolobeh.cz). The founders were from the Netherlands, the Czech Republic, Finland and Germany. With a rising popularity of scooter riding many countries set up their national scooter associations and started participating in scooter races on both national and international levels and this process is still in progress (Brouwer, 2014).

Since scooter riding is expanding, the local scooter producers are expanding as well, spreading their stores, both permanent and internet ones, to other countries even as far as to the United States of America and Australia. Nowadays, we can count tens of more or less specialised scooter producers in Europe and many more elsewhere in the world. In general, the scooters became very accessible for the public during the 21st century and are rapidly leaving their former marginal position in the sports and the means of transport (Kickbike.com; Kolobezka.com; Kostka-kolobka.eu (a); Mibo.cz (a); Yedoo.eu).

As a kind of vehicle the scooter had already existed in many European countries even before its contemporary expansion. That is why many European languages apply the unique name for the scooter, such as “trotinette” or “patinette” in French (Cnrtl.fr/etymologie), as “trettroller” or “roller” in German (Internationale-worterbuch.com), as “sparkesykkel” in Norwegian, bokmål (Falk, Torp, 1999, p. 797), as “hulajnoga” in Polish (Sciaga.pl) or as “самокат” in Russian (Ru.wiktionary.org).

6. Scooter Construction

A scooter is a light single-track vehicle. The basic scooter construction is rather simple, when compared, for instance, with a bicycle. Since the subject-matter of the thesis deals not with the small foldable aluminium scooters with the small radius rubber (or similar) wheels, their different construction description is not presented here.

The basic scooter construction principles are in use in a vast majority of the scooter types (Figure 3). The fundamental and most variable scooter component is frame, generally consisting of two parts, a vertical front part and a horizontal footboard part. The front of the vertical part of the frame is welded to a head tube, where a front fork steer is mounted within. A steering motion is transmitted via a steering head, usually containing a ball bearing. Upside of the head tube there is a stem connecting the steering to a handlebar. The footboard represents the part of the frame where the scooter rider stands. The rear ending of the footboard forms an immobile rear fork. Both front and rear forks hold each a wire-spoked tyre wheel. The wheel rim size varies from 12" up to 28", while the front wheel is either bigger or of the same size as the rear wheel.

The scooter is equipped with either rim or disk brakes. In addition, many scooters, especially the universal ones, are equipped with mudguards, a bicycle bell and reflectors.

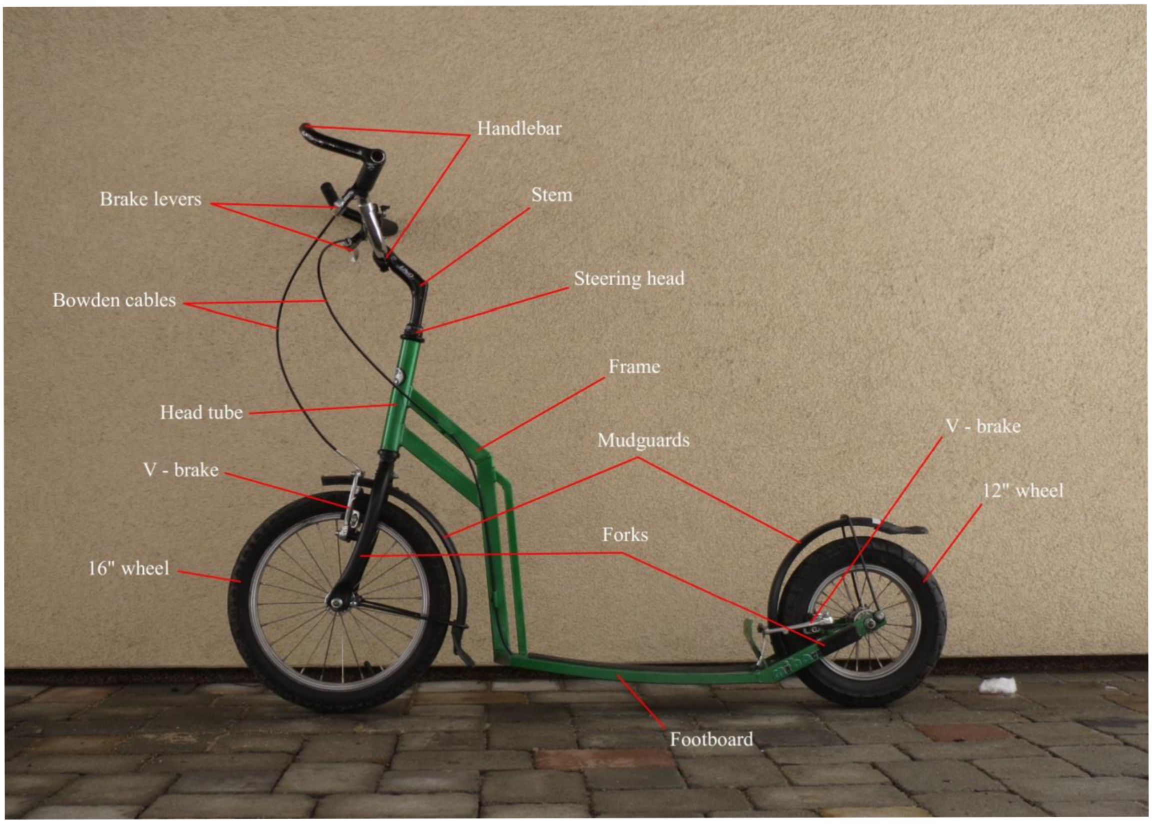

Figure 3: Basic scooter construction demonstrated on Mibo Crazy, basic model 2005 (author’s archive).

7. Scooter Parameters

Every serial-fabricated scooter should be submitted with information about its general parameters. Knowing these parameters, together with a tyre type, the basic riding characteristics of the scooter can be anticipated.

The general parameters are: scooter length, wheelbase, footboard length, scooter height, frame height, clear height, footboard height, stem length, stem angle, front wheel diameter, rear wheel diameter, handlebar width and weight (Figure 4).

Nevertheless, not every scooter producer submits all of these parameters and some producers present different parameters.

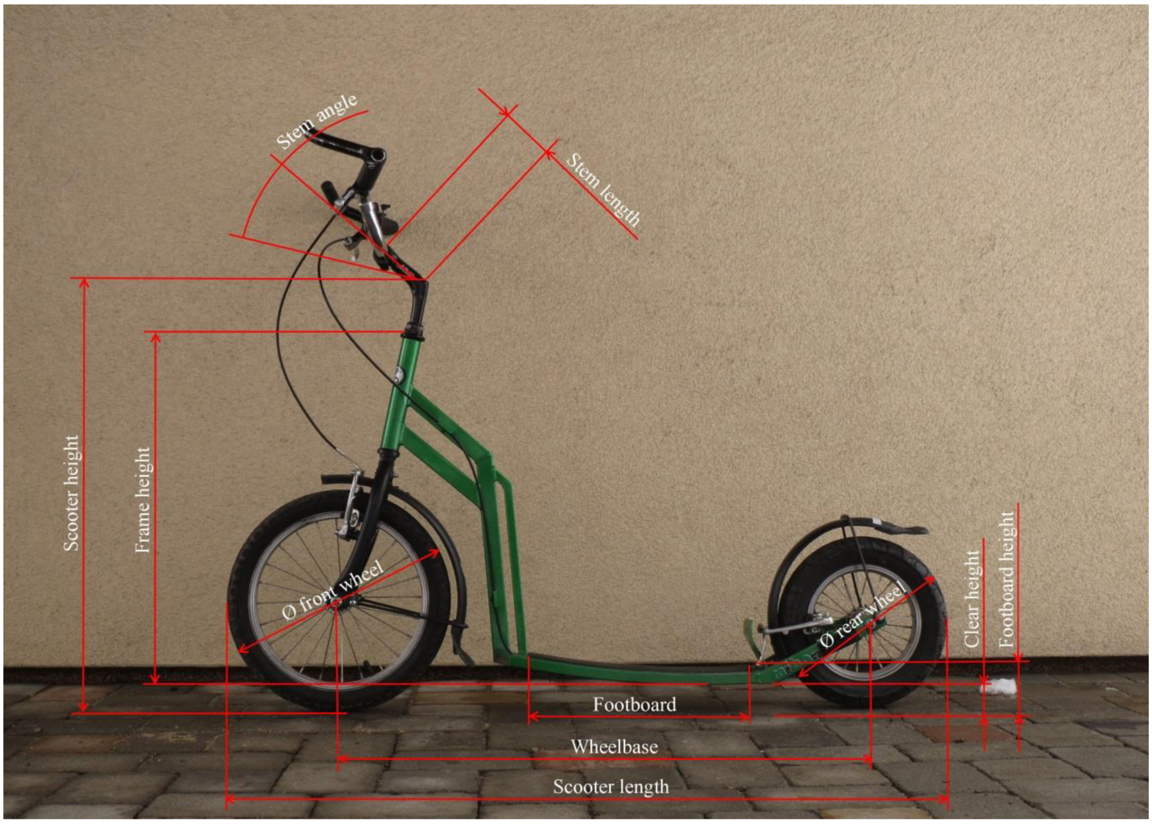

Figure 4: Scooter parameters demonstrated on Mibo Crazy, basic model 2005 (author's archive).

8. Scooter Types

With exploring new possibilities of scooter riding, many scooter types have emerged, fitting a broad variability of different uses.

The separation to scooter types is not cascade but rather smooth, similar as in bicycles. Functionally, there exist some extreme types and the majority represented by either universal or hybrid types. The diversification and modification of scooters is still continuous process.

8.1. Universal Scooters

A basic or universal scooter model (Figure 3 – Figure 5) is suitable for very broad variety of uses. Historically, there were very similar scooters to contemporary universal scooters which constituted most of later types (Ceskykolobeh.cz, 2013).

The morphology of a universal scooter is the same one described above in the chapter *6. Scooter Construction*. The wheel rim size varies from 12" up to 26", still with the front wheel either bigger or as big as the rear wheel. The ground clearance of a footboard is usually about 50 mm [Kolobezka.com (a); Kostka-kolobka.eu (a); Mibo.cz (b)].

Some universal scooters are standardly equipped with cowhorn bar, mudguards, reflectors, bell, water bottle holder and/or with kick-stand [Kolobezka.com (a); Kostka-kolobka.eu (a); Mibo.cz (b)].

The universal scooters owe for their broad use mostly to great variability of wheel sizes and a relatively high positioned footboard. In general, they are suitable for every but not extreme use. They are medium fast on road, medium safe and comfortable on downhill, medium enduring and medium heavy (from 5 to 10 kg), depending on size and material used. The price varies mostly from 5.000 to 10.000 Czech crowns (Kolobezky-pro-dospele.cz).

Figure 5: Mibo Express Top, a universal scooter (Mibo.cz).

8.1.1. Folding Scooters

The specific sub-type of universal scooter is a folding scooter (Figure 6). Aiming to compactness, most of folding scooters are rather small, with wheel rim size 12" or 16" [Kostka-kolobka.eu (a); Mibo.cz (b)]. The principle of folding the scooter varies both between and within the producers. There is always a joint in a frame which serves to fold the scooter up to smaller dimension. The folding scooters are more expensive (Kostka-kolobka.eu (a); Mibo.cz) and usually either heavier or not so stiff in the frame than the same-dimensioned non-folding scooters (Lindner, 2012b).

The use of folding scooters is especially practical for shorter rides in bigger cities. Their portability when folded up is easily compatible with public transport.

Figure 6: Mibo Tiny Top, a folded scooter (Mibo.cz).

8.2. **Off-road Scooters**

Off-road scooters are, as a name reveals, significantly specialised for off-road purposes, such as forest paths or loose terrain (Figure 7). A downhill riding is becoming popular recently, recognizing ski slopes as a good place for extreme downhill, as long as the slopes remain without snow.

Off-road scooters are usually large with front wheel rim size from 26" to 29" and rear wheel rim size 20". A heavy and very enduring construction is characteristic for off-road scooters. A solid frame with a suspension fork is supposed to tolerate even a harsh treatment and absorb mighty shocks. The footboard is sometimes protected from above and below with changeable wooden planks (Gravityfreescooters.com). Mountain wheels and high quality disk brakes comprise on safe and non-slippery ride (Kickbike.com).

The off-road scooters are rather expensive (15.000 to more than 30.000 Czech crowns) and very heavy due to the solid materials. Also the ground clearance is significantly higher compared to any universal scooter – usually more than 100 mm (E-kolobezka.cz; Gravityfreescooters.com).

As a result of heavy weight and high ground clearance the use of the off-road scooter is very limited and riding on the road is mostly very tiring. On the other hand, the off-road scooter represents the only scooter type with capability to ride the rough terrain, although 100 mm ground clearance is not enough to ride every off-road.

Figure 7: Gravity Iron Cols, an off-road scooter (Gravityfreescooters.com).

8.2.1. Mushing Scooters

As a sub-type of the off-road scooter there is a mushing scooter considered to be (Figure 8). The mushing scooters are the scooters specialised for a dog pulling. Since 2013 there already exists one specialised mushing scooter producer in the Czech Republic, called Doxtor (Doxtor.cz).

The most visible and common mushing scooter construction specificity is in a spring steel flexible adaptor mounted to a frame, to which a dog is fasten through a bungee line. The adaptor prevents the bungee line to get trapped by a front wheel [Kostka-kolobka.eu (a)]. Alternatively, this adaptor can be absent in some mushing scooters (Doxtor.cz).

Figure 8: Kostka Mushing Pro, mushing adaptation (Kostka-kolobka.eu).

8.3. **Road Scooters**

The road scooters are adapted for the fastest possible riding on road and they represent the scooter alternatives to road bicycles (Figure 9).

Typically, a road scooter constitution is very light, despite the large scooter size. The front wheel rim size is always 28", while the rear wheel alternates 16", 20" and 28" rim size. Both wheels are equipped with either road or tubular tyres, usually of a high quality. A frame is the lightest among all scooter types and the footboard is put to the lowest ground clearance level, about 35 mm [Lindner, 2010, 2011a, 2012a; Kostka-kolobka.eu (a);

Mibo.cz (b)]. The road scooters are standardly equipped with rim brakes. A handlebar is positioned very low for the two main reasons. Firstly, rider challenges less of the air resistance, what is often supported by an employment of some kinds of drop-handlebar [Lindner, 2011a, 2012a; Kostka-kolobka.eu (a); Mibo.cz (b)]. Secondly, the lower positioned handlebar provides rider a better steering possibility (Horák, 2011, p. 11).

The road scooter construction is made to generate as much speed as possible with the smallest energy losses especially on road. On the other hand, even a small road roughness can become hardly driven-through obstacle.

In general, there are two best ways of fulfilling the road scooter specialisation. The first one is exploiting its speed capacity and making the scooter ride as fast as possible, usually for only few-kilometres trails. The second way is to use this most energy-economical scooter type to ride very long distances, even more than 100 km per day. During such a long ride the highest speed will not be attained nevertheless.

The purchase cost of the road scooter differs from a brand and employed components. In the Czech Republic the attainable serial fabricated road scooters are from 13.000 to 23.000 Czech crowns (E-kolobekza.cz).

Figure 9: Kickbike Race Max 20, equipped for long expeditions (author's archive).

8.4. **Stunt Scooters**

The stunt scooters (Figure 10) are rather small and with a durable construction, primarily used for the freestyle trick/stunt performing usually in skate parks [Mibo.cz (b)]. The wheel rim size varies between 12" and 20". There are models produced either with or without brakes. Some stunt scooters can be equipped with pegs. All another miscellanea such as mudguards, cowhorn bars or reflectors are redundant, therefore often missing [Kickbike.com; Kostka-kolobka.eu (a)].

The stunt scooter price oscillates between 5.500 and 7.500 Czech crowns, depending on a standard equipment [E-kolobezka.cz; Mibo.cz (b)].

The stunts are very often performed on small aluminium scooters as well, which are described below.

Figure 10: Mibo Rival Plain, a raw model of stunt scooter (Mibo.cz).

8.5. **Small Aluminium Folding Scooters**

During the last 15 years a very original model of folding scooters has appeared (Figure 11), seen mostly in the cities (Microscooters.com.au). This scooter type underwent significant changes in a conception of tyre wheels, rim/disk brakes and even a frame. As a result there is the smallest and the lightest scooter type in a serial fabrication, the aluminium folding scooter. The light frame is usually made of aluminium and functionally consists only of a footboard and a very tiny rear fork. The vertical T-shape handlebar represents the composite of the original front part of the frame and a head tube and is typically telescopic for a height adjustment with the foldable side grip parts. The main folding joint is located in the attachment of handlebar basis to the footboard. The wheels are very similar to in-line-skate wheels. They have been turned into rubber or plastic ones and the size has been reduced. This scooter is decelerated with the rear mudguard trample. The price oscillates between 1.500 and 4.500 Czech crowns (Micro-kolobezky.cz).

Although Žďárek (2005, p. 14) pointed the aluminium scooters as a dying phenomenon and predicted their fast depression, ten years later we can still see many of these scooters roaming the bigger cities in the Czech Republic.

The main advantages of these aluminium scooters are swift and agile mobility in the city and trick performing in the skate parks. On the other hand, the stiff rubber or plastic wheels come as the insurmountable barrier in any uneven ground, such as cobblestones; then the riding becomes very unpleasant or even impossible and often dangerous (Powell, 2003).

Figure 11: Micro White, folding aluminium scooter (Micro-kolobezky.cz).

8.6. **Scooters for Children**

The scooter as original child's toy is still in use nowadays. There is a variety of small sized scooters, both in universal solid and light aluminium form. What is more, many adult scooters have the adjustable handlebars, so they can fit even a child's size (Svetkolobezek.cz). Some scooter producers offer even specialised scooters for children [Kostka-kolobka.eu (a)].

8.7. **Motorised and Electric Scooters**

During the last decade there have appeared artificially propelled scooters with a morphological similarity to the non-motorised scooters (Figure 12). In general, there exist two basic types, petrol propelled engine scooter and electricity propelled accumulator scooter. They are often equipped with a saddle (Motokolobezky.cz).

The use of motorised and electric scooters is rather marginal. The relatively high purchase cost contributes on this fact (varies from 5.000 to 40.000 Czech crowns). The full tank/battery range varies from 8 to 40 km, according to price and type (Motokolobezky.cz).

Personally, I assume that the lack of elementary scooter-ride-feeling factor favours the non-motorised scooters, while the better comfort and reach favours the classical motorised scooters or motorcycles when compared to this hybrid machine.

Figure 12: Nitro scooters XG10 Allroad, the petrol propelled scooter (Motokolobezky.cz).

8.8. **Kicksled**

An origin of modern scooters in Finland is derived from a winter vehicle called kicksled. A very light construction of kicksled consists of two parallel runners connected via a perpendicular T-shape handlebar pole at the front side of the runners (Kickbike.com, Figure 13).

Nowadays, the kicksled is still in use, mostly in Northern Europe, although the first kicksled pioneers have already appeared also in Czech mountains. The original kicksled material was wood, the current kicksleds are usually made of aluminium. Founded in 1994 there is Finnish brand Kickbike manufacturing both the Kickbike scooters and, as its subdivision, the kicksleds called Kickspark (Žďárek, 2005, p. 10). As in the scooters there are more kicksled types depending on the applied runners: for snow, ice and downhill riding (Kickbike.com).

The modern sport kicksled is available for 5.500 to 8.300 Czech crowns (Kickbike.com).

Figure 13: Kickspark, the modern sport kicksled (Kickbike.com).

9. Scooter Producers in the Czech Republic

Nowadays, there are tens of scooter producers in Europe. This chapter describes only the main producers accessible in the Czech Republic, both national and foreign. Specifically, the listed producers fabricate only the larger scooters, *id est* not the foldable aluminium scooters. The producers are sorted alphabetically.

9.1. **K-bike**

K-bike is a small family company founded in 1998 by Petr Vavruša in the south-eastern Moravian city of Zlín. From the very foundation the company specialises in 12" wheel rim size sport scooters manufacturing. The company offers three models, the newest one is equipped with 16" front wheel [Kolobezka.com (b)].

9.2. **Kickbike**

The most important foreign scooter brand in the Czech Republic is Kickbike. The company was founded in 1994 by Hannu Vierikko in Helsinki, Finland. Kickbike produces many types of large (26" or 28" front wheel rim sizes) road and off-road scooters of higher price and high quality (Figure 9). Nowadays, the company exports products to more than 15 countries across the world (Kickbike.com).

According to references the Kickbike road scooters belong to the fastest scooters in Europe (Lindner, 2012; Kickbike.com; Kickfrance2013.com).

9.3. **Kostka**

Kostka – kolobka s.r.o. was founded in 1992 by Marek Kostka in the northern Moravian town of Hanušovice. At the beginning the company specialised in metalworking and locksmithing. During the years Kostka has transformed into the scooter frames producer, although the metalworking as an important part of income has remained. Nowadays, the Kostka is the major Czech scooter producer with more than 25 models offering, able to meet most of customers' demands (Figure 8). The company sells scooters in about 50 shops across the country and exports scooters to most European and some extra-European countries as well [Kostka-kolobka.eu (b)].

9.4. **Mibo**

Mibo scooters s.r.o. was founded in 1998 by Břetislav Michálek in the eastern Moravian town of Rožnov pod Radhoštěm. Mibo manufactures a broad variety of scooters in more than 20 models, oscillating from smaller children's scooters to large road or off-road scooters (Figure 4, Figure 5, Figure 6 and Figure 10). To this date Mibo sells scooters in 17 shops spread across the country and Europe [Mibo.cz (a, b, c)].

9.5. **Morxes**

The new Czech scooter producer, Morxes, was founded by the end of 2014 by Vašek Pechr in a Moravian village of Ústín. Morxes so far manufactures six scooter models of different scooter types with customised component selection. One of the models is supposed to be attuned to woman size, having a narrower handlebar, a shorter stem and a lower head tube. All the models are rather high-class for relatively high price. To this date Morxes sells scooters in eight shops in the Czech Republic (Morxes.com).

9.6. **Sixteen**

The Sixteen scooters are produced by Brno 4frtm s.r.o. company (4frtm stands for *For free time*), specialising in manufacturing and import of electric and foldable bicycles. In 2014

Michal Homola, a head of 4frtm, started manufacturing the scooters. The Sixteen brand offers two models, first a universal of two 16" rim size wheels and second is customised. As the stylish specifics there is an employment of single-blade fork in the Sixteen scooters (Sixteen.cz).

9.7. **Vella**

Vella-Náchod s.r.o. was founded in 1989 in the north-eastern Bohemian town of Česká Skalice under the name Vilko, specialising in yacht and windsurf tackling and ironworking. In 1992 the company moved to near city Náchod, renamed to current Vella-Náchod and enhanced the range of products. Nowadays the company produces ironwork, sport clothes and equipment, promotional items, unicycles, scooters and many others (Vellacz.eu).

Vella offers two scooter models with two 20" wheels and one model with 26" front wheel and 18" rear wheel rim size. All models usage is more or less universal (Vellacz.eu).

9.8. **Yedoo**

The Yedoo scooters are produced by Intrea – Piko company (Yedoo.eu).

Intrea company was founded in 1992 in Prague by Dan Pilát and its focus was in interior designing. In 1995 the company renamed to Intrea – Piko s.r.o. and around 1998 the company started a scooter production. In 2008 Yedoo was founded as a primary scooter brand (Intrea.cz).

The Yedoo scooters are cheap, very accessible and comprising many universal types, although the scooters quality is often disputed (Lindner, 2011b). Nevertheless, a brand’s popularity increased rapidly and the scooters are distributed to more than 30 countries worldwide (Intrea.cz).

10. Scooter Community in the Czech Republic

The most experienced scooter riders are either those ones often participating in organised scooter races or expeditionary ones, who travel very long distances on their scooters. In both these scooter riders, the best scooter-riding technique and the most scooter-adapted body structures can be expected, due to the richest experience and the longest time spent on scooter. The racing riders are likely to be found on the organised scooter races. The racers practise to attain the best possible outcomes and they are well known among a scooter community. The expeditionary riders, if not belonging to the first group as well, are harder to encounter. Their outcomes are based on a rich and a long-lasting scooter riding.

The majority of scooter racers in the Czech Republic are involved in some of the scooter organisations. As it was mentioned in the chapter *5. Brief History of Scooter Riding*, the Czech Republic has one of the longest tradition in an organised scooter riding in the world. Nevertheless, the major expansion of organised scooter riding in the Czech Republic came in nineties (Ceskykolobeh.cz). Then many particular scooter clubs one by one appeared and some of them began to organise their own competitions (Bezpedalu.cz; Kkplzen.cz).

10.1. **Czech Scooter Federation (Český Svaz Koloběhu – ČSK)**

Since 1994 when founded, ČSK (Czech scooter federation) organises the Rollo league and promotes the scooter sport in the Czech Republic. ČSK also represents the national scooter agent to communicate with other national scooter organisations and co-arrange international scooter competitions, such as Eurocup, European championship and World championship (Ceskykolobeh.cz).

10.1.1. Rollo League

Having its premiere in 1968, the Rollo league is the most important Czech scooter competition lasting until today. It annually comprises 5 – 7 league rounds. Within 1982 and 1987 there was a pause in league holding. Altogether, Rollo league is already over 40 years persisting scooter competition with current annual participation about 100 racers (Ceskykolobeh.cz).

10.2. **Ultima K.lap Team**

Ultima K.lap Team, founded in 1999 in Prague is probably the most important and prestige scooter club in the Czech Republic. It is said to be the only scooter club in the world with international membership (Ceskykolobeh.cz). Its prestige is caused by phenomenal competition successes on both national and international level (Ultimaklapteam.cz).

Besides participating in competitions, Ultima also organises challenging events, such as Kick France project (Kickfrance2013.com).

10.3. **Other Scooter Clubs in the Czech Republic**

Besides the Ultima, there are seven other registered clubs spread mostly in the west of the Czech Republic. Club riders are regularly participating in Rollo league and other scooter competitions.

In alphabetical order there are following registered clubs in the Czech Republic: *Bez Pedálů* (Bezpedalu.cz), *Jafiduto Kadaň* (Ceskykolobeh.cz), *Kidokai Jablonec* (Ceskykolobeh.cz), *Klub Koloběhu Lipník nad Bečvou* (1klubkolobehulipnik.cz), *PSP – Klub Koloběhu Plzeň* (Kkplzen.cz), *RC Zlín* (Kolobezka.eu), *Sportovní Klub Koloběhu Lipník nad Bečvou Lipenští Draci* (Kolobehlipnik.cz).

10.4. **Kick France Project**

There are not many organised long expeditionary scooter rides in Europe. The Czech Kick France project represents one such a ride.

The project is a scooter challenge organised by Ultima K.lap Team. In 2013, at the occasion of 100th season of probably the most famous bicycle stage race in the world, the Tour de France, six scooter riders (four Czechs, one Finn and one Dutch) managed to ride the Tour de France on scooters (Kickbike Race Max 20, Figure 9), one day prior the main bicycle peloton. The aim was to popularize scooter riding in Europe and to find man's limitations as well. The event was richly sponsored by many scooter organisations in Europe and a subsequent success of the ride attained an extraordinary publicity (Kickfrance2013.com).

In April 2015 the second Kick France challenge took place. The Kick France 2015 led participants to another famous bicycle race, the Paris – Roubaix (Kickfrance2013.com). Despite the great scooter riders attendance the publicity of the sequel was rather unsatisfactory and the challenge remained publicly undiscovered.

11. Scooter Mechanics

Scooter is a mechanical body. The fact that it has two bicycle wheels links its mechanics to the mechanics of bicycle. Nevertheless, the most important similarity between scooter and bicycle mechanics lies in present resistances and in braking principle. The way of propelling the scooter is completely different and mechanically simpler, as the bicycle propelling relies on a complex chain of mechanical components.

There are not many literary sources analysing the scooter mechanics specifically hitherto. Probably the best accessible source there is Jak na koloběžku (How to treat a scooter), a complex of thoughts of Czech scooter enthusiast Jan “Fido” Horák (2011). The bicycle mechanics literature can be studied for the common aspects of the scooter and bicycle mechanics.

11.1. **Resistance**

Every mechanical body has to overcome a physical resistance to be moved and to move on. Representing no exception, the scooter has to overcome a sum of five different resistance types: bearing, rolling, air, gradient and inertia (Cibula, 2004, p. 49–52; Horák, 2011, p. 4–15).

11.1.1. Bearing Resistance

The scooter motion is caused by rider kicking the ground and consequent wheels turning. In a wheel hub there is a ball bearing responsible for its smooth turning. However, some friction force is always present and increases with the weight put on the hub, *id est* also with the rider’s weight. The bearing resistance F_{rb} [N] can be calculated as follows (Cibula, 2004, p. 49):

$$F_{rb} = \frac{2M_r}{d}, \qquad (1)$$

where M_r [N·mm] represents a reactive moment of bearing and d [mm] a wheel diameter. The formula of the reactive moment of a bearing can be expressed in the form

$$M_r = \frac{1}{2} i F d_b, \tag{2}$$

where i stands for a coefficient of rolling resistance in bearing (with a range between 0.02 – 0.002), F [N] for a load in bearing and d_b [mm] for a bearing diameter.

The bearing resistance is relatively low, as visible from the formulae calculations and the demonstration in the Table 1 (Cibula, 2004, p. 49).

11.1.2. Rolling Resistance

The rolling resistance is a force against movement of round body rolling over the solid surface (Tarábek *et al.*, 2006, p. 26). The rolling resistance of the bicycle or scooter wheel is based on the elastic deformation of the tyre and road surface at the area of common contact, whilst the road surface deformation is rather negligible. When rolling a wheel, there is a specific pressure shift on the tyre. The pressure in front of the contact area increases due to an elastic deformation, meanwhile the pressure in back of the contact area decreases due to a friction of re-springing (Cibula, 2004, p. 49). This pressure shift moves a pressure resultant u and causes the rolling resistance moment Nu [N·m], the force against rolling forward (Figure 14).

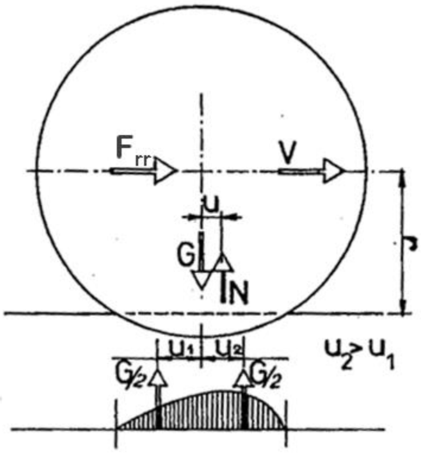

Figure 14: Rolling resistance (adapt from Cibula, 2004, p. 50).

The rolling resistance F_{rr} [N] can be calculated according to the formula

$$F_{rr} = mgC_{rr}, \tag{3}$$

where m [kg] stands for a mass, g (9.81 m/s^2) for a gravity of Earth and C_{rr} for a coefficient of rolling resistance in wheel. According to Cibula (2004, p. 50) the variables participating in the rolling resistance render the following relations:

$$\begin{gathered} Nu = F_{rr}r \; => F_{rr} = \frac{Nu}{r}, \\ N = G = mg, \\ \frac{u}{r} = C_{rr}, \end{gathered} \tag{4}$$

where r [m] stands for a radius of the loaded wheel, N [N] for a normal force and G [N] for a gravity force.

Besides the wheel radius, the coefficient of rolling resistance is dependent on the air pressure in the inner tube, the tyre type, the road material and the road surface condition (Cibula, 2004, p. 50).

11.1.3. Air Resistance (Drag)

Air resistance (also called a drag) F_{rd} [N] is a force of the fluid (air) acting oppositely to the motion direction. The air resistance can be expressed by the formula

$$F_{rd} = \frac{1}{2}\rho AC_d v^2, \tag{5}$$

dependent on a velocity v [m/s], a dimension of frontal area of the body A [m^2], an air density ρ [kg/m^3] and a drag coefficient C_d (Halliday *et al.*, 2000, p. 124; Tarábek *et al.*, 2006, p. 56).

As visible from the formula (5), the air resistance increases with the second power of the velocity. In case of the air flow (for example wind) this flow has to be counted with in the formula, considering the flow direction (Halliday *et al.*, 2000, p. 124; Cibula, 2004, p. 52).

The drag coefficient is dependent on an ability of the system to let the air flow smoothly around it. The coefficient is therefore also altered by the rider's position on the scooter, frame construction, road surface and, finally, by the rider's clothing as well (Cibula, 2004, p. 52; Tarábek *et al.*, 2006, p. 56).

When riding scooter the frontal area comprises both the frontal area of the scooter and approximately the upper half of a rider's body and his kicking leg. This organic part of the total frontal area can be altered by changing the standing position on the scooter. For example, during a downhill ride, as the rider changes his position by putting feet together, bending the chest forward over the handlebar and putting arms close to the body, the frontal area is smaller and eventual speed is higher (Horák, 2011, p. 10–12).

The air resistance is also significantly influenced by an air density. The air density is dependent on the air temperature and altitude. The basal air density is $\rho = 1.293$ kg/m^3 when temperature $t = 0$ °C and normal atmospheric pressure $p_0 = 1013.3$ mbar in altitude 21 m above the sea level (Cibula, 2004, p. 52). With the increasing altitude both atmospheric pressure and air temperature decrease (Braun *et al.*, 1978, p. 273). As a result, the air resistance is lower in higher altitudes.

11.1.4. Resistance Proportion

The Table 1 shows the percentage proportion of bearing, rolling and air resistance when accelerating in racing bicycle on horizontal plane. The variable values are adapt from Cibula (2004, p. 54–57) and serve as a comparison to scooter. The increasing speed of the vehicle increases relatively the air resistance, whereas decreases the rolling resistance. All the time of the ride the bearing resistance is negligible, with most importance during the moving-off.

Table 1: The speed influence on proportion of particular resistances in racing bicycle on flat. The only changing variable is a speed. Adapt from Cibula (2004, p. 54–57).

Resistance	**Bicycle velocity**				
	10 km/h	20 km/h	30 km/h	40 km/h	50 km/h
Bearing resistance – F_{rb}	0.5%	0.3%	0.2%	0.1%	0.1%
Rolling resistance – F_{rr}	74.6%	43.3%	25.3%	16.1%	10.9%
Air resistance (drag) – F_{rd}	24.9%	56.4%	74.3%	83.8%	89.0%

When counting same proportions in scooter, there would be some changes, depending on a scooter model taken into consideration. Horák (2011, p. 4) writes that a scooter compared to the racing bicycle from the Table 1 evinces the most important difference in a smaller frontal area and therefore lower percentage of the air resistance while higher percentage of the rolling resistance due to the smaller wheels. Any clear evidence for the smaller frontal area in scooter when riding on flat Horák does not provide nevertheless.

The speed on horizontal plane in scooter will not attain as high speed as in bicycle, not even in racing riders, therefore the last column of the Table 1 is not very likely to happen.

11.1.5. Gradient Resistance

To all mentioned resistances there merges another resistance when riding uphill, the gradient resistance F_{rg} [N], comprised of a certain portion of gravity force parallel to road, impeding an increase of potential energy (Tarábek *et al.*, 2006, p. 35). If a road inclination is known, we can calculate the gradient resistance using the formula

$$F_{rg} = mg \sin \alpha, \tag{6}$$

where α [°] stands for a road inclination angle (Cibula, 2004, p. 50).

It is common that the road inclination p is presented in %, meaning the ratio of the elevation difference h [m] and the horizontal distance l [m] multiplied by 100 (Cibula, 2004, p. 51) as follows:

$$p = \left(\frac{h}{l}\right) 100. \tag{7}$$

The relation of the percentage expression of the plane inclination and the plane inclination angle can be expressed as

$$\tan\alpha = \frac{p}{100}. \quad (8)$$

11.1.6. Inertia

The inertia is a resistance of body to change its speed or direction (Tarábek *et al.*, 2006, p. 28). In scooter, the inertia manifests always when accelerating and decelerating, *id est* when moving-off and braking and, what is the most important, always when propelling the scooter by kicking the ground. The scooter riding comprises a series of an accelerating push off and a decelerating free ride (when the kicking leg swings back and forth respectively), all together reminiscing a pendulum swing. During this subtle speed swinging the inertia impedes the speed gain when pushing-off and the speed loss when riding freely (Horák, 2011, p. 14).

The inertia is only dependent on a body mass. The total body mass can be divided to two portions – the static mass is a portion moving only straightforward, while the dynamic mass is an additional portion generated by rotating particles of the system, *id est* by wheels in a scooter case (Halliday *et al.*, 2000, p. 299).

The dynamic mass is liable for a flywheel effect. This effect makes the mass of the rotating body (wheel) to cumulate kinetic energy at a periphery of the body. The flywheel effect increases the total inertia of the moving body (Halliday *et al.*, 2000, p. 89; Tarábek *et al.*, 2006, p. 49).

11.2. **Weights**

Apart from the air resistance the weight (mass) influences all scooter-linked resistances. Within the bearing, rolling, gradient and accelerating inertial resistances the weight burdens a rider. There is the only one resistance advocating the scooter weight – the inertia against slowing down, appearing especially during downhill ride (Cibula, 2004, p. 49–52).

Nevertheless, in most scooters the downhill is not the only favoured riding style and every additional kilogram will make the scooter slower and more ponderous.

Realising this, the majority of both scooter riders and producers pursue to have the lightest possible scooter (if not specialised in extreme downhill).

The scooter compounds of many components (Figure 3). The vast majority of serial produced scooters is a hybrid of the components belonging originally to either scooter or bicycle. The original bicycle components such as wheels, brakes and miscellanea are employed by the scooter producers for their scooter compatibility. In the market there is a broad variability of these components and the lower weight is one of the aspects to pay for (E-kolobezka.cz).

What the scooter producers fabricate on their own is often only a frame, sometimes also a stem or a handlebar [Kickbike.com; Kostka-kolobka.eu; Mibo.cz (b)]. Therefore, the scooter producers strive to attain the lightest possible frames in their universal and road scooters, ideally together with no or just a small frame stiffness deterioration, which importance is explained further.

Investing to the lighter components, there are many ways how to make the scooter very light. However, as Horák (2011, p. 23) wittily points out, the weight contributing to the negative riding characteristics takes into account the mass of the all system. Consequently, for the noticeable weight loss for the reasonable price it is sufficient to wear lighter clothes and to eat a lighter lunch.

11.3. **Frame Stiffness**

Usually, for the ideal scooter construction it is crucial to have a very stiff frame. The frame is mostly a simple bent tubing (or a set of uniformly directed tubings) connecting both wheels. When riding the scooter, every frame tends to bend down as the rider is squatting and standing up. Doing that the scooter system loses a noticeable portion of energy given by its propelling (Horák, 2011, p. 3).

The frame stiffness is dependent on a material used, frame construction (shaping, bending, welding *et cetera*) and a wheelbase length (Horák, 2011, p. 3–4).

The close-to-absolute frame stiffness is essential for the sport road scooters, where even a very small energy loss can make a final ranking difference. The springing, necessary for the smooth and non-harming body conduction, is performed by minute bendings in the standing leg (Horák, 2011, p. 3–4). On the other hand, in recreational universal scooters the subtle frame springing causes no serious problem. The rider may even appreciate a shock-absorption at the coast of small energy loss, always when riding over the rough surface (Lindner, 2012c).

There are several ways how to support the frame stiffness in scooter. Probably the easiest way is to employ more stiff material. The frame stiffness can also be enhanced by employing an appropriate design solution by using computer models to stiffness calculations, such as a hollow and light material of larger frame tubing diameter, to build up an exclusive stiff frame architecture, albeit at the cost of higher footboard height, as Kickbike fabricates it (Kickbike.com).

Rather conceptual design solution of supporting the scooter stiffness is close to bicycles. The solution uses a supporting pole that connects the front and rear fork of the frame and leads between rider's legs and which enhances the frame stiffness. There already exist some scooter models using this supporting pole (for example the scooters of Dutch producer Exion or an early version of conceptual model Mibo Revoo; in the latest Revoo version the pole conception was abandoned). The question can follow, how severely the pole will restrict the rider's comfort and his riding possibilities (Lindner, 2013; Exionscooters.nl).

To sum up, the scooter producers' challenge is to find the "happy medium", to fabricate very stiff frame from the light material for reasonable price at once with a small frame diameter to keep the footboard low.

11.4. **Braking Mechanics**

Braking in scooters is the very same as in bicycles. For these two vehicles there are two main brake types, rim and disk brakes, based on a different acting position and with a different braking radius (Oertel *et al.*, 2010).

The rim brakes have braking jaws attached to a fork, close to the wheel rim. The braking force is applied by friction pads to the wheel rim. The disk brakes contain the metal disk attached rigidly to a wheel hub and the small caliper, containing the friction pads, attached to one fork blade. The braking force is transmitted by the pads to the integral disk (Oertel *et al.*, 2010).

In general, the use of both brake types results in the same effect, the wheel and, consequently, all the kinetic system stops moving.

There are many physical relations to the braking. When a braking impulse is generated, the vehicle rides over the so called stopping sight distance. The stopping sight distance consists of two sections. The first section is ridden over the track with an unchanged speed, it is only dependent on a reaction time of a rider, and a time of pushing the brakes. The second section comes when the braking occurs and it is called a braking distance (Cibula, 2004, p.70).

To express the length of the braking distance l_b [m] in a case of gradual braking, we can use the formula

$$l_b = \frac{v^2}{2a}, \tag{9}$$

where a [m/s^2] stands for a gradual deceleration.

However, the braking is not always gradual. In general it depends on many factors, such as braking intensity, tyre-road adhesion, height and position of centre of gravity, division of braking forces between front and rear wheel, road inclination and ride resistances (Cibula, 2004, p. 71). Estimation of the braking distance in all consequences is rather complicated.

As a braking result there is an increased gravity force in a front wheel, while in a rear wheel a gravity force reduction occurs (Cibula, 2004, p. 72). This consequence can lead to two phenomena occurring more likely in scooters then in bicycles.

When riding the scooter at high speed and braking very suddenly, the rider faces a danger associated with a persisting inertia. At the centre of gravity there acts the gravity of Earth oriented vertically and the deceleration force oriented horizontally and dependent on a braking intensity. As a resultant of these two forces reaches the point of a front-wheel-road contact, the forward oriented force load will move the centre of gravity forward to an excessive degree and, in a simplified way, the rider falls over the handlebar (Cibula, 2004,

p. 71). That is why Mlýnek (2010, p. 62) recommends to take a balanced, low position with feet together during downhill riding. This safe position moves the centre of gravity lower and backwards and the critical resultant will be achieved more difficultly.

The second phenomenon connected to the gravity force load reduction of the rear wheel is the rear wheel slither. Especially at high speeds when braking on a bend, the rear wheel can lose the contact with the road surface, become completely blocked and “hover” uncontrollably across the road surface. Under such a condition the wheel loses both its braking and stabilising function. Sometimes this unpleasant situation can lead to a serious accident (Žďárek, 2005, p. 34–35).

The hovering rear wheel effect can be magnified by a bald tyre and by a wet and slippery road surface (Cibula, 2004, p. 72).

12. Scooter Biomechanics

The biomechanics of riding a scooter represents a set of human-made motions performed in order to propel and ride the scooter. The more complex a movement performed, the more structures involved and more complicated is its description.

Kittlerová (2009, p. 4) bifurcates scooter ride to an active ride, when the rider performs some active movement, usually to propel the scooter; and a passive ride, when the rider stands passively on a footboard and lets the scooter move without propelling. From a biomechanical perspective the active scooter ride is a composition of several circularly repeating basic movements.

The Scooter Biomechanicschapter aims for a thorough description of the basic scooter-propelling movement, which is called a scooter-propelling cycle. Also, as a necessary part of the scooter ride, the moving off and the leg switch are being described. However, some other scooter-riding situations and modifications, such as uphill and downhill ride, curves, riding over obstacles *et cetera*, are not essential for this work and therefore omitted. For the description of some of these biomechanical situations I encourage the reader to see the works of Žďárek (2005), Kittlerová (2009), Mlýnek (2010) and Horák (2011).

Most of on-scooter performed movements originate in a standard scooter standing position.

12.1. **Standard Scooter Standing Position**

The standard scooter standing position is adopted during the active ride; during the passive ride it can be modified. In the standard scooter standing position, a rider stands with one foot placed in parallel on a footboard, while the second foot is pushing (kicking) the ground along the footboard. The body is slightly bent forward so that the hands can safely hold a handlebar. The head is approximately in a horizontal plane and the eyes are directed forward (Žďárek, 2005, p. 25). Crucially, there are two scooter-propelling movements performed by both legs simultaneously; described further. One leg can be declared kicking or swinging, while the second leg is standing or squatting.

The scooter represents a single-track vehicle as it has only two common ground contact points – the wheels. The specifics of a scooter, however, lies in one additional temporal contact point of the kicking foot once in a scooter-propelling cycle. To remain in the standard standing position and to ride the scooter confidently, the rider is required to achieve some basic balance skills. The balance skills are in general provided by a common movement repetition forming a conditioned reflex, making the movements easier to proceed, provided probably by the improved sympathetic transmission of motor neurons (Heitkamp *et al.*, 2001; Seliger *et al.*, 1983, p. 314). However, as Mlýnek (2010, p. 78) points out, in scooter these skills are rather easy to learn for two main reasons. Firstly, there is a centre of gravity situated relatively low, resulting in good stability. Secondly, there is a possibility of a quick balance correction by the kicking leg, as it is always very close to the ground.

To achieve a better riding stability of single-track vehicles in general contributes to a gyroscopic moment principle that can be simplified as "the faster a vehicle moves, the more balanced it is" (Cibula, 2004, p. 33).

12.2. **Scooter-propelling Cycle**

Within typological scooter movements, such as scooter-propelling cycle, moving off, leg switching, uphill and downhill ride *et cetera* there are substantial differences between riders. Every rider has his/her own style and it does not necessarily have to correspond to the following descriptions. The descriptions are based on outcomes of a kinematic recording of scooter riding (see the chapter *18.2.1. SR – Individual Movement Comments* in the practical section; for an example of the kinematic record of scooter riding see the Appendix K), Žďárek's thesis (2005) and author's personal experience.

Žďárek (2005, p. 25) divides the scooter-propelling cycle to four phases: push off, back swing, front swing and kick. A typical scooter-propelling cycle begins when the scooter is already in motion. All described propelling movements occur during a horizontal straight ride. In general, the movements are performed in a sagittal plane. The more significant lateral movement deviations are typical for unexperienced riders.

The major body movement is performed with the lower extremities and the back. The upper extremities hold the handlebar and remain still. Likewise the head remains still, facing forward.

The associated overview of angle changing and vertical movements within the lower extremities joints in a scooter rider during the particular phases are presented in the Chart 10 – Chart 15 in a practical section.

Push Off Phase

A scooter rider adopts the standard scooter standing position. The body weight is held by a standing leg with a knee in a minute flexion. The kicking foot lends on a ground to a straighten tiptoe along the footboard triggering the push off phase. The kicking leg takes a portion of the rider's body weight for a moment and immediately pushes off by an extremely swift tiptoe plantar flexion (rotation about 65° in 0.1 s).

Simultaneously, as the scooter spurts forward due to the pushing off, the standing leg squats a little, flexing in a knee, prolonging the kicking foot ground contact and retaking the body weight. During the squat the back leans slightly horizontally and backwards by the hip flexion. All motions apart from the initial push off are performed from the kicking leg's tiptoe only if performed correctly.

Back Swing Phase

When the scooter is pushed as far forward as the kicking foot ground contact can be sustained, the back swing phase begins. During the phase the kicking leg swings backwards by its own inertia, straightening and causing a hip joint extension. It straightens close to 180° in both knee and hip joint. The kicking ankle joint is continuously relaxing from the tiptoe flexion. The kicking leg muscles relax during the phase.

The standing leg finishes the squat and starts straightening during the phase. The phase is terminated as the kicking leg reaches the maximal back swing position and its movement converts into the front swing.

Front Swing Phase

The front swing phase lasts twice as long as the other phases. In the first half the kicking hip joint swings the leg from its maximal back swing extension to the standing leg level, in the second half the kicking hip continues the swing into a flexion in front of the body. The front swing is already a muscle-supported process. The kicking knee joint remains in a minute flexion during the first half of the swing; the flexed knee prevents the kicking foot from scratching the ground in the lowermost front swing position. In the second half of the phase the knee extends almost to 180°. In the kicking ankle a minute dorsiflexion occurs by the end of the phase. In the end of the front swing phase the kicking leg is straightened with the knee in full extension and the ankle in dorsiflexion which serves as the potential energy generator for the subsequent kick phase. The foremost position of the kicking foot terminates the front swing phase.

The standing knee and hip, as well as the back, straighten completely in the course of the front swing phase. Most often during this phase, the maximal straightening of the rider occurs, both in knee and hip joints, and the back. This straightening lasts about 0.2 s and it is the only instance when the knee extensors of the standing leg relax. By the end of the phase some riders increase the potential energy of the kicking foot by increasing its total height by an additional standing tiptoe dorsiflexion (Žďárek, 2005, p. 25).

Kick Phase

The kick phase begins as the kicking foot in its front swing position is ready to transmit the additional kinetic energy to the scooter. The kicking leg kicks forcibly against the ground along footboard by the hip and knee joint extension. The stronger the force used against the ground, the more energy is transmitted and the faster the scooter will ride. The kicking ankle swiftly rotates from dorsiflexion into plantar flexion and the foot lands on the ground at the tiptoe; a common touch is terminating the kick phase and triggering the consequent scooter-propelling cycle.

As the kicking foot is approaching the ground the standing knee flexes to a squat, which would be completed in the consequent push off phase. In the standing hip the flexion begins as the whole body leans down and backwards, following the squat. If there is a dorsiflexion in the standing foot in the beginning of the phase, the standing heel lends back to the footboard during the kick.

12.3. **Moving Off**

Setting the scooter into a motion is similar to the scooter-propelling cycle, with the major difference in the first few kicks cadence. Moving off from a stationary position, it is necessary to push off the ground with the kicking foot a few times either in a swift tempo, or with much deeper squat and longer push off, prolonging the cycles until the sustainable and well-balanced speed and rhythm are achieved. During the moving off, neither back nor front swing reaches its terminal point.

Depending on the scooter type and rider experience there is a big difference in how long the rider needs to get into a natural scooter-propelling cycle rhythm from the moving off phase.

12.1. **Leg Switch**

Riding scooter with the constant leg employment is both very exhausting and impairing the body posture for the unilateral body load (Dylevský *et al.*, 1997, p. 180; Žďárek, 2005, p. 31). When riding the scooter there is usually a standing leg hurting, in spite of much simpler movement.

To avoid unilateral body load, the scooter rider should switch the standing and kicking leg regularly, about every five to twenty scooter-propelling cycles (Žďárek, 2005, p. 31). There are two basic ways of the leg switch in motion, the twist-switch and hop-switch.

The twist-switch is initiated in the beginning of the front swing phase. The body weight is concentrated in the standing heel as the tiptoe twists to the lateral side, making room for the approaching kicking tiptoe. As the tiptoe lands on the footboard (the standing foot yet twisted laterally), this leg becomes the standing leg and takes the body weight. The fresh kicking leg leaves the footboard and initiates the new scooter-propelling cycle at the push off phase. The standing leg's heel aligns on the footboard and the ordinary ride continues (see Kittlerová, 2009, p. 16). There is also an alternative variant of twist-switch by twisting the heel instead of the tiptoe. In this case the process continuum is in general very similar, with some logic differences connected to the twist in heel instead of tiptoe.

The hop-switch is performed very quickly and smoothly, when performed correctly. The hop-switch begins as the kicking leg is in beginning of a front swing phase. The standing leg takes-off the footboard slightly, making a room for approaching kicking foot, and all the trunk jumps to the lateral side. The original kicking foot lands smoothly on the empty footboard and becomes the standing foot immediately. The original standing leg becomes the kicking leg continuing the scooter-propelling cycle in push off phase (see Kittlerová, 2009, p. 18).

13. Muscles Participating in Scooter Propelling

When propelling a scooter there is the major movement occurrence in the lower extremities, as described in the chapter *12. Scooter Biomechanics*. The standing leg is squatting, while the propelling leg is pushing against the ground. The rest of the body remains more or less still except for the movements associated to circular squatting.

The electromyographic research into the movement of a single scooter rider took place at University of Jyväskylä, Finland. The research aimed for a muscle activity (product of intensity and duration of muscle contraction) in kicking leg (Žďárek, 2005, p. 36–37). There, the highest muscle activity was recorded in *musculus biceps femoris*, which causes hip joint extension during the push off phase, back swing phase and the kick phase. The second highest activity was recorded in *m. erector spinae*, responsible for dorsal flexion of lumbar spine during the kick phase. *Mm. triceps surae, rectus femoris et vastus lateralis* co-operatively extend knee joint during the push off phase. Furthermore, *m. triceps surae* is responsible for the pushing-off plantar flexion. *Caput mediale musculi gastrocnemii* is active both during the kicking and push off phase, causing the plantar flexion of the tiptoe. *M. gluteus maximus* is active both during the kicking and push off phase, responsible for the hip joint extension.

Apart from the most distinctive muscles, according to the electromyography, there is typical an activity of other muscles during the scooter-propelling cycle. IKSA (Iksaworld.com) reported the appreciable activity of *m. tibialis anterior*, responsible for the foot dorsiflexion during the front swing phase and *m. quadriceps femoris*, responsible for the knee extension during the kick phase.

The muscles active in the standing leg are different, performing cyclic squats. All four heads of *m. quadriceps femoris* are responsible for the knee extension and their tension holds the most of the body weight in the squat. The *m. quadriceps femoris* is usually the hurting muscle in the standing leg, often motivating the leg switch. According to IKSA (Iksaworld.com), the additional thigh squatting muscles are *m. gluteus maximus* and hamstring muscles, altogether extending the hip joint. *M. gastrocnemius medialis* is also involved in straightening from the squat, performing a plantar flexion (McBride *et al.*, 2006).

13.1. **Breathing**

An importance of regular paced breathing during scooter riding has not been discussed by any author hitherto. Scooter riding is very dynamic set of motions and, when breathing irregularly, the rider can experience an unpleasant stitch in the side, very similar to which can occur during running. In the scooter this happens most often as the rider quickly rides uphill without getting into the paced breathing in time.

13.1.1. Breathing Movements

A diaphragm is the main breathing muscle. An inspiration is performed by a diaphragm contraction, as the diaphragmatic arches descend and a negative pressure arises in thorax cavity. As a result the air flows inside the lungs. An expiration occurs as the relaxing diaphragm arches return to their original position, compressing the lungs and deflating the air (Wilhelm *et al.*, 2010, pp. 44–45).

Musculi intercostales externi participate on the breathing movements by the ribs lifting (Horáčková, 2007, p. 74). Accessory breathing muscles are *mm. scaleni*, *m. serratus anterior*, *m. latissimus dorsi*, *m. serratus posterior superior*, *m. pectoralis major*, *m. pectoralis minor*, *m. subclavius et m. sternocleidomastoideus* (Horáčková, 2007, p. 150).

13.1.2. Breathing Synchronization

Many natural movements, such as walking or running, are more or less linked to natural breathing cycle. Usually, the faster and more exhausting a movement, the deeper and more coordinated to the breathing (Bernasconi, Kohl, 1993; Raßler, Kohl, 1996; Fabre *et al.*, 2007). Across the studies there are proposed two possible explanations for the breathing and movement synchronization. Firstly, a common neurological drive could simultaneously activate locomotor and respiratory pattern generators. Secondly, the natural locomotion can influent the ventilation mechanically (Fabre *et al.*, 2007).

In both experienced runners and cyclists a higher degree of breathing and movement cycle synchronization was reported when compared to unexperienced ones (Kohl *et al.*, 1981; Bramble, Carrier, 1983). Nevertheless, the coordination was lower in cyclists compared to runners, as the cyclists keep their breathing rhythm partly independent on the rhythm of cycling, probably to be able to switch from one gearing ratio to another (Garlando *et al.*, 1985; Fabre *et al.*, 2007). The scooter ride, in comparison, is very dynamic, relatively closer to running than to cycling. Therefore, more synchronized breathing in scooter riding than in bicycle riding is expected, although less than in running.

As the breathing and movement cycles are highly coordinated in experienced sportsmen in order to enhance the output, then, for the most effective scooter ride it is also reasonable to coordinate the scooter-propelling and the breathing cycle. Inspiring, the diaphragm descends and vice versa. I personally suggest to synchronize an inhale (descending diaphragm) with descend of a kicking leg, so no force or spatial clash would occur in the abdominal cavity as if it was reversely. The inspiration should therefore take place during the kick and push off phase as the kicking leg descends and does not restrict the deep inhale. An expiration should occur during the front swing phase. The lungs-compressing ascend of the diaphragm is enhanced by the kicking leg on the front swing phase as the thigh pushes the viscera inside the abdominal cavity. Parenthetically, the presented breathing installation corresponds to yoga principles as well (Kennedy, 1990).

For the breathing ease, Horák (2011, p. 11) recommends to implement negative stem angle in handlebar. Having the handlebar in a lower position enables the scooter rider to lean on it and incorporate the accessory breathing muscles as well (Vargová & Páč, 2008, p. 44).

14. Body Posture

Human bipedalism makes the spine extremely sensitive to endogenous and exogenous agents. Some of these agents bring up potential dangers affecting a body posture. What is more, many aspects of contemporary human activity, such as long sitting in a car and by a computer or a heavy work load, may potentially impair the body posture as well (Gilbertová & Matoušek, 2002, p. 59–63).

An upright body posture in a human forms already in 10–14 months of age, after the cervical and lumbar lordosis are formed respectively and a child is able to stand. Then the correct body posture is provided by the adequate physical activity (Opálková *et al.*, 2013).

There exist more than one definition of the correct body posture. Haladová & Nechvátilová (2005, p. 80) define the correct body posture as the symmetric stand at attention with relaxed but not flabby muscles. Švestková (2008, p. 10–11) provides the alternative definition: a person stands with legs put together and stretched moderately. The body projects on the imaginary line connecting both hip joints. From lateral view a spine forms an S-shaped curve. Shoulder joints are relaxed, scapulae lean with *facies costalis* to thorax. Head is straighten, chin and body axis form the right angle. An imaginary line connecting right and left auditory canal is horizontal. Finally, Čermák *et al* (1998, p. 26) define the correct body posture as the posture that brings no negative effect neither to the lateral symmetry of the body (in the terms of bones, muscles and so forth), nor to the frontal/dorsal plane of the spinal curvatures, with the lowest possible energy expenses.

There are many methods in use how to evaluate the body posture. The plumb line method belongs among the most used ones; the plumb line shows the particular body segments successions and deviations (Haladová & Nechvátalová, 2005, p. 87; Opálková *et al.*, 2013). Also, 3D Topography, RTG (Radioisotope Thermoelectric Generator), CT (Computed Tomography) and MR (Magnetic Resonance) methods are broadly in use (Pallová *et al.*, 2003). Two other body posture evaluation methods, *id est* Klein, Thomas, Meyer method and silhouettographs, are thoroughly described in the chapter *16.3. Visual Inspection of Body Posture*, for their direct application on the evaluation of the body posture in scooter riders.

14.1. **Muscle Imbalance**

Čermák *et al.* (1998, p. 33–49) differ three most common types of the movement system impairment: the muscle imbalance, postural impairment and vertebrogenic impairment. Among the presented impairments only the muscle imbalance is linked directly to scooter riding.

The muscle imbalance occurs when the antagonist muscles coordination and tonus are uneven. This imbalance may lead to an asymmetric shift of the related structure to the side of the hypertonic muscle, and consequent flawed posture of the structure. Until the reason of the imbalance is present, the imbalance ratio grows, flawing on the total body posture (Čermák *et al.*, 1998, p. 33–34). Such an imbalance can be both sagittal and unilateral. The unilateral imbalance is usually caused by the unilateral activity (Čermák *et al.*, 1998, p. 39).

For uninitiated or novice riders the scooter riding may remind a unilateral sport. The footedness, or the natural preference of one leg, determines one leg for squatting and second leg for pushing off (Peters, 1988; Auerbach & Ruff, 2006). For the beginners, it is more exhausting and less balanced to ride the scooter with switched legs. However, to avoid both unilateral muscular load with the muscle imbalance risk and early fatigue of standing leg, it is necessary for the rider to overcome the initial inconvenience in switched legs riding and to habituate to regular leg switching (Žďárek, 2005, p. 31; Horák, 2011, p. 30).

15. Scooter Ergonomics

Ergonomics is a scientific discipline engaged in optimising of human activities, considering the contact objects, workplace, and human mental comfort as well. The term “ergonomics” is derived from Greek word *ergon*, meaning “work” and word *nomos*, meaning “natural law” (Gilbertová & Matoušek, 2002, p. 14–16).

As for the scooter, the ergonomics deals with dimensions, shapes and inclinations of the particular scooter components, in order to avoid the possible health risks, to enhance comfort of the rider and to maximize riding efficiency.

During the scooter existence many practical ergonomic problems have arisen. Mostly, these problems are to be solved by the scooter constructors themselves owing to the lack of erudite literature. Nevertheless, as the scooter sport becomes popular, the scooter ergonomics needs to be processed more thoroughly. Horák (2011, 2015) and Lindner (2010, 2011a, 2012a, 2012b, 2012c) pursue an ideal scooter ergonomics.

The essential postulate of the scoter ergonomics is the construction of the lightest possible, yet considerably stiff, scooter frame, with the footboard clear height fitting the particular scooter type (see the chapters *11.2. Weights* and *11.3. Frame Stiffness*). The reasonable price is an important contributor.

The other scooter ergonomics proportions are also bound by the scooter type. The frame shape (the front part inclination, rear fork width), handlebar height, width and inclination (the stem angle) or the footboard length and width are the main examples of practical ergonomics in scooter.

The contemporary ergonomic practice proposes the employment of more-sized products such as furniture, sport equipment *et cetera*, to satisfy needs of variably sized people, based on XS/S/M/L/XL scale; copying the practice of the clothing industry (Kovařík, 2011, p. 52). The personified product is the solution to many ergonomic deficiencies. In bicycles, the size diversification has become a norm already, while in scooters this has not happened yet (Laios & Giannatsis, 2010; Horák, 2011, p. 13; Balasubramanian *et al.*, 2014).

Some scooter dimensions are adjustable by user. Horák (2011, p. 13) mentions the handlebar rotation, stem pivoting and different tyre usage as the ways of customising the scooter.

The herald of incoming times in scooter ergonomics is the new Czech producer Morxes, which produces a scooter model dimensioned to woman size. The handlebar in this scooter is narrower and the stem and head tube are shorter (Morxes.com). The rest of domestically produced scooters are made unisex hitherto.

15.1. **Frame**

Shape and weight of the scooter frame subordinate its multiple function – merging the handlebar and front fork and forming the standing board and rear fork. Simultaneously, the frame is demanded to be considerably stiff, even during the rider's propulsive squatting. The last but not least aspect of the frame is its ergonomic competence.

The vertical front part of the scooter frame may be fabricated in many ways, depending on a scooter type. The front part differs mostly in its height and the inclination to the footboard. The most general ergonomic problem here is to sustain the rider's active radius, in other words, to build the vertical part rather declining away of the rider so the frame does not restrict the squat of the standing leg.

The head tube carries the front fork. The fork inclination (deviation from the vertical plane) affects riding characteristics of the scooter. The more inclined the fork, the more stable the scooter, but less disposed to turning and vice versa (Horák, 2011, p. 26).

A big challenge for the scooter frame designers arises from the variable human body size. The solution of the problem lies in the production of more than only one frame size (Horák, 2011, p. 13; see the practical section of the thesis).

15.1.1. Footboard

The footboard is an integral part of the scooter. The ergonomics connotes with the footboard height, length and width, all associated in the riding comfort.

The low-positioned footboard saves the rider's energy, the squat during the ride can be shallower and the fatigue of the standing leg will come later. On the other hand, the very low-positioned footboard disables the ride on a rough surface for its low clear height.

To enhance the frame stiffness the footboard is used to be fabricated rather thick. With the constant clear height, the thicker the footboard, the bigger its height. The ideal, hypothetic, footboard would therefore be as thick as a metal sheet, in which case the clear height and the footboard height (see the Figure 4) would be close to the same (Horák, 2011, p. 2).

When turning in high speed, the footboard inclines laterally with one of the margins getting closer to the road surface, lowering the clear height. In some extreme cases the margin and the road surface may get into a contact which may lead to a dangerous accident. To avoid such a danger, Horák (2011, p. 24) advices to apply a triangular or trapezoid profile of the footboard tubings to enable deeper yet still safe footboard lateral lean.

The footboard width connotes with the rider's feet width. The footboard length forms an action area for a rider and it influences the general features of whole scooter for defining margins of the wheelbase. The shorter the wheelbase, the easier manoeuvring characteristics the scooter has and vice versa (Horák, 2011, p. 25–26). The active area of the footboard should correspond to the rider's feet length.

The footboard standing surface influences both riding and leg-switch. During riding the surface is supposed to be sufficiently anti-slip, to hold the standing foot in a not-sliding way. On the other hand, the anti-slip surface should restrict neither the twist-switch nor the hop-switch, when the incoming feet is being adjusted to appropriate position on the footboard. The most often used functional surfaces are rubber [Mibo.cz (b)] and sand paper (Kickbike.com). Kostka scooters use the special metal bumps to limit slides [Kostka-kolobka.eu (a)].

15.1.2. Rear Fork

The rear fork both contributes on the total frame stiffness and carries the rear wheel. The carrying function is related to a phenomenon typical for scooter riding, the kicked ankles. Many scooter riders have experienced the kicked ankles in relation to wide rear fork or exposed skewers (see the Chart 20). During the back swing the kicking leg swings parallel but close to the rear fork. Under certain circumstances (for instance a fatigue) the kicking leg may swing closer than habitually, causing the minor, yet unpleasant injury.

Some scooter producers install an additional ankle protection (such as a rubber pyramid just in front of the sharp skewer, see the Figure 3), sink the skewer into the rear fork (Figure 10) or apply the rear wheel with the narrowed hub enabling to narrow the rear fork construction consequently (Figure 9, Lindner, 2012a).

15.2. **Handlebar**

The handlebar is a structure easily adjustable to specific purposes and body dimensions. The ergonomic concerns are handlebar height, breadth and shape and stem inclination.

It is recommended to adjust the handlebar lower, close up to the hip joint height, as it was already described in the chapter *13.1.2. Breathing Synchronization*, to ease the breathing and to incorporate also the accessory breathing muscles if necessary (Vargová & Páč, 2008, p. 44; Horák, 2011, p. 11).

Surprisingly, according to personal consultations, some riders strictly prefer to ride scooter with an extremely low handlebar position (about the middle of thigh height). Holding such low-positioned handlebar pronounces the spine to significant thoracic kyphosis and cervical lordosis; the installation can be extremely unpleasant for riders not used to such position. However, the riders were not complaining about the backache and were even able to ride considerable distances (100 km). An explanation of this paradox would deserve further research in any case.

The handlebar width influences the riding characteristics. The wider the handlebar, the easier turning provided. On the other hand, the too wide handlebar may not provide the sufficient support for the propelling. What is more, the larger frontal area would increase the air resistance. For normal ride it is perfectly sufficient to have the handlebar as broad as the rider's shoulder breadth (biacromial breadth). If narrower, the arms would restrict the full pulmonic inspiration and the common frictional contact between arms and trunk would scratch (Horák, 2011, p. 11).

The drop-handlebar or the cowhorns are handlebar structures adapted to be held laterally in a natural semi-pronation position of forearms and palms. Some of these contraptions are very ergonomically sophisticated (Kickbike.com).

The handlebar shape has been broadly questioned recently, especially by the scooter producers. Typical scooter handlebar is straight, usually with some kind of cowhorn. However, many new recreational handlebars tend to have the old-fashioned ends bent backwards to the rider, to increase a comfort and support balance of a ride (Kickbike.com).

The stem inclination influences the riding characteristics. As Horák (2011, p. 25–26) writes, the larger angle the stem and the road form, the more comfortable straight ride but worse turning capability the scooter has. The stem inclination angle is typically negative in racing scooters, to forward the centre of gravity and diminish the frontal area when a chest is lying on handlebar during downhill. At the same time, the low-positioned handlebar should not restrict an action radius of the kicking leg in the front swing course. As usual, the ideal setting is therefore a compromise. Most of non-racing scooters have applied the positive stem angle (see Kostka-kolobka.eu (a); Kolobezka.com (a); Mibo.cz (b) *et cetera*).

16. Methods

According to the objectives, the anthropological evaluation of scooter riders and ergonomic evaluation of scooter was pursued in the practical section of the thesis. The employed methods comprised classical anthropometry, kinematic recording of scooter riding and visual inspection of body posture. In addition, each participant was asked to fill in a questionnaire.

All subjects signed an informed consent form prior to participation in the study (Appendix A and B). Each participant was assigned an identification number; sex and age were noted.

16.1. Anthropometry

The applied anthropometry consisted of 40 measurements extracted from a complex Knußmann's anthropometry (Knußmann, 1988). Reaches and some other anthropometric measurements were adapted from the Czech technical standard (ČSN EN ISO 7250-1, Basic human body measurements for technological design, Part 1: Body measurement definitions and landmarks). The hand grip strength was measured according to Knußmann (1988).

Anthropometry always proceeded in a private room, where only an investigator with a colleague had access.

For a different character of particular measurements these were divided into five categories. Four categories were determined by Knußmann (1988), the fifth category is complementary to reconcile the remaining two measurements (Table 2).

For the height measurements take the participants stood in standard anatomic position, *id est* in upright posture, leaning the head, back, buttocks and heels against the wall. A head is in Frankfort horizontal plane. Arms are relaxed along the body. Legs are stood apart moderately, feet are parallel (Bláha *et al.*, 1986, p. 35; Riegerová &Ulbrichová, 1998, p. 9).

Most of lateral measurements were taken on a right-hand side. Exceptions were the measurements of frontal hand grip reach length, elbow-hand grip length, gluteal thigh circumference, medial thigh circumference and maximal calf circumference, which were taken on both hand sides. The hand grip strength was measured three times in both hands.

The heights, reaches, breadths and circumferences were measured in centimetres. The skinfold thickness was measured in millimetres. The body weight was measured in kilograms. The hand grip strength was measured in kilogram-forces.

Measurement precision was established to 0.1 cm in lengths and 0.1 kg in weights.

16.1.1. Measuring Instruments

The heights and reaches were measured with anthropometer. The breadths were measured with pelvimeter and slide caliper. The circumferences were measured with common tape measure. The skinfolds were measured with Harpenden skinfold caliper. The weight was measured with Tanita BC 545 scale. The hand grip strength was measured with hydraulic Saehan dynamometer.

16.1.2. Measurements

The list of all 40 measurements is presented in the Table 2. The graphical representation is provided by the Figure 15 – Figure 18. For definition of the measurements see the Appendix C.

The participants were measured in underwear to diminish measurement error. Not all taken measurements were applied for the analyses for some of them did not fit any of expanding methods.

Table 2: The list of anthropometry measurements. The measurements applied in the final analyses are highlighted in yellow.

Heights and reaches		**Breadths**	
1.1	Standing height (M1)	2.1	Biacromial breadth (M35)
1.2	Acromial height (M8)	2.2	Biiliac breadth (M40)
1.3	Elbow height (M9)	2.3	Bispinous breadth (M41)
1.4	*Dactylion* height (M11)	2.4	Elbow breadth (M52 3)
1.5	Iliocristal height (M12)	2.5	Wrist breadth (M52 2)
1.6	*Iliospinale* height (M13)	2.6	Palm breadth (M52)
1.7	*Trochanterion* height (M14)	2.7	Palm length
1.8	Knee height (M15)	2.8	Knee breadth (M68)
1.9	*Sphyrion* height (M16)	2.9	Ankle breadth
1.10	Frontal hand grip reach length	2.10	Foot breadth (M59)
1.11	Elbow – hand grip length	2.11	Foot length (M58)
Circumferences		**Skinfolds**	
3.1	Head circumference (M45)	4.1	Suprailiac skinfold
3.2	Thorax circumference (M61)	4.2	Abdominal skinfold
3.3	Gluteal circumference (M64 1)	4.3	Triceps skinfold
3.4	Relaxed arm circumference (M65)	4.4	Biceps skinfold
3.5	Contract arm circumference (M65 1)	4.5	Subscapular skinfold
3.6	Forearm circumference (M66)	4.6	Calf skinfold
3.7	Wrist circumference	**Other measurements**	
3.8	Gluteal thigh circumference (M68)	5.1	Body weight
3.9	Medial thigh circumference	5.2	Hand grip strength
3.10	Maximal calf circumference (M69)		

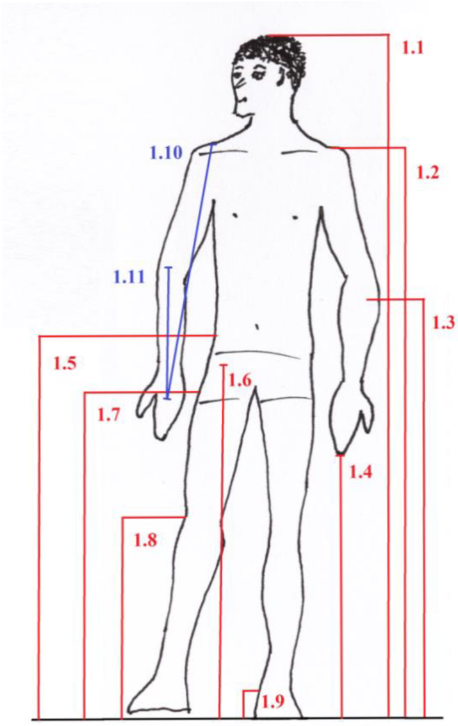

Figure 15: Measured heights and reaches.

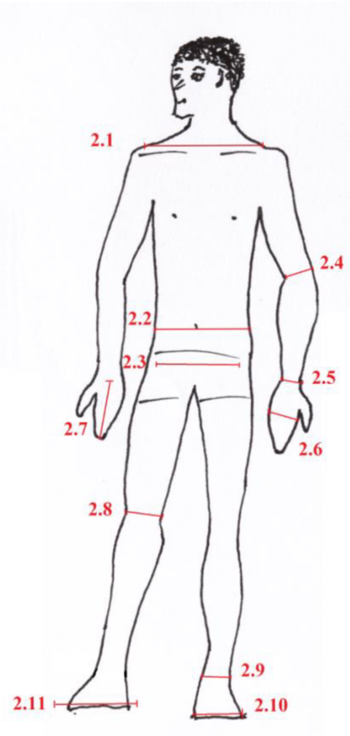

Figure 16: Measured breadths.

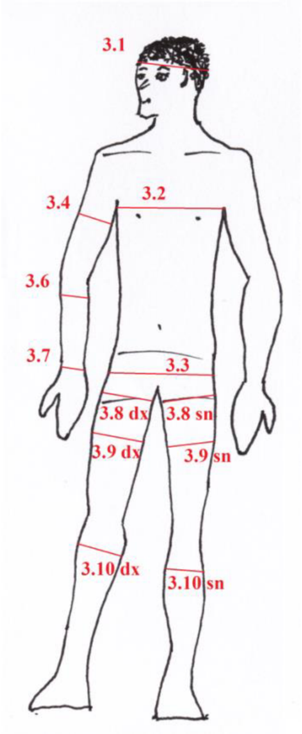

Figure 17: Measured circumferences.

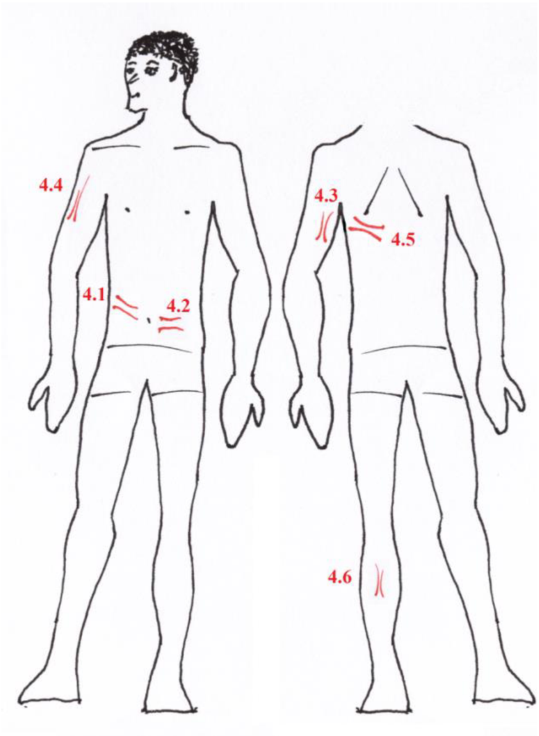

Figure 18: Measured skinfolds. The front and back side of the body.

16.1.3. Subjects

Anthropological Subjects – Scooter Riders

A sample for an anthropological-ergonomic evaluation consisted of 30 scooter riders (further referred to as SR), 24 males and 6 females. As SR were declared the subjects who confirmed active scooter riding in 6 preceding months at least. The sample mostly comprised members of Brno scooter community, scooter racers and some coincidentally met scooter riders. All participants were adult (in age between 23 and 60 years old).

As mentioned, not all taken measurements were used for presented analyses. Some measurements were applied for their relation to ergonomics, the others were applied to be associated with body posture and questionnaire evaluation. A thigh length measurement was added, computed as *trochanterion* and knee height difference. The thigh length was attached to analysis in order to provide the knee action radius linked to handlebar position. What is more, an average frontal hand grip reach length was applied instead of separate right and left hand reach.

Differences between males and females were inquired, and, even though a vast majority of nowadays scooters are produced unisex, the results were based on separated sexes.

Ergonomics-related Scooter Structures

The scooter structures which were compared with the measured SR dimensions comprised footboard length and breadth, handlebar breadth and position and scooter load capacity.

Likewise as in bicycle, the handlebar in scooter is adjustable and its position can be altered by user. The footboard, on the other hand, is a solid structure which originates in its producer' assembly and, therefore, should be constructed for corresponding proportions. The same attention should be payed to the scooter load capacity.

The ergonomic results are provided in general form. No specific scooter model was taken into consideration.

16.2. **Kinematic Recording of Scooter Riding**

The kinematic recording of scooter riding was accomplished in order to better understand and describe individual's motion during scooter riding. The record was accompanied with questionnaire and visual inspection of body posture. Together it was given to assess an influence of scooter riding to body posture.

16.2.1. Method Background

The kinematic recording was made through so called optical tracking system. The recorded objects are provided with reflexive markers (so called trackers) which are scanned by an infrared imaging camera network arranged around.

The cameras emit an infrared radiation which reflexes from the trackers back to cameras' sensors. This process filters unnecessary data and only defines the trackers for a further software processing. Since at least three cameras at once detect one particular tracker, the software can determine coordinates of this tracker in a defined space.

A software OptiTrack (NaturalPoint, Inc.) collects the data from the infrared imaging cameras and processes them further to output data for either visualising (motion capture visualisation) or analysing (Matlab, Excel) purpose.

A workspace was established and the recording was made with a tight cooperation with colleagues from Department of Computer Graphics and Design at Faculty of Informatics, Masaryk University, Brno.

The recording took place in an empty open space at the Faculty of Informatics, which was sufficiently spacious to perform some complete scooter-propelling cycles. During the recording the window blinds were pulled down and a light in a room was dimmed. There were 16 infrared imaging cameras (resolution of 1.3 megapixel, 120 frames per second) arranged around the room to build a cuboid corridor of lasting overlapping cameras monitoring. The diameters of this corridor were 14 x 5 x 3 metres (Figure 19).

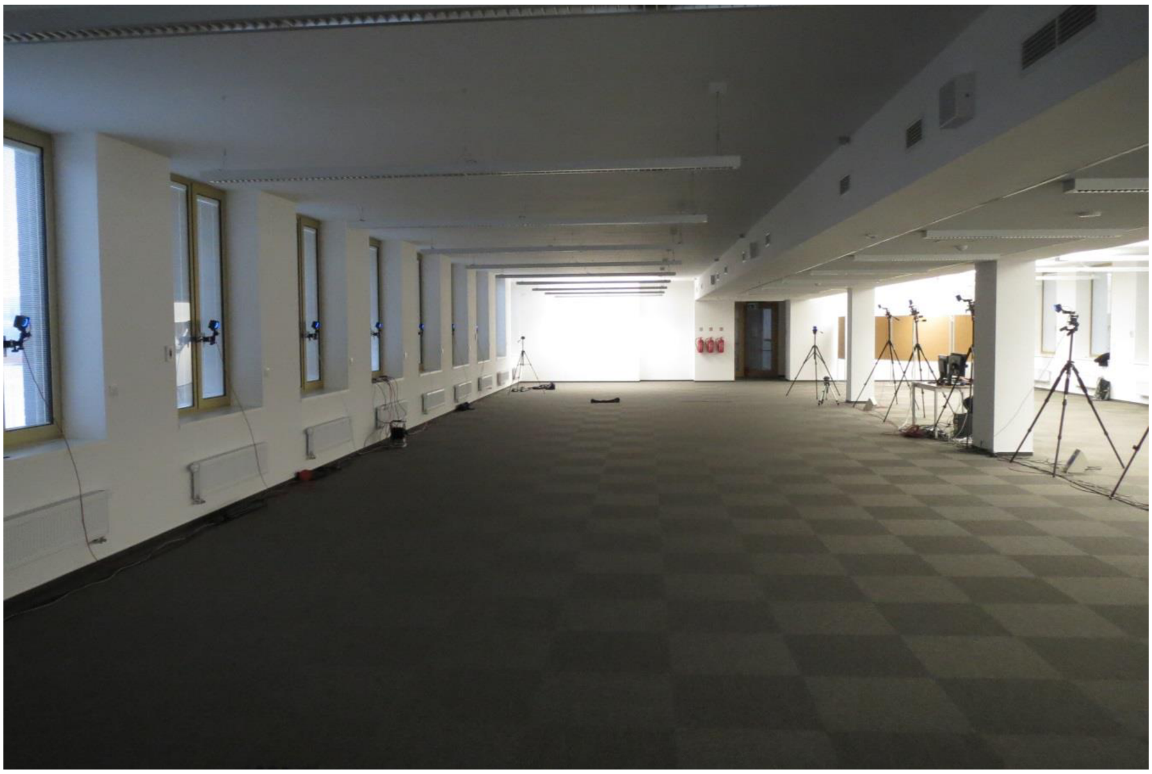

Figure 19: The monitored corridor for recording of scooter ride. There are 8 cameras installed at the windows and 8 cameras installed on the stands (author's archive).

16.2.2. Recording Arrangement

Before the recording a calibration took place, to synchronize the cameras and the software, and to define real dimensions of the monitored corridor. After the calibration the measurement precision was set to 0.25 cm.

The recorded objects are generally of two types, according to their rigidity and perceptibility by the software. The first type, a rigid body, represents a stiff object. The second type, a skeleton, represents a human. Both object types were applied for the recording.

Two rigid bodies were arranged, representing a scooter frame and a handlebar, both acting independently on move. Both rigid bodies were equipped with the trackers placed on the non-exposed spots to maintain the fluent scooter-propelling movement.

Every safety reflexive feature of the scooter was either removed or covered not to disturb the infrared oscillation between the cameras and the trackers. Only one scooter underwent such an arrangement and was given to ride to every participant (Figure 20).

Figure 20: The Kickbike Race Max 20 scooter arranged for the kinematic recording of scooter riding. The reflexive trackers are installed and the scooter safety features are covered (author's archive).

An arrangement of participants was provided using a special stretchable suit. The participants had on disposal two different sizes of the suit. Both suits were equipped with the velcro trackers located on the very specific body positions (mostly the anthropometric landmarks) and recognized by the software forming a virtual skeleton. According to a body dimension, the trackers had to be adjusted for every participant individually. The suit had to be tighten by the multiple velcros, not to sag on the participant, for the trackers sustain their position even during the fast moving. For the recording a full trackers software mode was used, *id est* the mode with 37 trackers over the body, a head and feet included (Figure 21 and Figure 22).

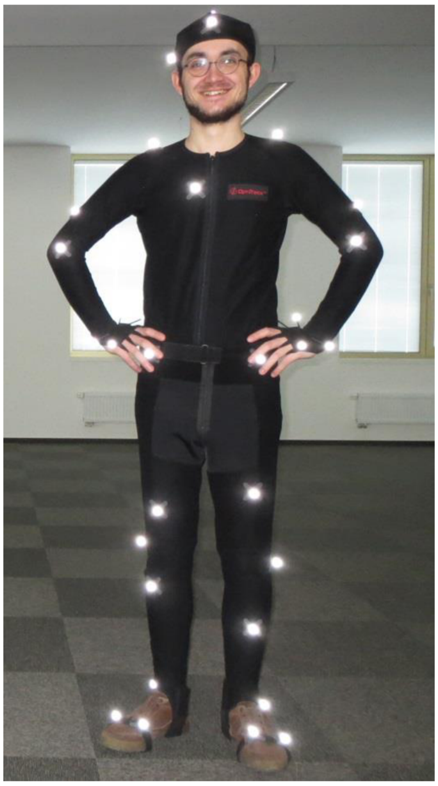

Figure 21: A participant dressed in a suit with trackers (author's archive).

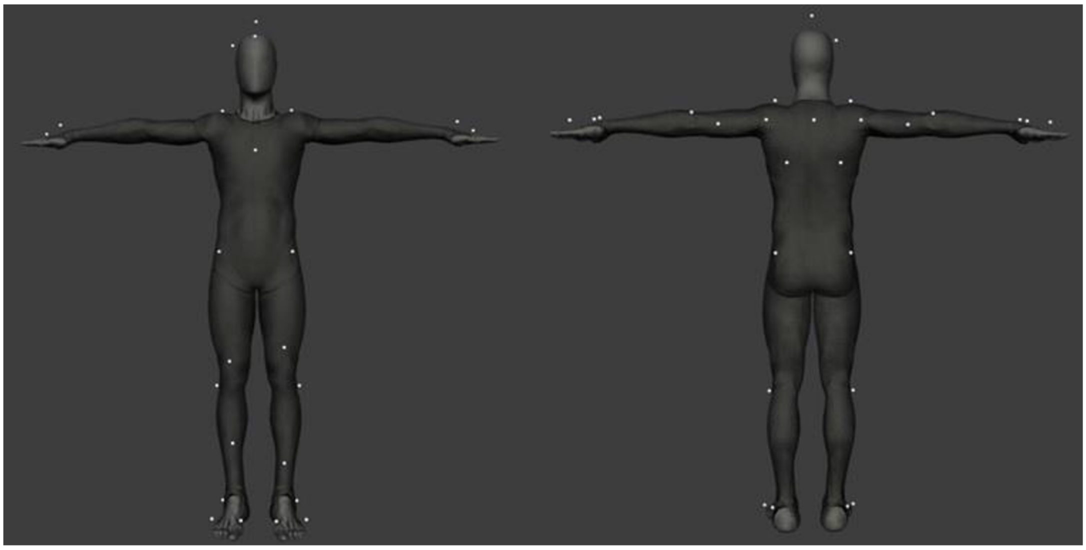

Figure 22: A trackers placement on a body from anterior and posterior view. A grey humanoid figure represents the skeleton estimated by the software, approximated from the trackers position (OptiTrack).

After a participant was arranged to the suit and the trackers were placed to appropriate positions, the participant was provided with the scooter and, to get used to it, was asked to ride it for a while before an actual recording took place. Then, he or she was instructed to enter a monitoring corridor and to ride from one side to another. The ride was supposed to be as natural, comfortable and fluent as possible. His or her ride took place and was recorded three times.

16.2.3. Recording

The kinematic recording of scooter riding took place in four days on February 2015. In the recording 24 SR and 27 non-scooter riders (further referred to as NSR) participated. The SR were the subjects who confirmed the active scooter riding in 6 preceding months at least, while the NSR were the subjects with no or a very little scooter riding experience in last 10 years. For the purpose of an analysis the participants were classified to groups according to experience and sex (in total 15 male SR, 14 male NSR, 9 female SR and 13 female NSR). All participants were adult (in age between 20 and 42 years old).

For the recording a Kickbike Race Max 20 scooter was used (Figure 9 and Figure 20). The reason for using the only one scooter is mostly a difficulty in different trackers and software setting for the other potential scooters, connected with a lack of time. The applied scooter was a big racing scooter (wheel rim sizes 28" and 20"). The reason for using this particular scooter was its accessibility (an author's personal scooter) and also the average-man size handlebar setting (for approximately 177 cm high person). Although an ideal setting would respect the specific body size of every participant, the single scooter creates very similar conditions for every participant, since its setting is close to the average.

An additional important reason for the scooter choice there was a premise that the SR will not change their riding style instantly after riding the unexperienced scooter and the most of important features of the riding style will be preserved. Especially, the movement of lower extremities and lumbar area were expected to be rather conservative for the areas being less influenced by the varying handlebar position. On contrary, the upper extremities were expected to be liable to the handlebar position, especially in the riders varying from average body size. Hence the upper extremities were excluded from the analyses.

No participant complained about an inappropriate scooter size.

16.2.4. Data Selection

For the most relevant data selection both visualising and analysing record types were gathered from the records (for example of the visual and analytic record types see the Appendixes K and J).

Using the visual record of every particular scooter ride the most representative scooter ride was chosen for every participant. The criteria for the selection were the natural and fluent motion of the ride and a high quality of the record without a disturbing noise.

Some NSR had a problem to ride fluently and their every ride differed significantly from each other. In such cases the best quality record was chosen for the further processing.

16.2.5. Data Processing

The further processing of the kinematic recording data took place using the Microsoft Excel 2010 software.

An original analytic data set in one participant consisted of actual XYZ coordinates of a position and a rotation of all the applied trackers, *id est* of 37 trackers placed on the participant, and additional 7 trackers placed on the scooter. Furthermore, the original data set was enriched with some additionally OptiTrack software-computed XYZ coordinates of a position and a rotation of associated joint centres. The position of the XYZ coordinates of the computed joint centres represented the cardinal data source for the further analysis.

Variables Used

During some 7 seconds lasting scooter ride with a frame rate of 120 frames per second the original single-participant data set comprised about 250 columns and 1000 rows. After the reduction process the following analysis-associated joints and computed points coordinates were preserved (Figure 23): Chest (computed centre of a middle of a thoracic spine), LThigh (left hip), LShin (left knee), LFoot (left ankle), RThigh (right hip), RShin (right knee) and RFoot (right ankle).

The original scooter trackers which also were recorded and were expected to provide a scooter speed information, had failed in being representative for their instability in the record. That is why they were dismissed from the analysis.

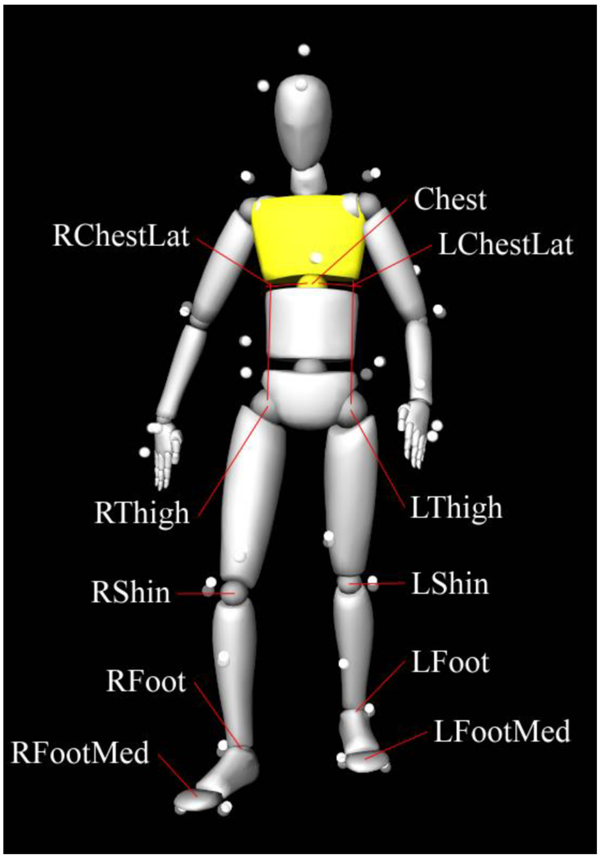

Figure 23: Joints and computed points on a body analysed after the kinematic recording.

The LFootMed and RFootMed points were computed additionally as the 3D average of the coordinates of the original lateral and medial tiptoe tracker in the left and right feet respectively (Figure 23). Ideally, the tiptoe trackers would be placed on dorsum of bare feet. However, since a barefoot scooter riding is not natural, the trackers were placed over the shoes instead in most individuals. Only the individuals wearing the boots were instructed to ride barefoot. This shoe variability might had nevertheless influenced the ankle angle in individuals.

The LChestLat and RChestLat are the lateral (left and right respectively) projections of the Chest point. The vertical (Y) and sagittal (Z) coordinates correspond to the Chest point, the lateral (X) coordinate corresponds to an appropriate Thigh point (Figure 23). The Thigh serves as a source of the X coordinate in order to the LChestLat and RChestLat run through the same plane with associated lower limb joints.

Division to the Scooter-propelling Phases and Cycles

The next step represented the division of the data (XYZ coordinates of the variables) into separate scooter phases and cycles. In most scooter-ride records, at least three complete scooter-riding cycles were recognized. Each complete scooter-riding cycle is defined with a push off phase in its beginning and a kick phase in its end. The four phases are as follows: push off (further referred to as PO), back swing (further referred to as BS), front swing (further referred to as FS) and kick (further referred to as K). The division into phases was based on a position of the FootMed point of a kicking leg (either left or right).

The PO phase evinces a relative stillness in the FootMed of the kicking leg (further referred to as KFootMed). The beginning of the PO is therefore defined as a sudden stability in FootMed on y-axis, clearly distinguishable relative to a rapid volatility in the preceding K phase. Yet, during the PO the Y value slowly decreases and, by the end of the phase, there starts a slow increase again, as the kicking tiptoe is straightening to conduct the push off as such. The end of the PO phase is introduced by a suddenly faster increase of the Y values, as the kicking foot lefts the ground and swings back by means of inertia.

At the very point of disconnection the BS phase begins. The BS end is unequivocally defined as when the KFootMed reaches the high peak values on the y-axis after which the values decrease again. This position corresponds to the maximal back swing after which the kicking leg swings forward by means of inertia.

At the same point the FS phase begins and lasts as the leg swings in front of the body. The y-axis values decrease at first, then increase again following the upward swing of the KFootMed. The end of the phase is unequivocally defined as when the KFootMed reaches the high peak value on the y-axis after which the values decrease again. The position corresponds to the maximal front swing.

At the same point the K phase begins. The K phase evinces a steady decrease in the KFootMed values on the y-axis. Once this steady decrease suddenly ceases, the tiptoe of the kicking leg had landed on the ground again, ending the K phase and ushering the PO phase of the next scooter-propelling cycle.

Measurements

Once the data had been divided into separate sections the following measurements were taken.

Firstly, a lasting of particular phases (PO, BS, FS, K) and particular scooter-propelling cycles were measured.

Secondly, values of the maximal (deepest) squat were measured (further referred to as MaxSq), counted as a difference in the antipolar maxima in the Y (vertical) coordinates of the Chest point within a single scooter-propelling cycle.

Thirdly, a Z coordinate (sagittal) distance between the FootMed of both sides was counted, at the maximal back swing (further referred to as MaxBS) and the maximal front swing (further referred to as MaxFS). Using the y-axis of the KFootMed the maximal values of the BS and FS were found out and their z-axis counterparts were marked out for each scooter-propelling cycle. Thereafter, the sagittal (z-axis) difference between the maximal BS and FS values in the KFootMed and the same-time values of the FootMed of the standing leg (further referred to as SFootMed) was counted for every scooter-propelling cycle.

Because the absolute MaxSq, MaxBS and MaxFS values are body-size dependent, the additional measurement was determined to relativize them. The new measurement represented a distance between the Chest and the SFootMed in the y-axis (the measurement further referred to as Chest-SFootMed), in other words it represented a distance between the middle thoracic point and the middle tiptoe point of the standing leg. The Chest-SFootMed served as a denominator for index values counted out of the MaxSq, MaxBS and MaxFS establishing a new, relative RelMaxSq, RelMaxBS and RelMaxFS values.

The next collected variable was a phase-based occurrence of the MaxSq and maximal straightening (further referred to as MaxStr). The variable expresses what percentage of the particular phase had already elapsed in the very time when the maximal squat or straightening had occurred.

Furthermore, the velocities of the FootMed of both sides were computed for the consecutive frames and were averaged for every scooter-propelling cycle and every phase. The particular velocities v [m/s] were computed according to the formula

$$v = \frac{d}{t}, \tag{10}$$

where d [m] stands for a 3D distance between two consecutive FootMed positions (frames) and t [s] for a time difference between these two positions (frames). The relatively most still point in a body during scooter ride, the SFootMed, was postulated as representing the scooter velocity as such.

Additional measurements were angle-related. The considered angles were enquired in an ankle (3D angle between FootMed – Foot – Shin), knee (3D angle between Foot – Shin – Thigh) and hip (3D angle between Shin – Thigh – ChestLat) for both sides. The angles were computed for every recorded frame.

Finally, an angle shift was computed, representing a difference between two consecutive angle values. The angle shift reports about an angular change in a particular joint, *id est* of what angle the joint shifted between two following frames. The shifts were added for every particular phase. The addition of the constituent values reports about the total angle shift within a single phase, yet does not report about the direction of the shift, since there are some multipolar shifts within certain phases.

Averaging Controversy

The most of measurements were applied for at least three scooter-propelling cycles. These were averaged afterwards. However, as the recording area was dimensioned to only about 14 metres, the most participants were not able to speed up to any sustainable speed. This continuous setting in motion provided no expected information. That is why the averaged data were not deployed.

Each of the three recorded scooter-propelling cycles had its specifics. The first cycle was the very initiation of the motion, therefore it had the lowest speed and, for instance, the deepest squat. The third cycle, on the other hand, had often occurred as late as close to the termination of the recorded area, making some riders to commence braking earlier due to approaching a wall. The second scooter-propelling cycle was selected for the analyses. Although most participants were still speeding up and therefore the cycle was not ideal, I consider it the most representative among what the recording possibilities provided.

16.2.6. Data Correction

In some specimens a minor record noise occurred within the recorded data, being caused by an occasional instability of the skeleton perceived by the cameras, most likely triggered by covering of some trackers with a part of a body. This noise resulted in the misleading artefact outcomes. As such, some data were missing, leaving empty cells, some were temporarily shifted.

The variables were regulated to purify from these artefacts – the averaged variables containing empty data were omitted for the affected phases, the averaged variables with shifted values were omitted if these were distinguishable within the single-phase values, *id est* if the values were significantly higher or smaller among the rest or they proved an abrupt few-frames turn in a course. The interval variables (such as a lasting of whole scooter-propelling cycle or particular phases) were preserved for analyses even in occurrence of the artefacts since these did not emerge in the marginal sections of the interval.

The variables MaxSq occurrence and MaxStr occurrence expressed what percentage of the particular phase had already elapsed in the very time when the maximal squat or straightening had occurred. The MaxSq occurred either during PO or BS, the MaxStr occurred either during FS or K. Originally, there was an interval from 0% to 100% set for every single phase. However, as the variables exceeded the occurrence of a single phase (both variables were occurring during two phases), there was a need to connect the paired phases to make the occurrence clearly visible. For the purpose, the chronologically second of the paired phases was added a cipher 100, simulating the addition of the first phase. The outcome therefore shows an interval of the particular phase. The early phase is margined with 0 and 100, a value 50 represents the 50% of the early phase interval, the later phase is margined with 100 and 200, a value 150 represents the 50% of the later phase interval.

16.2.7. Statistical Testing of Kinematic Recording Findings

The statistical processing took place in Microsoft Excel 2010 and STATISTICA 64 12. The processing was applied on the second scooter-propelling cycle.

A descriptive statistics was processed for the groups SR males, SR females, NSR males and NSR females and comprised median, average, minimum value, maximum value and standard deviation.

Normality of all variables was tested through the Kolmogorov-Smirnov test, independently for males (both SR and NSR) and females (both SR and NSR).

For statistical testing of difference between SR and NSR in groups of males and females there was the two-sampled unpaired Student’s t-test applied.

Statistical testing of the correlation in scooter speed, RelMaxSq and MaxSq occurrence was enquired through the Pearson’s correlation coefficient. The correlation was applied in order to examine a hypothesis that all three variables are based on an experience in scooter riding and they might manifest some communal pattern in presence. Additionally, the significance of the Pearson’s correlation coefficient was computed according to the formula

$$t = \frac{r}{\sqrt{\frac{1-r^2}{n-2}}}, \tag{11}$$

where t represents the testing criterion, r the Pearson's correlation coefficient and n the sample size.

16.3. **Visual Inspection of Body Posture**

The visual inspection of body posture proceeded within both anthropometry and kinematic recording of scooter riding.

Sagittal (lordotic and kyphotic) spinal inclination was evaluated according to a postural stereotype evaluation by Klein, Thomas, Meyer method (Riegerová & Ulbrichová, 1998, p. 137–138). Lateral (scoliotic) spinal inclination was adapted from the silhouettographs (Riegerová & Ulbrichová, 1998, p. 140–143).

The body posture was inspected and evaluated in 29 male SR, 11 female SR, 14 male NSR and 13 female NSR. All participants were adult (in age between 20 and 60 years old).

16.3.1. Klein, Thomas, Meyer Method

The non-metric method of Klein, Thomas, Meyer is used to visually inspect the sagittal inclination of the spine. The method was used for its effectivity in fast estimation. On the contrary, the method is subjective, dependent on experience of an operator. Hence, the comparison among different authors can be misleading (Riegerová & Ulbrichová, 1998, p. 137). The body posture standards of Klein, Thomas, Meyer method recognize four consecutively deteriorating levels varying from a perfect body posture to a flawed body posture. For the particular posture level evaluation see the Appendix H.

16.3.2. Silhouettographs

The silhouettographic estimation of body posture is a non-metric method, therefore fast and effective, however, it can be biased by the subjective evaluation.

The list of silhouettographs for a posture estimation in Riegerová & Ulbrichová (1998, p. 140–143) is complex and contains thirteen visual inspections of particular body areas. The body areas are given the scale images of three consecutively deteriorating alternatives.

For the purpose of the thesis only four silhouettographs were used, associated with neck, shoulder girdle, back and pelvic posture.

For the particular silhouettographs evaluation see the Appendix I.

16.3.3. Statistical Testing of Visual Inspection of Body Posture

The statistical comparing of selected variables in SR and NSR took place in Microsoft Excel 2010, STATISTICA 64 12 and Chi-Square Test Calculator web application (socscistatistics.com).

Normality of variables was not expected due to the ordinal character of data, with only single entry corresponding to the physiological state.

For statistical testing of associations in body posture among SR and NSR the chi-square test of association for 2 x 2 contingency table was used, separately for males and females.

16.4. **Questionnaire**

After the anthropometry, kinematic recording of scooter riding and the spinal curvature inspection, the questionnaire was given to the participants. The questionnaire served as a complementary source of data for ergonomics and body posture evaluation, as well as an original source of additional descriptive findings related to scooter preferences among the

SR. A state of health of NSR was enquired by an alternative questionnaire provided only to the control sample.

All measurements were expected to be applied to Czech or Slovak participants, hence the questionnaire was written in Czech language. For the both original Czech and translated English versions of the questionnaires see the Appendixes D, E, F and G.

The number of participants for particular inquiry differs according to an associated variable. All participants were adult (age of SR was 23 – 60, while age of NSR was 20 – 32).

16.4.1. Selected Inquires

Back and Neck Ache

A relation between two groups (SR and NSR) and ache in areas listed in the questionnaire was surveyed. The sexes were evaluated independently.

The ache in back and neck only were of further concern, for the ache among the other inquired areas evinced low occurrence.

The sample for the back and neck ache evaluation comprised 29 male SR, 14 male NSR, 11 female SR and 13 female NSR.

Skiers vs Athletes

Among the scooter riders there is a belief that many of the riders are split into two groups – the "skiers" and the "athletes". The division is provided by the rider's background sport which modifies the riding style of its possessor. The "skiers" are believed to perform skiing as the background sport, which causes the scooter being distinctively propelled by a deep and long squat that prolongs the propelling PO. The "athletes", in contrast, are believed to practice athletic disciplines connected rather to a plantar flexion, which habituates the scooter propelling in distinctively swift kicking ankle angle shift and consequent faster transmission of the energy.

Multiple different variables in SR were combined and compared, in order to scrutinize this hypothesis. The questionnaire-ascertained background sport (identified as primarily thighs-stimulating, primarily calves-stimulating or other) was associated with the RelMaxSq, kicking ankle angle shift, average circumference in gluteal and medial thigh and calf and with the PO duration.

The sample for evaluation of correlation in background sport to various variables comprised either 23 or 30 SR; the sexes were evaluated together.

Preferred Leg Association

In the questionnaire, the SR were also asked for the preferred standing leg. If the riders were not used to regular leg switch, the more developed musculature in a standing thigh (trained through performing squats) and a kicking calf (trained through performing push offs) would be expected.

The circumferences of the gluteal and medial thigh and the calf were measured during the anthropometry. A side of larger circumference in three variables was compared to the preferred leg side.

Additional Findings

Finally, the separated answers from the questionnaire were extracted and presented in form of pie charts. Specifically, the following topics were of interest: scooter types distribution, scooter brands distribution, hours per week spend on scooter, preferred track length, preferred standing leg, leg switch frequency, scooter-related injuries and back ache.

Additionally, I inquired what the SR like and dislike on their scooters and whether they train for scooter riding.

16.4.2. Statistical Testing of Selected Questionnaire Inquiries

All questionnaire-related statistical processing took place in Microsoft Excel 2010 and STATISTICA 64 12.

Normality of variables was not expected due to either ordinal character of data, with only single entry corresponding to the physiological state, or alternative nominal character of data.

For statistical testing of association in the back and neck ache and the preferred leg a chi-square test of association for 2 x 2 contingency table was used, separately for males and females (back and neck ache case), and for both sexes (preferred leg case).

For statistical testing of correlations between “skiers” and “athletes” SR and their background sport a Spearman’s rank correlation coefficient was applied.

17. Results

17.1. Anthropometry Results – Descriptive Statistics

The surveyed sample consisted of 24 males and 6 females.

The descriptive statistics comprised median, average, minimum and maximum value, lower (25%) and upper (75%) quartile and standard deviation. The statistics of separated sexes are presented in the Table 3 and Table 4, while the statistics of both sexes are presented in the Table 5.

Table 3: Anthropometry, descriptive statistics, males. The dimensional values are in kilograms for body weight and in centimetres for the remaining variables.

Males							
Measurement	Median	Average	Minimum	Maximum	Lower quartile	Upper quartile	Standard deviation
1.1 Standing height	179.2	179.3	164.9	190.3	175.5	184.6	6.3957
Thigh length	40.0	40.5	33.3	47.4	38.5	42.6	3.0897
Average frontal hand grip reach	72.9	72.1	62.2	80.3	69.2	74.8	4.4265
2.1 Biacromial breadth	37.9	37.9	30.3	47.0	35.0	40.5	3.8106
2.10 Foot breadth	10.4	10.4	9.1	11.7	9.9	10.8	0.6438
2.11 Foot length	27.4	27.1	24.0	29.5	26.3	27.8	1.3086
5.1 Body weight	82.7	81.8	60.5	104.6	71.5	92.1	12.5841

Table 4: Anthropometry, descriptive statistics, females. The dimensional values are in kilograms for body weight and in centimetres for the remaining variables.

Females							
Measurement	Median	Average	Minimum	Maximum	Lower quartile	Upper quartile	Standard deviation
1.1 Standing height	167.3	167.9	163.0	176.3	164.0	169.6	4.8557
Thigh length	39.5	39.2	37.1	41.2	38.0	40.1	1.4959
Average frontal hand grip reach	65.3	66.3	63.7	71.3	64.4	67.9	2.8537
2.1 Biacromial breadth	35.6	35.4	31.7	37.5	34.6	37.2	2.1040
2.10 Foot breadth	9.5	9.5	8.4	10.5	9.0	10.3	0.7935
2.11 Foot length	24.8	24.8	23.8	26.4	23.9	25.3	0.9688
5.1 Body weight	60.7	64.5	44.7	101.5	56.2	63.5	19.3575

Table 5: Anthropometry, descriptive statistics, both sexes. The dimensional values are in kilograms for body weight and in centimetres for the remaining variables.

Both Sexes							
Measurement	Median	Average	Minimum	Maximum	Lower quartile	Upper quartile	Standard deviation
1.1 Standing height	177.6	177.0	163.0	190.3	169.9	182.5	7.6077
Thigh length	39.9	40.2	33.3	47.4	38.4	41.7	2.8678
Average frontal hand grip reach	71.3	70.9	62.2	80.3	66.3	74.1	4.7392
2.1 Biacromial breadth	37.1	37.4	30.3	47.0	35.0	39.2	3.6475
2.10 Foot breadth	10.3	10.2	8.4	11.7	9.7	10.7	0.7494
2.11 Foot length	27.2	26.7	23.8	29.5	25.5	27.7	1.5457
5.1 Body weight	78.8	78.3	44.7	104.6	64.6	89.6	15.4773

17.2. **Kinematic Recording of Scooter Riding Results**

17.2.1. Descriptive Statistics

The surveyed sample consisted of four groups: 15 male SR, 14 male NSR, 9 female SR and 13 female NSR.

The descriptive statistics comprised the median, average, minimum and maximum value and standard deviation. The particular results are presented in the Table 6 – Table 9.

A distinctive finding valid throughout the whole sample there was the FS duration about 0.5 s, approximately twice longer than the other scooter-propelling phases, which lasted comparably about 0.2 s. The RelMaxBS proved itself as about two-third longer then its counterpart, the RelMaxFS. The speed specifics of both kicking and standing feet are presented in a following sub-chapter.

Table 6: Kinematic recording, descriptive statistics, male SR. The dimensional values are in seconds for duration variables, in metres for maximal variables and in metres per second for speed variables.

Male Scooter Riders						
Variable	Number of specimen	Median	Average	Minimum	Maximum	Standard deviation
PO duration	15	0.21667	0.21556	0.16667	0.25000	0.02268
BS duration	15	0.21667	0.21722	0.13333	0.35833	0.05460
FS duration	14	0.65833	0.69048	0.52500	0.90000	0.12527
K duration	13	0.21667	0.22628	0.10833	0.36667	0.07838
Cycle duration	14	1.31250	1.30952	0.86667	1.72500	0.21816
RelMaxSq	15	0.14086	0.16404	0.06941	0.24802	0.05064
RelMaxFS	14	0.46940	0.46327	0.13505	0.71843	0.14634
RelMaxBS	15	0.73234	0.76438	0.58798	1.03890	0.12870
KFootMed, PO speed	15	0.28787	0.33489	0.20559	0.59630	0.11780
KFootMed, BS speed	15	3.09462	3.32376	2.46976	4.96020	0.69284
KFootMed, FS speed	14	5.18685	5.23713	3.89311	6.69402	0.68953
KFootMed, K speed	14	2.16620	2.17819	1.38651	2.89400	0.46021
SFootMed, PO speed	15	3.88950	4.01678	2.97356	5.15673	0.66181
SFootMed, BS speed	14	3.50634	3.50606	2.62608	4.42471	0.50836
SFootMed, FS speed	14	3.09999	3.20543	2.52299	4.28780	0.45762
SFootMed, K speed	14	3.67213	3.80617	2.87885	4.66027	0.49261

Table 7: Kinematic recording, descriptive statistics, female SR. The dimensional values are in seconds for duration variables, in metres for maximal variables and in metres per second for speed variables.

Female Scooter Riders						
Variable	Number of specimen	Median	Average	Minimum	Maximum	Standard deviation
PO duration	9	0.23333	0.23148	0.02191	0.28333	0.04035
BS duration	9	0.20000	0.23056	0.05275	0.35000	0.07360
FS duration	6	0.57083	0.57083	0.12071	0.68333	0.09110
K duration	6	0.21250	0.21111	0.07531	0.24167	0.02670
Cycle duration	6	1.22917	1.23750	0.21023	1.46667	0.13711
RelMaxSq	8	0.15568	0.16341	0.12434	0.22457	0.03693
RelMaxFS	8	0.45030	0.48820	0.11380	0.71319	0.12887
RelMaxBS	9	0.75468	0.75147	0.56308	0.94875	0.11094
KFootMed, PO speed	9	0.30892	0.29617	0.18580	0.37833	0.06561
KFootMed, BS speed	9	3.03154	3.03356	0.63937	3.73156	0.38180
KFootMed, FS speed	8	5.00027	5.02839	0.48987	5.53269	0.39608
KFootMed, K speed	8	1.72883	1.96228	0.44098	2.73118	0.42883
SFootMed, PO speed	9	3.58942	3.55119	0.47469	4.04593	0.32180
SFootMed, BS speed	9	3.07958	3.04783	2.58253	3.53053	0.30278
SFootMed, FS speed	8	2.77757	2.79102	2.37947	3.32584	0.33975
SFootMed, K speed	8	3.36733	3.44759	2.97194	4.30457	0.39944

Table 8: Kinematic recording, descriptive statistics, male NSR. The dimensional values are in seconds for duration variables, in metres for maximal variables and in metres per second for speed variables.

Male Non-scooter Riders						
Variable	Number of specimen	Median	Average	Minimum	Maximum	Standard deviation
PO duration	13	0.23333	0.22308	0.14167	0.27500	0.03230
BS duration	13	0.23333	0.24103	0.13333	0.33333	0.06423
FS duration	11	0.55833	0.57500	0.31667	1.04167	0.21874
K duration	10	0.12500	0.18500	0.10000	0.39167	0.10547
Cycle duration	11	1.26667	1.22803	0.80000	1.99167	0.35078
RelMaxSq	13	0.13552	0.13199	0.02248	0.25903	0.06812
RelMaxFS	13	0.31639	0.34378	0.25115	0.56490	0.09388
RelMaxBS	14	0.66384	0.68336	0.54381	0.97793	0.12004
KFootMed, PO speed	13	0.23839	0.26216	0.12048	0.51176	0.10310
KFootMed, BS speed	14	2.99043	2.98891	1.58840	4.57521	0.93579
KFootMed, FS speed	13	4.87469	4.99008	3.62734	7.11900	1.10090
KFootMed, K speed	13	1.69856	1.85782	1.13055	2.95705	0.49207
SFootMed, PO speed	13	3.46512	3.39134	2.31659	4.70051	0.64120
SFootMed, BS speed	14	2.99998	3.15694	2.32129	4.65488	0.67865
SFootMed, FS speed	13	2.75891	2.80129	2.19856	4.08550	0.54871
SFootMed, K speed	13	3.29361	3.20814	2.32783	4.49919	0.66809

Table 9: Kinematic recording, descriptive statistics, female NSR. The dimensional values are in seconds for duration variables, in metres for maximal variables and in metres per second for speed variables.

Female Non-scooter Riders						
Variable	Number of specimen	Median	Average	Minimum	Maximum	Standard deviation
PO duration	13	0.21667	0.21410	0.12500	0.27500	0.03733
BS duration	13	0.20000	0.20192	0.14167	0.26667	0.03619
FS duration	11	0.48333	0.52955	0.38333	0.77500	0.13403
K duration	11	0.16667	0.16818	0.09167	0.30000	0.05735
Cycle duration	12	1.04167	1.10000	0.84167	1.48333	0.18302
RelMaxSq	12	0.06877	0.08140	0.02763	0.18127	0.04288
RelMaxFS	11	0.30645	0.33423	0.21973	0.51390	0.09218
RelMaxBS	13	0.52758	0.56089	0.41182	0.83861	0.11358
KFootMed, PO speed	12	0.25742	0.30126	0.18272	0.56194	0.10390
KFootMed, BS speed	13	2.32300	2.39806	1.90186	3.26985	0.38647
KFootMed, FS speed	11	4.06874	4.19920	3.43934	5.11280	0.56728
KFootMed, K speed	10	1.60845	1.58936	1.16784	2.08142	0.25558
SFootMed, PO speed	12	2.66939	2.85197	2.35170	3.68146	0.46544
SFootMed, BS speed	13	2.51810	2.64205	2.23470	3.24058	0.31622
SFootMed, FS speed	11	2.34691	2.48414	2.14634	3.08810	0.31584
SFootMed, K speed	10	2.75439	2.78286	2.35568	3.38356	0.39158

Speeds

The averaged speeds of the kicking and standing foot (KFootMed and SFootMed respectively) for the particular groups during the second scooter-propelling cycle are presented in the Chart 1 and Chart 2. Although the absolute speed values differ between groups, the general speed ratios set a certain pattern.

The KFootMed attains its highest speed during the FS phase. The second fastest it is during the BS phase, the third fastest it is during the K phase. The lowest speed it has during the PO phase.

The SFootMed (representing the scooter) attains its highest speed during the PO phase. The second fastest it is during the K phase, the third fastest it is during the BS phase. The lowest speed it has during the FS phase.

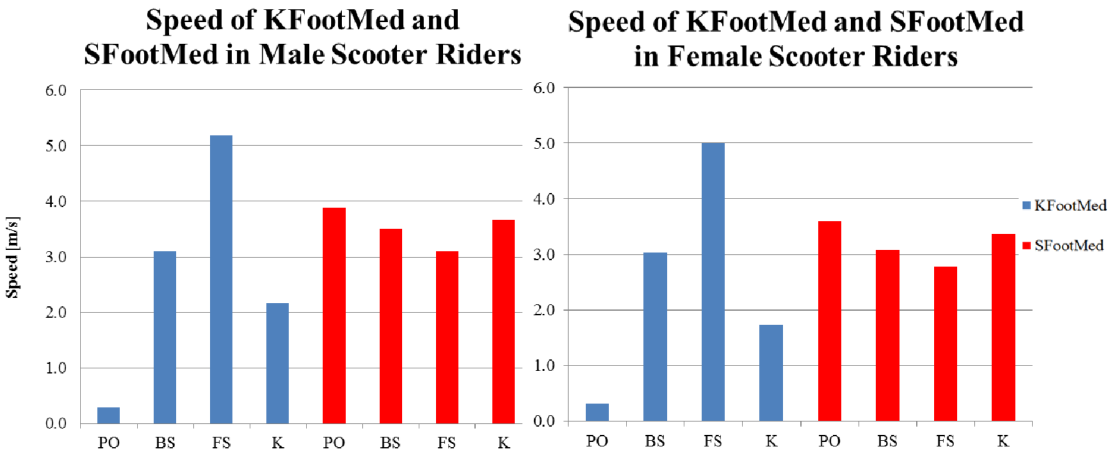

Chart 1: Speed of the KFootMed and SFootMed in male and female SR for particular phases. The KFootMed (blue columns) represents the kicking foot speed, the SFootMed (red columns) represents the standing foot speed (approximated scooter speed).

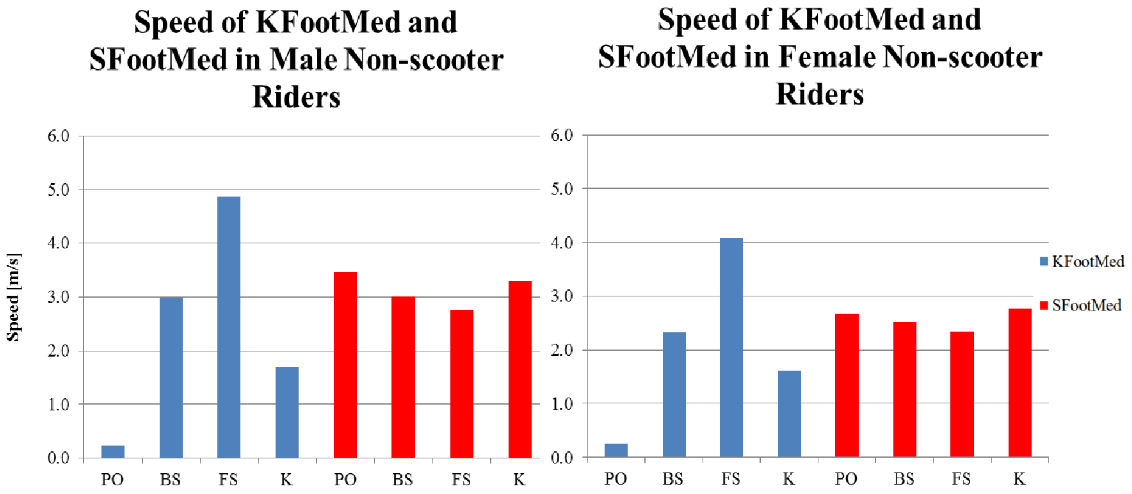

Chart 2: Speed of the KFootMed and SFootMed in male and female NSR for particular phases. The KFootMed (blue columns) represents the kicking foot speed, the SFootMed (red columns) represents the standing foot speed (approximated scooter speed).

17.2.2. Maximal Squat and Straightening Occurrence

The values of the MaxSq occurrence within particular groups are presented in the Chart 3 – Chart 4. The values of the MaxStr occurrence within particular groups are presented in the Chart 5 – Chart 6.

The MaxSq occurred mostly between the last 20% of the PO and the first 20% of the BS. The MaxStr occurred mostly during the second half of the FS and the first 20% of the K.

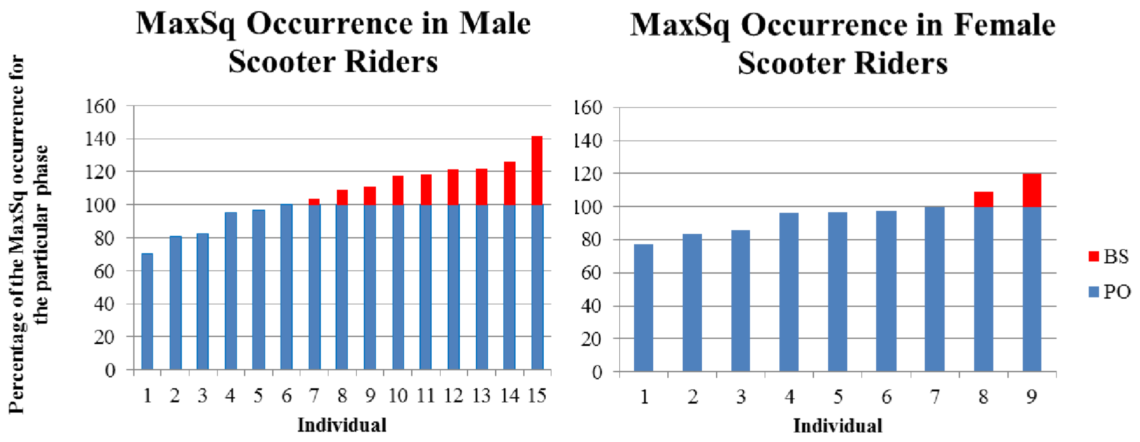

Chart 3: MaxSq occurrence in male and female SR. The values between 0 and 100 represent the percentage in first scooter-propelling cycle when the MaxSq was occurring (PO) and the values between 100 and 200 represent the percentage in subsequent cycle when the MaxSq was occurring (BS).

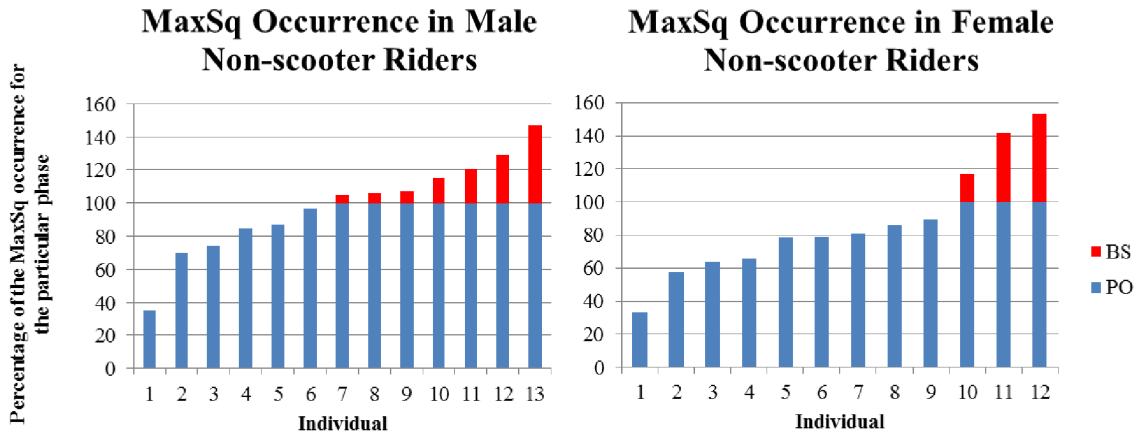

Chart 4: MaxSq occurrence in male and female NSR. The values between 0 and 100 represent the percentage in first scooter-propelling cycle when the MaxSq was occurring (PO) and the values between 100 and 200 represent the percentage in subsequent cycle when the MaxSq was occurring (BS).

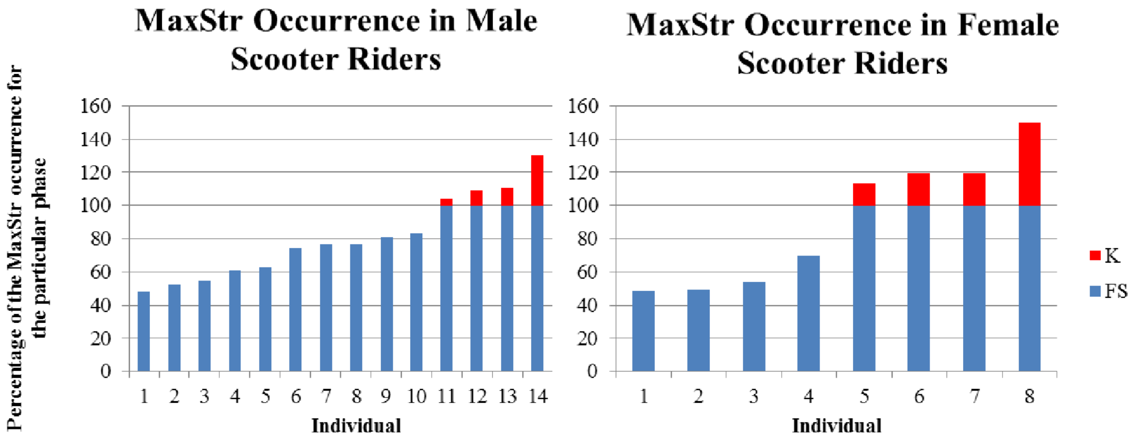

Chart 5: MaxStr occurrence in male and female SR. The values between 0 and 100 represent the percentage in first scooter-propelling cycle when the MaxStr was occurring (K) and the values between 100 and 200 represent the percentage in subsequent cycle when the MaxStr was occurring (FS).

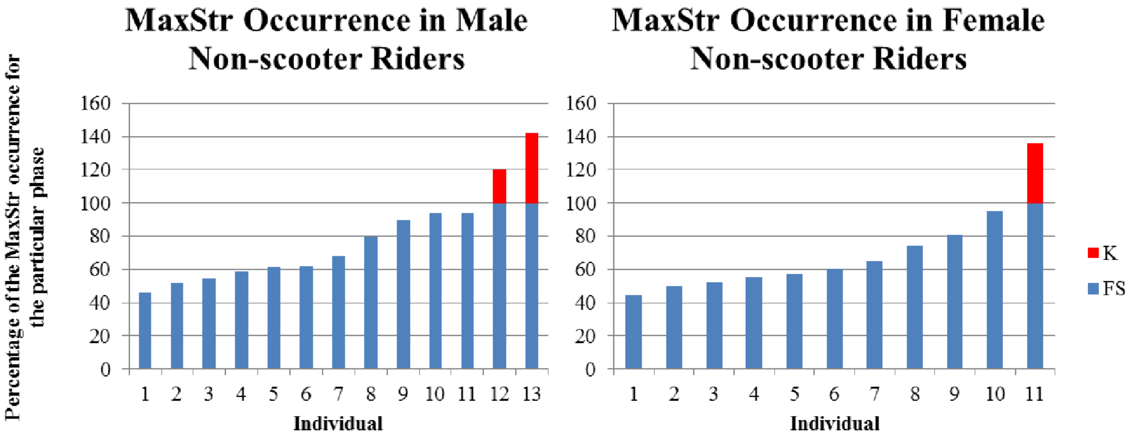

Chart 6: MaxStr occurrence in male and female NSR. The values between 0 and 100 represent the percentage in first scooter-propelling cycle when the MaxStr was occurring (K) and the values between 100 and 200 represent the percentage in subsequent cycle when the MaxStr was occurring (FS).

17.2.3. Angle Shift

The angle shift variable evinced a big variability, both in general and through the particular groups. The angle shift values for particular joints within the groups are presented in the Table 10.

A cursory check proved that in most individuals the standing ankle and knee evinced a smaller angle shift than kicking ankle and knee. The hip joint evinced a very similar angle shift in both legs.

In a standing ankle there was the lowest angle shift in general through all examined joints. The highest angle shift in the ankle occurred during the FS.

On the other hand, a kicking ankle was one of the most active joints and evinced the high angle shift through the scooter-propelling cycle. The highest shift occurred during the PO, the lowest shift occurred during the K.

In a standing knee the highest angle shift occurred during the PO, while the lowest shift occurred during the K.

A hip joint angle shift in both legs evinced the most differences between SR and NSR according to t-test. For the high variability of the hip angle shift it is not favourable to make assumptions, however, the FS and PO in the standing hip showed quite high angle shift compared to the other phases in both groups.

Table 10: Angle shift in ankle, knee and hip joint in kicking and standing leg within the particular groups. The values are in degrees; some data are missing due to the noise presence during the recording, while some other data were dismissed in the course of the data correction.

	Angle shift, kicking ankle				Angle shift, standing ankle				Angle shift, kicking knee				Angle shift, standing knee				Angle shift, kicking hip				Angle shift, standing hip			
Specimen	PO	BS	FS	K	PO	BS	FS	K	PO	BS	FS	K	PO	BS	FS	K	PO	BS	FS	K	PO	BS	FS	K
Male SR																								
1	50.8945	33.8706	32.5948		5.2923	4.8280	16.7706		46.1623	23.1555	23.1621		23.9517	18.1513	55.8686		36.1757	18.4144	65.6073		44.6479	12.2422	64.0818	
3	84.6777	26.9164	44.7413	23.7203	8.1384	2.7467	23.2794	19.5823	61.9047	41.1640	81.1570	40.9518	37.5918	15.8032	66.0521	37.5643	43.2858	15.6515	47.6583	13.6532	33.7933	16.3637	67.4080	43.1597
4	74.1378		31.5464	3.5564	7.8452	9.3988	10.0697	4.1893	46.8282	42.4102	48.9364	12.8723	27.4609	24.3039	24.2077	12.8453	35.2087	23.0461	33.9197	3.1117	27.7590	14.9504	20.3307	12.0723
5	90.7017	23.7918	41.8224	14.5937	9.8332	3.1949	15.6536	12.7702	46.9736	21.3639	35.6184	19.0695	33.2737	7.8639	66.5997	31.4716	41.9871	14.9071	66.0483	21.5906	53.0010	14.3247	74.2477	34.8009
8		39.6082				2.8877				36.1683				9.2727		40.4998		15.7658				11.8688		
10	51.9431	16.6202	54.0494	7.7414	5.6844	5.3197	13.6314	9.7884	42.5398	21.6205	23.2832	18.3806	29.4745	6.2974	63.9488	31.7628	37.8342	9.3043	45.3815	7.8953	30.5837	6.9494	63.7457	25.5600
11	34.0206	34.5098	31.7213	5.4411	4.5866	5.8595	20.2848	5.8105	15.4035	15.4200	31.6989	15.0112	25.5994	14.9928	54.1396	20.7304	22.7808	9.3909	32.6769	2.0215	25.6536	6.9816	53.6584	15.6695
12	99.2995	25.9224	46.9507	11.3950	12.4689		38.6177	10.2161	63.5043	22.4873	22.9369	20.2679	46.8828	17.7573	64.0487	21.9860	48.0345	6.9686	40.4414	7.2082	49.6719	19.4974	66.4472	18.5500
13	53.2197	22.2576	34.4495	12.2577	7.7403	11.8279	21.6889	5.0716	29.6478	32.1004	41.5625	22.9806	17.0862	23.9281	36.7658	11.5635	33.9750	6.9833	35.2295	6.5474	21.4240	18.6236	32.8454	13.7799
14	59.2537		30.0189	8.4810	8.4731	8.3240	14.8150	5.3414	23.5016		20.2251	6.7036	18.7771	16.0206	35.7451	12.3738	43.7073	10.9971	45.5727	9.1851	20.8783	13.8212	28.6555	11.1578
32	44.8236	24.4660	27.6563	18.2501	9.2106	2.0019	16.1806	5.6983	25.9400	11.2171	24.6951	14.3081	33.4932	6.4548	48.4465	13.5159	23.7080	15.9452	53.6506	19.9831	32.0668	6.6823	55.9835	22.8357
34	81.4132	15.3844	51.8972	23.2771			18.4150	8.7606	37.5021	31.0693	45.4417	15.5024	34.4116	13.6244	42.1025	26.0397	30.8211	6.5423	36.9353	19.9982	48.5438	11.0381	82.5740	47.9927
35	40.9826	44.9187	53.1411	16.8266	6.5504	9.5988	16.8636	17.5586	17.6972	51.7381	69.5566	20.7728	24.7950	14.1210	43.3819	36.4324	26.3617	16.9151	39.4279	14.3745	31.5284	16.4129	43.7416	29.1675
36	93.3483	31.2709			12.2254				44.3402	98.9020			45.7122				53.5339	44.4694			37.9381			
39	41.6008		39.8718	9.8882	3.7704	9.0700	12.2749	4.4355	9.9153	45.6326	85.3189	15.6872	19.5012	17.6858	23.0485	8.2877	26.2682	13.9201	42.1786	14.3945	26.0575	18.5012	28.0192	12.0769
Female SR																								
2	71.7148		44.9289	17.8749			9.5369	8.6668	58.5959		106.7407	16.0140	49.4758	42.2785	24.1565	24.5839	36.3891	16.8864	40.6330	8.3920	57.3780	33.2656	40.7884	18.2861
6	60.2091	34.5261	49.0179	22.7768	6.4477	3.8176	20.3786	9.1733	47.8872	35.1968	48.5373	29.1898	34.1874	11.3610	64.0958	37.1635	31.4258	17.9917	30.4044	6.5439	37.4064	12.0323	60.2527	36.4263
7	90.3168	15.5739			19.3940	4.1448			48.9393	31.1711			42.9818	14.4862			48.3969	12.3038			48.2389	14.7309		
9	51.3928	27.1802	48.6122	12.3663		6.8264	33.6002	24.8292	37.1203	16.9065	70.3485	53.9166		20.5958	67.8193	39.3700	40.9652	12.0134	73.4419	24.8515		16.0157	67.4287	47.0373
31	88.4865	18.0688			14.1225	3.1521			42.6520	24.5135			38.4617	13.8727			38.7466	7.8041			47.3233	10.9589		
33	58.8908	26.3590			4.2310	4.3151			36.8004	41.3732			21.3633	19.8189			38.6981	18.1041			18.7793	20.4141		
37	71.1270	32.5904	37.4335	13.0910	10.8638	5.3107	15.8814	11.4068	30.1641	25.6362	49.1043	19.0288	33.2965	17.3345	39.9193	23.0021	26.6361	11.8022	22.8797	8.5662	28.6904	8.7111	38.2726	20.2387
38	72.3898	39.9747	46.8966	6.6649	7.1222	4.3076	8.7188	3.2992	35.0326	39.4846	63.1752	23.5116	30.0709	14.7562	28.3896	8.9474	35.6025	11.6737	34.0641	5.3553	31.0225	17.2528	28.5358	13.2605
40	59.8012	21.4980	43.6816	8.9930	6.7040	6.7179	12.7187	2.9826	46.0081	48.4211	85.0534	16.8946	20.6897	21.9485	18.7998	6.5320	37.1259	17.8267	48.3077	6.8596	32.7199	23.3507	25.0347	15.9492
Male NSR																								
100	70.4863	24.2060	43.0916	9.2607	5.0080	4.6230	8.0847	1.5816	47.5852	46.1208	63.8683	20.8514	15.4200	12.2256	6.5193	10.8229	71.3835	25.2409		5.9619	33.2122	13.1798	24.2881	3.1015
103	64.1649	37.3209	37.6799	15.1785	4.2520	1.7169	28.7245	12.0676	57.8022	24.4272	43.0598	14.2819	32.6083	18.5999	81.3730	38.7113	36.3409	14.2199	19.9045	7.2111	37.3410	17.4122	54.0402	17.1420
104	13.7941	27.2325	38.2869		3.3059	2.9874	4.1110	0.9437	11.5436	27.7534	48.1162	10.2221	8.9432	5.7252	7.1300	0.5628	26.3175	15.9842	34.7668	3.4054	11.7424	7.3620	7.9389	0.9436
106	46.3814	32.9918	33.9335	8.8427	7.6497	11.6520	11.8888	5.1103	32.5586	72.8777	88.3508	28.6806	21.9903	29.6192	30.4629	14.3480	39.8351	20.3353	33.7722	8.3564	22.3821	19.7551	28.7112	10.7353
107	47.7792		46.7391	15.9191	9.9330	10.5727	9.1740	7.9655	24.2247	29.9515	22.7025	12.0537	18.6877	15.5953	16.3982	10.6029	28.1097	12.8578	48.3456	17.4998	21.4425	13.0466	20.4139	10.2299
109	54.8705	32.9137	15.6649	4.1713			12.9401	4.9748	36.3107	49.6380	72.6025	13.7459	32.5472	12.4005	23.8589	10.4694	39.3663	14.8652	27.7598	4.2544	23.6786	9.1674	24.9209	12.6472
110	71.4458	53.1649			12.1254	4.7528			58.0867	87.3584			53.1977	24.4466			48.0972	37.4995			38.8344	21.3008		
111	59.1999	49.0081			8.7468	6.0696			41.4334	43.5653			41.2774	24.4935			36.7470	21.1003			32.6427	17.3219		
115																								
118	30.7126	21.4625			4.1497	7.0357	8.5653		53.1065	48.4074	55.9774		20.0481	22.6183	18.7617		55.5467	13.2454	51.4684		21.4888	21.6480	18.4685	
120	81.7086	24.8412		9.3505	10.4855	3.5317	13.2984	4.1628	68.4544	32.9597	96.6093		57.0793	5.4678	52.7379	12.6594	34.4602	17.5986	70.1071	9.4480	62.1483	13.1790	61.7428	7.0122
123	44.2513	44.5534	47.6420	11.1160	4.3644	4.4384	10.9279	3.7692	30.7484	56.4390	73.7063	31.4287	16.3100	13.6659	22.5258	10.9169	35.8070	11.5371	35.3586	6.7867	15.6827	7.6973	18.4873	6.7272
124	46.5915			12.9335	3.8292	10.0441	16.4393	8.7583	15.4432	24.4028	42.9127	8.8560	22.9129	28.4575	42.1781	27.9630	22.6514	8.3932	45.1980	18.8761	32.7470	16.1746	50.9442	18.3910
126	32.5687	37.6731	43.5341	6.4226	9.9670	11.0118	16.2106	2.6363	15.1495	25.9048	42.1462	7.4207	21.9726	16.2437	21.3756	7.0697	21.7277	6.8616	28.2237	3.3337	24.9205	13.1210	33.6661	6.1611
Female NSR																								
101	26.3776	36.8552	23.9223	10.0915	4.2493	0.7618	4.4543	2.5437	10.6311	30.6969	51.6061	4.9680	7.5446	4.3498	6.1195	9.4639	20.2097	6.5313	15.8681	7.7606	9.1649	2.7203	9.7923	6.4328
102	34.6380	32.7423	15.8480	9.0245	5.4512	3.1750	5.7431		11.5511	12.5465	37.6640	22.7475	10.9992	12.6440	12.1016		23.7563	6.7915	27.2969	4.1149	15.0646	12.0188	13.3078	11.1520
105	55.0610	29.1635	54.2226	11.7640	7.5833	2.9823	8.8739	4.8733	39.4042	17.7314	50.0389	11.4610	20.4011	6.3183	19.2696	6.6080	26.0734	9.5474	34.3228	4.2222	17.7206	12.4090	20.2288	6.4478
108	41.3755	55.6203	51.9200	10.9306	4.5686	5.6909	9.9497	6.1095	23.8695	58.0397	76.3843	31.6440	9.5413	16.9834	24.1766	10.7104	22.1879	16.4436	36.1008	10.5948	16.0081	9.1571	26.5884	6.1451
112	64.6485	35.4928	52.0329	15.3415				9.4326	59.9101	33.3207	48.2780	41.0449	27.7162	15.9143	36.7812	23.6661		13.1359	43.6702	7.6113		11.8323	43.7341	28.4928
113		34.2031	64.1288	12.0770		11.1661		10.4808	20.8202	29.1301	12.9671	24.1270	11.8167	31.8359		32.1513	31.6401	5.1027	37.6687	10.0717	29.7983	6.9786	39.8702	18.8093
114	82.1494	26.0254			7.5759	6.5748			39.5031	23.5696			31.4651	27.5305			26.7101	8.1415			27.2159	20.5209		
116	32.9322	36.9456	28.1494	9.0569	5.4933	2.2182	8.6211	4.5640	10.2412	11.5564	36.0630	15.0910	7.7436	4.0488	15.3337	5.6811	21.4956	7.0857	30.8763	4.8773	11.8270	5.5596	18.7156	4.9328
117	48.5186	26.0630	21.9237	7.7318	7.1273	6.8871	9.1931	3.5189	15.4946	8.4212	25.2858	14.4635	16.4151	12.5634	25.8751	8.1924	30.4505	11.0529	25.0543	1.3821	11.7784	3.9236	20.5234	3.8631
119	50.7271			12.1504	7.8862	9.6532			21.7426		59.5489	17.3824	16.0647	10.6071	18.1398	9.1918	26.4231	12.5265	30.6721	14.5253	21.2879	7.3725	20.9094	13.8269
121	82.8015	48.1034	37.9176	10.1588	10.2766	7.8990	8.9865	5.3696	38.6176	47.5301	64.3419	20.5620	42.3377	28.1452	18.1075	17.7183		5.9193	38.7932			23.7311	25.6659	
122	38.3610	23.9959	34.8645	5.2372	8.1642	4.5084	10.2238	1.1082	17.4553	22.8693	58.3229	5.4464	20.5651	5.3969	17.4357	1.5014	24.2915	11.4111	28.5101	2.9497	26.5111	6.5001	28.8803	1.9005
125		49.3860			13.8929	6.8073			35.5593	41.7126			16.5622	18.0368			31.1632	20.0075			9.3937	16.5113		

17.2.4. Kolmogorov-Smirnov Test

All evaluated variables proved the normal distribution according to the Kolmogorov-Smirnov test, hence the parametric statistical methods were justified for further processing.

17.2.5. SR vs NSR

Differences in variables between SR and NSR for males and females according to the Student's t-test are shown in the Table 11.

A significant difference ($p < 0.05$) manifested in the RelMaxFS in males, the KFootMed speed during the K in females, the SFootMed speed during the PO, FS and K in males, the kicking ankle angle shift during the PO and BS in females, the kicking knee angle shift during the FS in females, the standing knee angle shift during the FS in males and the standing hip angle shift during the FS in males and the BS, the FS and the K in females.

A high significant difference ($p < 0.01$) manifested in the RelMaxSq, the RelMaxFS and the RelMaxBS in females, the KFootMed speed during the BS and FS in females, the SFootMed speed during the PO, FS and K in females, both the kicking and standing knee angle shift during the PO in females, both the kicking and standing hip angle shift during the PO in females and the standing hip angle shift during the K in males.

Table 11: Student's t-test. Testing of the variable differences in SR and NSR individually for both sexes. The red numbers represent the significant difference between SR and NSR for the variable ($p < 0.05$), the additional yellow highlight represents the high significant difference between SR and NSR for the variable ($p < 0.01$).

	Durations					**Max values**		
	PO	BS	FS	K	Cycle	RelMaxSq	RelMaxFS	RelMaxBS
Males	0.47757	0.29871	0.10972	0.29295	0.48282	0.16608	0.01922	0.09155
Females	0.31109	0.30379	0.51302	0.10678	0.12530	0.00033	0.00730	0.00088
	KFootMed speed				**SFootMed speed**			
	PO	BS	FS	K	PO	BS	FS	K
Males	0.09634	0.28087	0.48766	0.09269	0.01780	0.13552	0.04750	0.01341
Females	0.89899	0.00110	0.00251	0.03549	0.00106	0.00692	0.05869	0.00268
	Angle shift, kicking ankle				**Angle shift, standing ankle**			
	PO	BS	FS	K	PO	BS	FS	K
Males	0.10820	0.11011	0.69982	0.30459	0.47622	0.83974	0.05743	0.05591
Females	0.02346	0.04628	0.25047	0.23922	0.23218	0.46651	0.07378	0.21543
	Angle shift, kicking knee				**Angle shift, standing knee**			
	PO	BS	FS	K	PO	BS	FS	K
Males	0.84663	0.29788	0.08727	0.57037	0.68429	0.27868	0.02331	0.06620
Females	0.00918	0.45236	0.03519	0.24435	0.00311	0.26281	0.05562	0.08076
	Angle shift, kicking hip				**Angle shift, standing hip**			
	PO	BS	FS	K	PO	BS	FS	K
Males	0.62926	0.62954	0.31379	0.24655	0.24062	0.50448	0.01107	0.00296
Females	0.00009	0.05015	0.24212	0.26322	0.00044	0.03531	0.01106	0.01421
	Occurrence							
	MaxSq	MaxStr						
Males	0.38666	0.48288						
Females	0.42115	0.19152						

17.2.6. Males vs Females

Intersexual differences within SR and NSR do not belong to objections of the thesis and were not accented in the data processing. For a cursory demonstration of differences between males and females see the Table 6 – Table 10 and Chart 3 – Chart 6.

The intersexual differences are based mostly on sexually dimorphic body dimensions. From the cursory check we can observe moderately higher speeds in males.

17.2.7. Pearson’s Correlation

Results of the Pearson’s correlation between a scooter speed, RelMaxSq and a MaxSq occurrence are presented in the Chart 7 – Chart 9. A significance of the particular correlations is shown in the Table 12.

The scooter speed vs RelMaxSq evinced the positive correlation which proved to be statistically significant.

The other variables evinced no significant communal correlation.

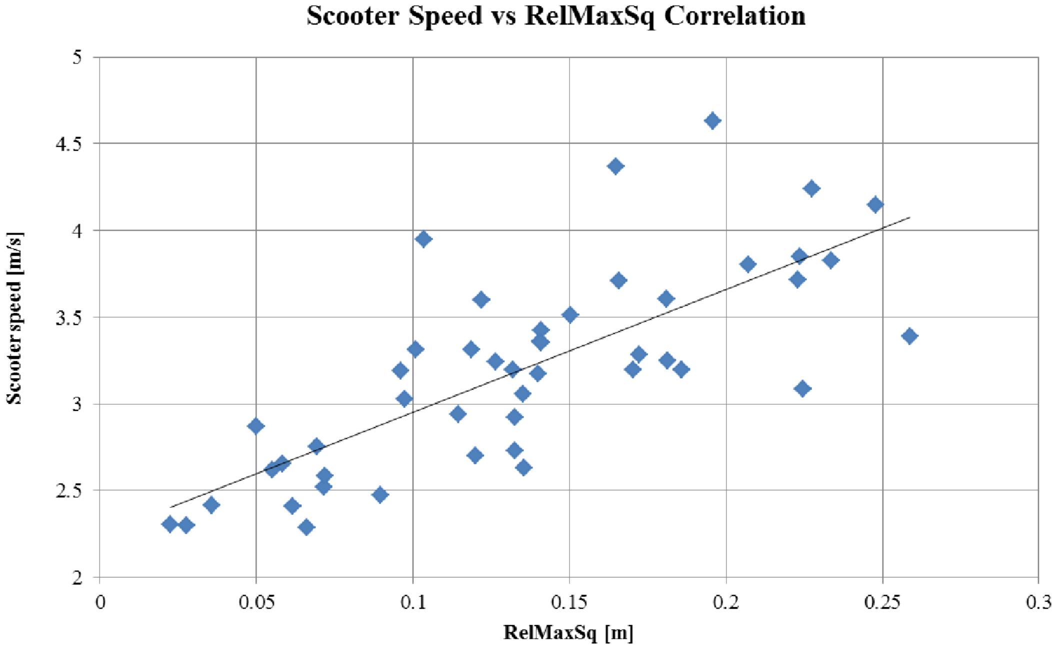

Chart 7: The correlation between the scooter speed and the RelMaxSq. The scooter speed values are in metres per second, the RelMaxSq values are in metres. As the regression line shows the existing correlation between variables is positive.

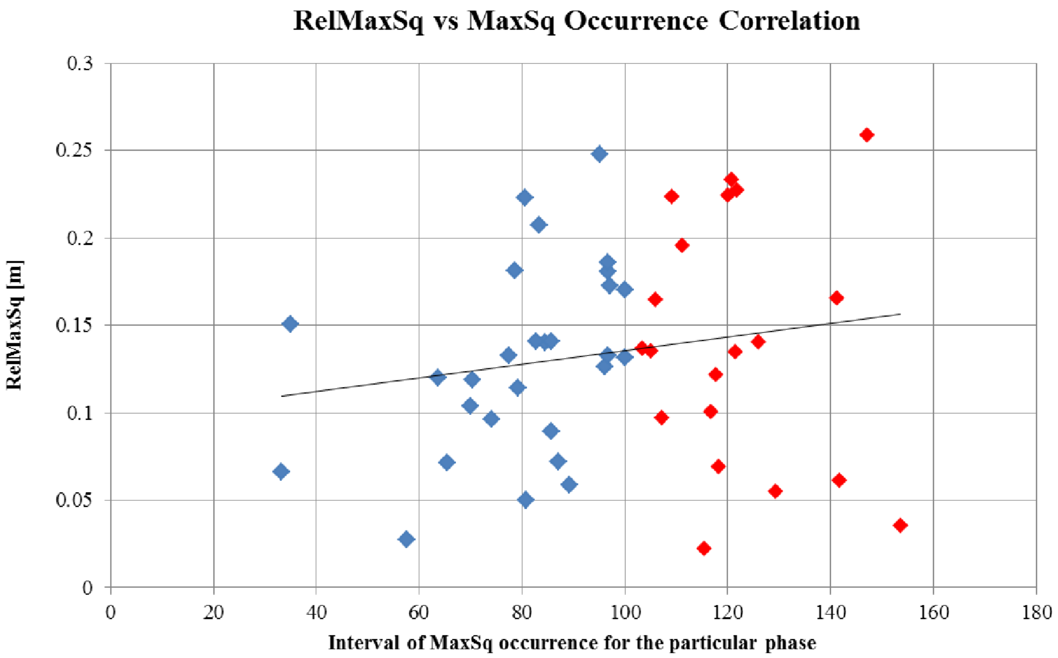

Chart 8: The correlation between the RelMaxSq and the MaxSq occurrence. The RelMaxSq values are in metres, the MaxSq occurrence values represent the consequent scooter-propelling cycles; the values between 0 and 100 (blue marks) represent the percentage of the PO when the MaxSq was occurring, the values between 100 and 200 (red marks) represent the percentage of the BS when the MaxSq was occurring. There is no significant correlation between the variables.

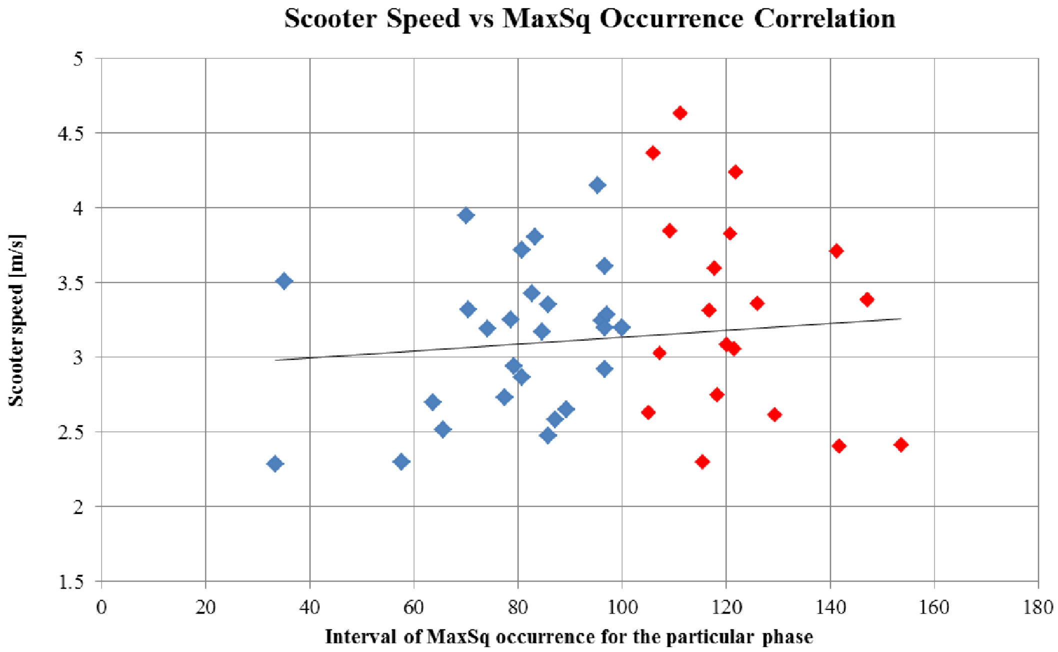

Chart 9: The correlation between the scooter speed and the MaxSq occurrence. The scooter speed values are in metres per second, the MaxSq occurrence values represent the consequent scooter-propelling cycles; the values between 0 and 100 (blue marks) represent the percentage of the PO when the MaxSq was occurring, the values between 100 and 200 (red marks) represent the percentage of the BS when the MaxSq was occurring. There is no significant correlation between the variables.

Table 12: Significance of the Pearson's correlation coefficient. ρ represents the Spearman Rho value and t represents the significance testing criterion. The red number highlights a significant correlation.

	Scooter speed vs RelMaxSq	RelMaxSq vs MaxSq occurrence	Scooter speed vs MaxSq occurrence
ρ	0.7576	0.1683	0.1329
t	7.8726	1.1579	0.9194

17.2.8. SR – Individual Movement Description

For a scooter riding movement description one male SR was chosen. Averaging of the collected specimens was not possible, since every individual took subjective time to ride through particular phases. The chosen individual's variables values lied close to the average values of the male SR group nevertheless.

In the description I especially concentrated on three joints in lower extremity: the ankle, the knee and the hip. The movement based on the kinematic recording is described thoroughly in the chapter *12. Scooter Biomechanics*, here I provide the individual-based movement charts. The Chart 10, Chart 12 and Chart 14 present the vertical position of the particular joint in kicking and standing leg, the Chart 11, Chart 13 and Chart 15 present the angle in the particular joint in kicking and standing leg. In the charts a separation into phases and scooter-propelling cycles is clearly visible. For the above mentioned comparing and correlation analyses the second scooter-propelling cycle was designated.

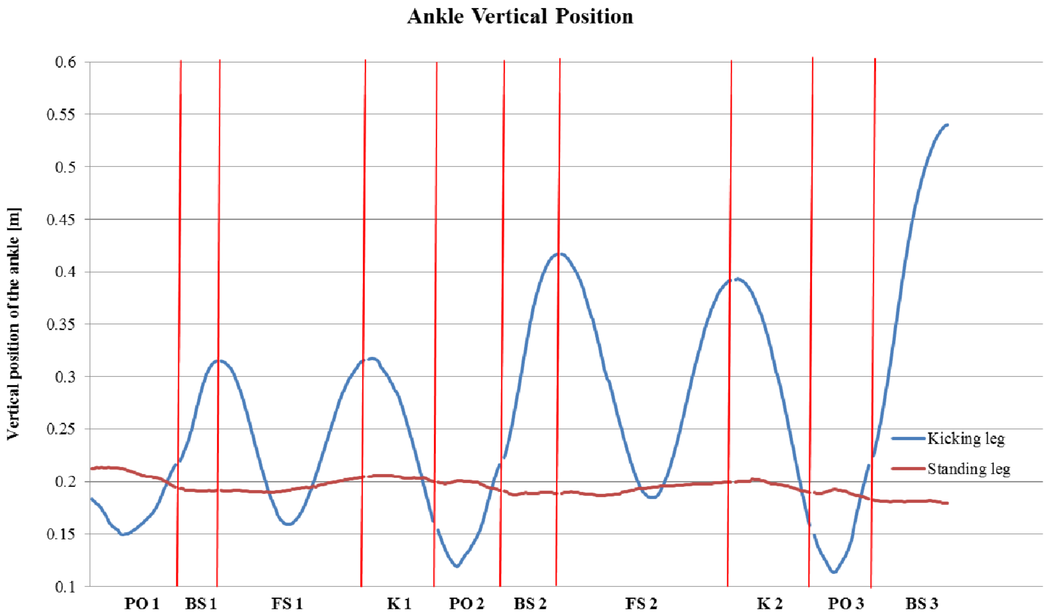

Chart 10: Vertical position of the ankle in both lower extremities during two and half scooter-propelling cycles. PO – push off, BS – back swing, FS – front swing, K – kick.

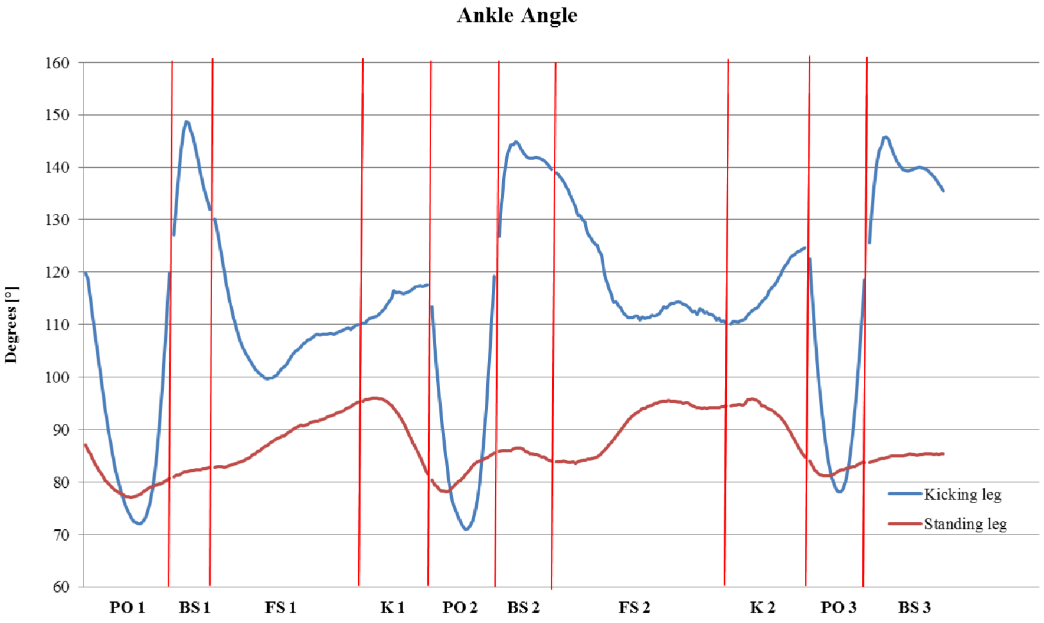

Chart 11: Ankle angle in both lower extremities during two and half scooter-propelling cycles. PO – push off, BS – back swing, FS – front swing, K – kick.

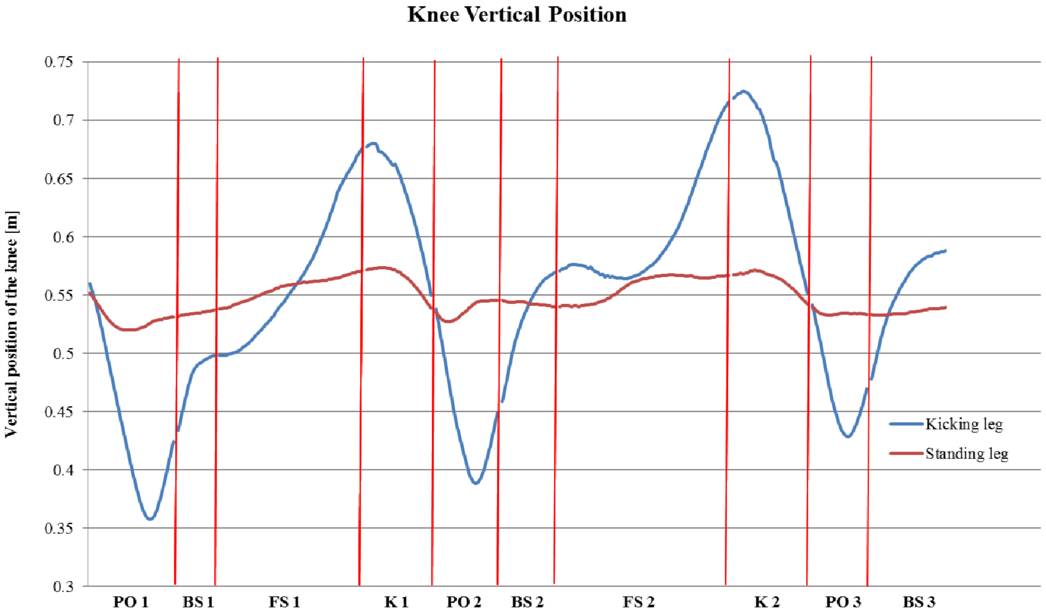

Chart 12: Vertical position of the knee in both lower extremities during two and half scooter-propelling cycles. PO – push off, BS – back swing, FS – front swing, K – kick.

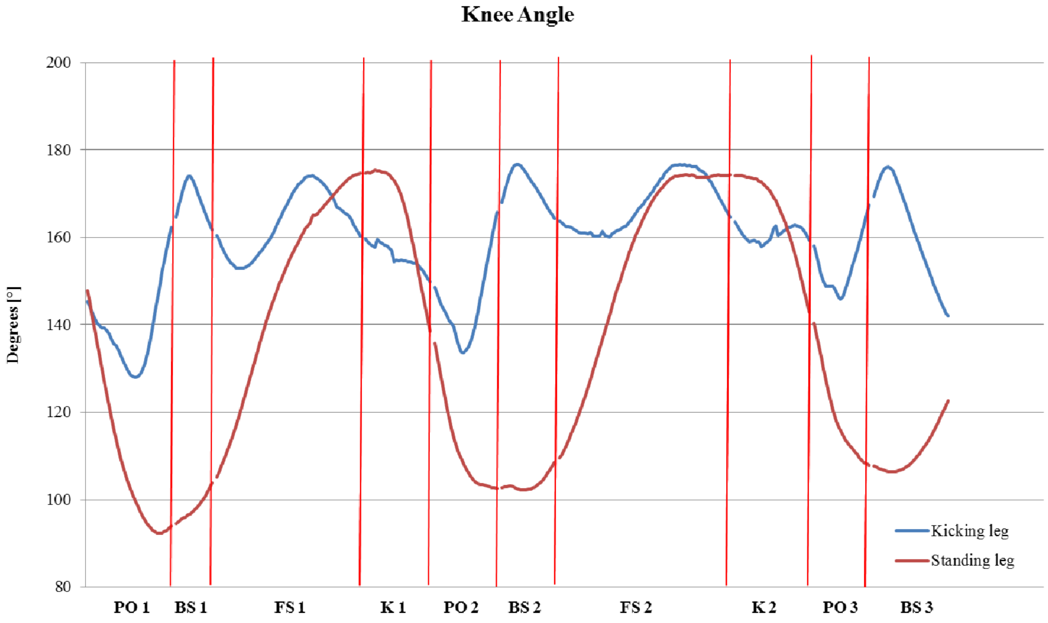

Chart 13: Knee angle in both lower extremities during two and half scooter-propelling cycles. PO – push off, BS – back swing, FS – front swing, K – kick.

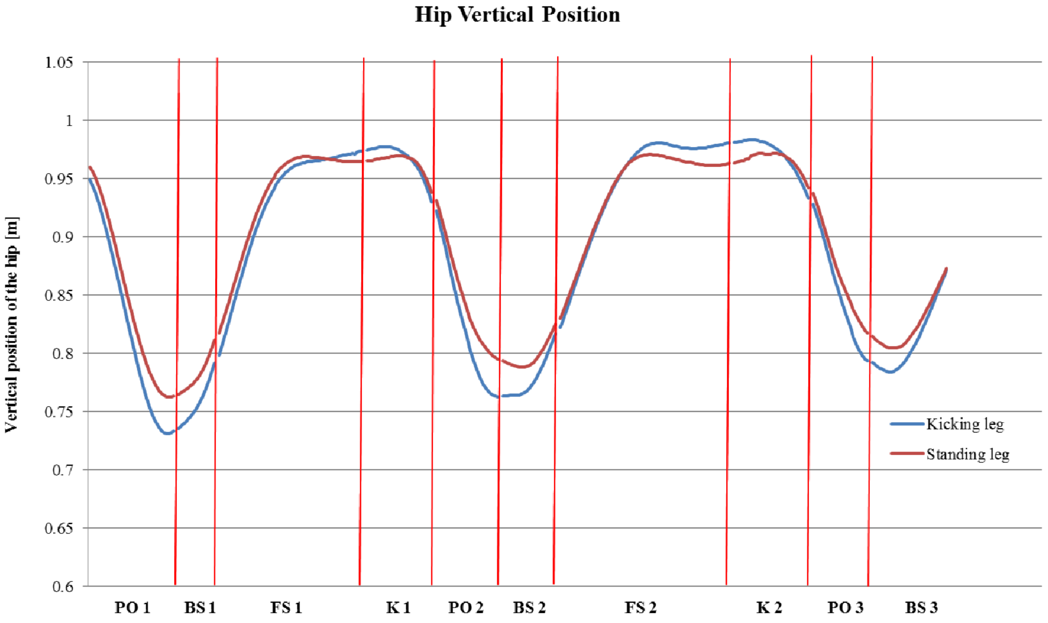

Chart 14: Vertical position of the hip in both lower extremities during two and half scooter-propelling cycles. PO – push off, BS – back swing, FS – front swing, K – kick.

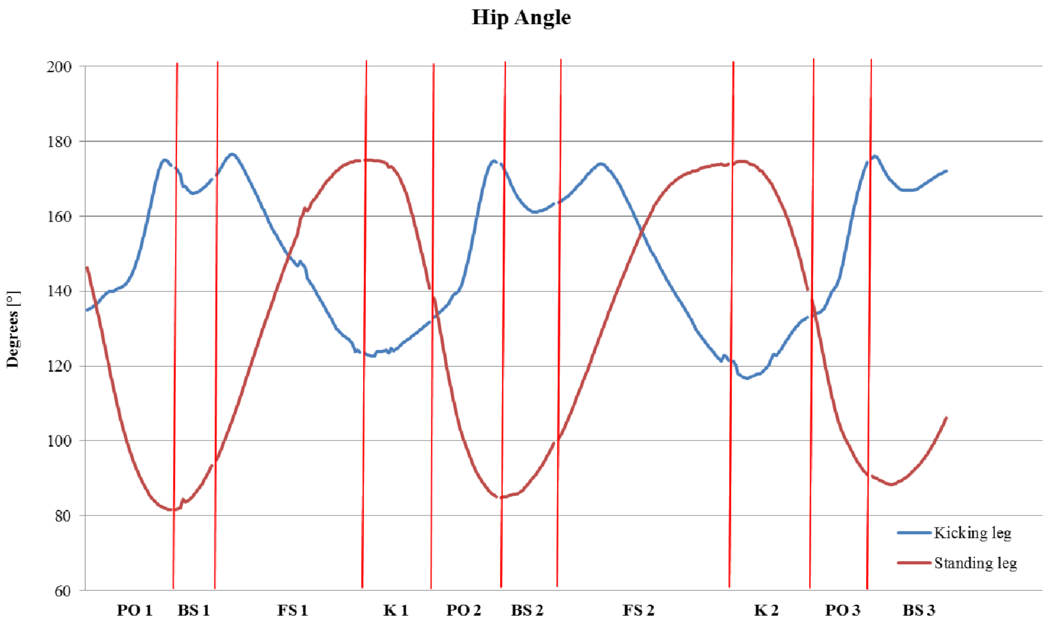

Chart 15: Hip angle in both lower extremities during two and half scooter-propelling cycles. PO – push off, BS – back swing, FS – front swing, K – kick.

The Chart 16 presents a speed in the KFootMed (kicking foot speed) and the SFootMed (standing foot speed, the scooter speed) during two and half scooter-propelling cycles.

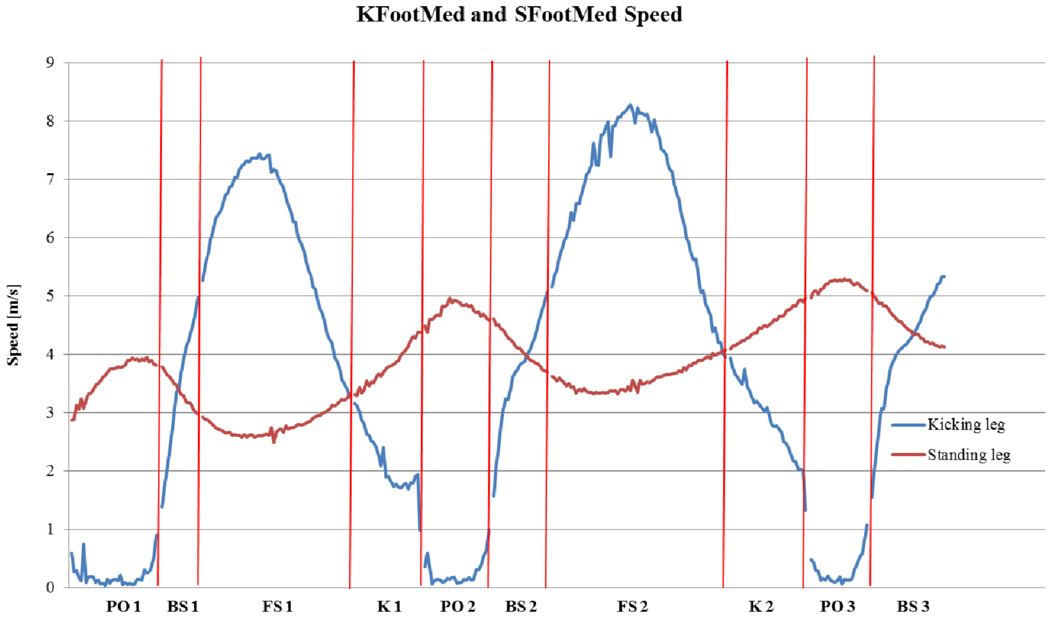

Chart 16: KFootMed (kicking foot) and SFootMed (standing leg, the scooter) speed of one individual during two and half scooter-propelling cycles. PO – push off, BS – back swing, FS – front swing, K – kick.

17.2.9. NSR – Individual Movement Description

Among the NSR there were several individuals who transcended the general pattern in a matter of scooter riding. These individuals made the group variable, although the other NSR (for instance sportsmen, bikers or people with scooter experience from childhood or a little recent experience) followed more or less the general pattern presented in the SR.

In the most unexperienced individuals (such as people with a very little bicycle riding experience as well) an insecurity during the ride was obvious, leading to a very slow and careful riding, instability in riding in a single track, almost permanent or a very shallow squat and low-reach moves in joints. In some riders the melting of the FS and K phase into one occurred, making the original differentiating between the phases undistinguishable.

The FS and K phases melting into one without the original phase-significant features does not necessarily be considered abnormal. When moving off or accelerating rapidly there can be an intentional cut of a second half of the FS (specifically, cutting off a swinging foot up for the sake of more powerful subsequent K phase) to enable kicking the ground as fast as possible to accelerate sooner. This alternative of acceleration is more energy consuming and is not sustainable for a longer ride, since the FS can serve as a recreational phase when most muscles relax.

17.3. **Visual Inspection of Body Posture Results**

For the body posture impairment distribution among SR and NSR see the Table 13. For the results of chi-square association analysis see the Table 14.

Each applied method has a different scaling – *A* stands for a perfect body posture in the both methods, *B* stands for a good body posture in Klein, Thomas, Meyer method but for a poor body posture in silhouettographs, *C* stands for a poor body posture in Klein, Thomas, Meyer method. No other body posture level was inspected.

The majority of participants displayed perfect or good body posture. However, the methods detected some poor body postures in both SR and NSR. The pelvic area displayed only perfect body posture.

A highly significant association ($p < 0.01$) in the scooter riding experience (either SR or NSR) in males and particular level of Klein, Thomas, Meyer method was proved.

Table 13: Body posture impairment distribution among SR and NSR. The values express number of participants fitting particular method and level.

Variable	Evaluation	Male SR	Male NSR	Female SR	Female NSR
Klein, Thomas, Meyer	A	13	3	6	5
	B	16	7	5	7
	C	0	4	0	1
Neck posture	A	25	12	10	13
	B	4	2	1	0
Shoulder girdle posture	A	21	6	7	10
	B	8	8	4	3
Back posture	A	24	12	8	13
	B	5	2	3	0
Pelvic posture	A	29	14	11	13

Table 14: Significance of particular chi-square test associations. $\chi2$ represents the chi-square statistics, p represents the p-value. The yellow cell fill highlights a highly significant association ($p < 0.01$).

	Klein, Thomas, Meyer		Neck posture		Shoulder girdle posture		Back posture	
	$\chi2$	p	$\chi2$	p	$\chi2$	p	$\chi2$	p
Males	9.23	0.0077	0.00	0.9652	3.53	0.0603	0.06	0.8057
Females	1.27	0.5309	1.23	0.2668	0.51	0.4755	4.05	0.0441

17.4. **Questionnaire Results**

Back and Neck Ache

The ache presence distribution among SR and NSR is shown in the Table 15, the significance of chi-square association test is shown in the Table 16.

The chi-square association test manifested a significant association in back ache among females and in neck ache among both males and females.

Table 15: Ache presence in back and neck area in SR and NSR. The values express number of participants fitting particular ache and sex.

Variable	Ache	Male SR	Male NSR	Female SR	Female NSR
Back	Yes	14	9	6	12
	No	15	5	5	1
Neck	Yes	3	6	2	7
	No	26	8	9	5

Table 16: Significance of particular chi-square test associations. $\chi 2$ represents the chi-square statistics and p represents the p-value. The red numbers highlight a significant association ($p < 0.05$).

	Back		Neck	
	$\chi 2$	p	$\chi 2$	p
Males	0.97	0.3240	6.03	0.0141
Females	4.53	0.0333	3.88	0.0487

Skiers vs Athletes

The Table 17 presents the results of the Spearman correlation for particular variables. As visible in the table, there was no statistically significant correlation proved with the testing.

Table 17: Spearman correlation for different variables. n expresses the sample size.

Variable	n	Spearman (ρ)	p-value
RelMaxSq vs thighs-sport	23	-0.12821	0.55991
Average gluteal thigh circumference vs thighs-sport	30	0.31779	0.08702
Average medial thigh circumference vs thighs-sport	30	0.25032	0.18214
PO duration vs thighs-sport	23	-0.02853	0.89717
Kicking ankle angle shift vs calves-sport	23	-0.06561	0.76615
Average calf circumference vs calves-sport	30	-0.09592	0.61410

Preferred Leg Association

The diverse sample size as well as the distribution of SR with different preferred standing leg associated to the larger circumference in three muscles is presented in the Table 18. The significance of the chi-square association test is shown in the Table 19.

No statistically significant association between the preferred standing leg and the more developed corresponding muscle was proved.

Table 18: Distribution of SR with different preferred standing leg associated to the larger circumference in three muscles. The values express number of participants fitting particular set.

	Larger gluteal thigh circumference		Larger medial thigh circumference		Larger calf circumference	
Preferred standing leg	Right	Left	Right	Left	Right	Left
Right	14	5	14	1	12	3
Left	5	1	6	5	6	3

Table 19: Significance of particular chi-square test associations. $\chi 2$ represents the chi-square statistics and p represents the p-value.

	$\chi 2$	p
Larger gluteal thigh circumference	0.23	0.6295
Larger medial thigh circumference	5.38	0.0204
Larger calf circumference	0.53	0.4652

Additional Findings

The additional findings are based on the 40 SR questionnaire responses. The sex differences were not considered. The number of responses exceeding the number of participants is caused by the occasional multiple responses of participants.

The scooter type, mostly used within the surveyed sample, was the universal scooter, followed by the road scooter. The big universal scooter, being also represented among the answers, stands for the versatile scooter type of large dimensions (*id est* with the front wheel rime size at least 26"). The scooter brands distribution was balanced, with Kostka, Mibo, K-Bike and Kickbike brands on a similar level. The scooter types and brands distribution are presented in the Chart 17.

Most of surveyed SR ride the scooter 1 to 9 hours per week during the season and prefer to ride the tracks shorter than 20 km. The time spent on scooter and the preferred track length are presented in the Chart 18.

Two-thirds of SR prefer right leg as a standing leg. Most of SR switch the legs every 5 to 14 scooter-propelling cycles. However, three SR admitted an imbalance in their riding – they either did not switch legs or the less preferred side was underused (Chart 19).

Vast majority of SR did not suffer any injury from scooter riding. Some complained about kicked ankles or some scrapes. Two SR suffered a severe injury. The back ache in SR was present for various causes, but there were only 4 SR who ascribed their back ache to the scooter riding. The injuries and back ache in SR are presented in the Chart 20.

The SR who ride the universal scooter favour its versatility (size, swiftness, applicability on more terrains, foldability, dexterity and price) but dislike its worse inertia (low speed, heavy weight and ponderousness). The SR who ride the road scooter favour its speed but dislike its big size.

7 of 40 respondents train specifically for scooter riding.

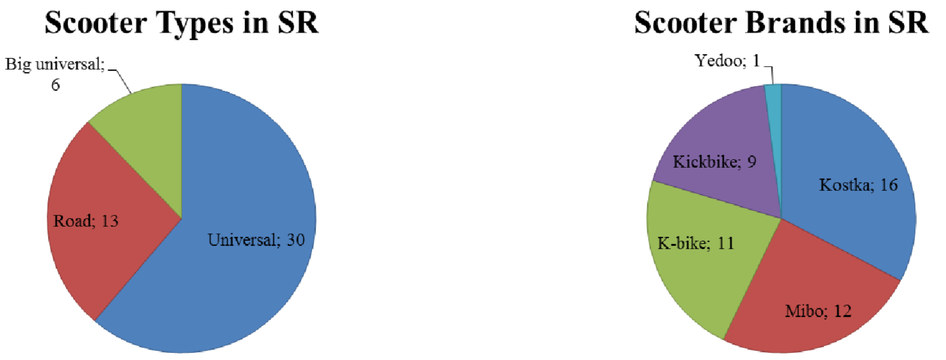

Chart 17: Scooter types and scooter brands distribution in SR.

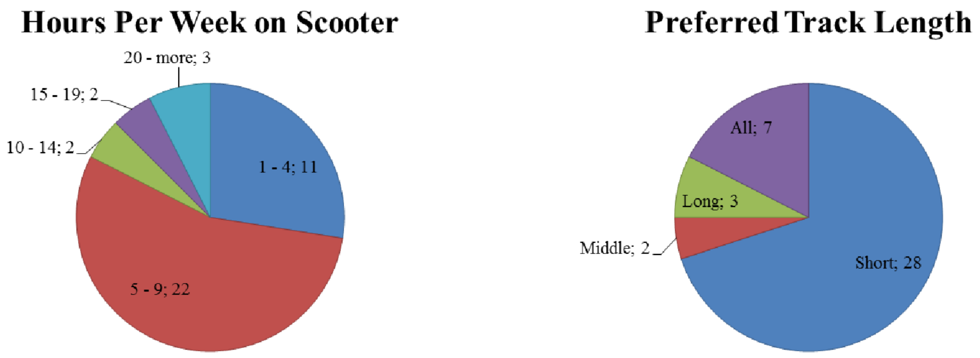

Chart 18: Hours spent on scooter per week and preferred track length distribution in SR.

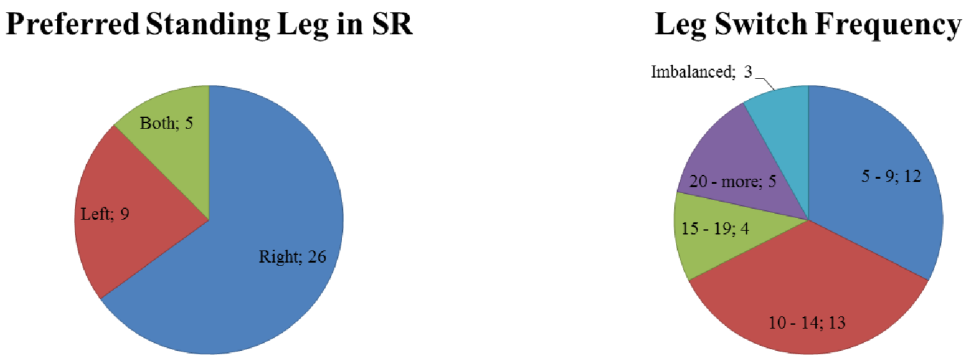

Chart 19: Preferred standing leg and leg switch frequency distribution in SR. The frequency number expresses amount of scooter-propelling cycles driven through without leg switch.

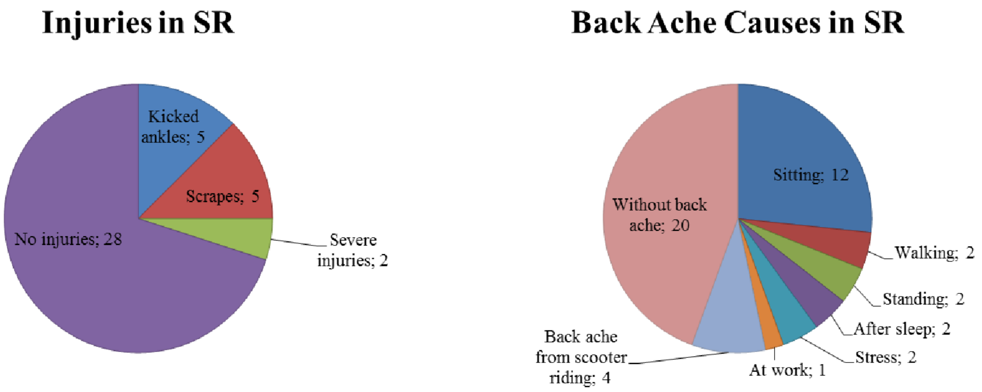

Chart 20: Injuries and back ache causes distribution in SR.

18. Discussion

The main aim of the thesis was to evaluate the scooter ergonomics and to analyse the scooter ride per se. An impact of scooter riding on the body posture was another cardinal objective. The particular findings are presented in the following sub-chapters.

18.1. **Anthropometry – Ergonomic Evaluation**

For an ergonomic inquiry the 25th and 75th quartile were designed as the limits for general conclusions, fitting the most participants and excluding the extreme values.

As we can observe in the descriptive statistics tables, many measurements within the 25th and 75th quartile in united sexes (Table 5) do not overlap with the quartiles in females (Table 4). In other words, the both sexes group is primarily based on the males sample, mostly due to its larger size. When the groups are observed separately, there are significant differences between males and females. Therefore, the both sexes quartile variance was used only for the conclusions in the variables with the present quartile overlap between both sexes group and separate sexes groups, and vice versa.

Especially, there is a striking difference between sexes in standing height. In his works Horák often pursues configuration of the racing scooter in relation to the body size (Horák, 2011, 2015); Horák (2015) accents the scooter height (see the Figure 4), a minimal dimension which cannot be adjusted by user to any lower position, although can be elevated with an appropriate stem employment. In road scooter, the handlebar is ideally adjusted as low as to a rider's hip joint level (Žďárek, 2005, p. 25; Horák, 2011, p. 28). In universal scooter, the handlebar can be positioned higher, however, the arms are still supposed to run forward and down. In shorter scooter riders the handlebar vertical position would not meet the recommended level since it cannot be positioned below the minimal scooter height.

Further, Horák adds that for the riders below 170 cm in standing height it is not favourable to apply the 28" front wheel for corresponding necessity of positioning the handlebar above the wheel level. Instead, he advises to employ the 26" wheel for the shorter riders. In the females group, the values between the marginal quartiles are all smaller than 170 cm in standing height, commented by Horák as demarking standing height.

Second dimension, the thigh length, defines a knee radius – the radius of the kicking knee linked to handlebar position. To avoid a potential painful impact, the handlebar course is set ideally out of the kicking knee reach. The thigh length within the 25th and 75th quartile in both sexes shows the minimal distance of the handlebar from the standing thigh (38.4 cm – 41.7 cm). Nevertheless, the knee radius is recommended to include approximately 5 cm reserve beyond the real thigh dimension, for the rider's psychological comfort. According to the findings, the handlebar should be constructed adjustable at least within the aforementioned range, to meet the variable knee reach.

Let me expand the handlebar position topic further. In standard scooter standing position, the rider is bent forward slightly and holds the handlebar while having straighten arms. As mentioned, in both road and universal scooter the handlebar is ideally adjusted as low as for the arms running forward and down. Hence, the handlebar should occupy the position corresponding to the reach of lowered but straighten arms while still not restricting any motion within the knee radius.

The average frontal grip reach measurement in the both sexes group demonstrated an overlap of the two separated groups. The handlebar adjustment for the straightened arms should therefore be approximately within 66.3 cm – 74.1 cm range.

The handlebar breadth should optimally correspond to the shoulder breadth and thus be related to another measurement, the biacromial breadth (Žďárek, 2005, p. 24; Horák, 2013). The biacromial breadth corresponds to distance of the axes of forwardly straighten arms; in horizontal palm grip it corresponds to the distance between the middle fingers. To cover even the lateral fingers' handlebar grip, additional 5 cm per side should be added to the total handlebar breadth. With the aforementioned handlebar breadth, the arms are straighten forwards to the handlebar in a natural and comfortable way. The narrower handlebar may restrict comfortable breathing due to the convergent arms, the broader handlebar, on the other hand, may not provide the sufficient support for the propelling.

Since the handlebar is often an external scooter component, there should be no serious problem even for small local scooter producer to deploy two handlebar sizes, corresponding to male and female biacromial breadth (without the 5 cm reserve per side 35.0 cm – 40.5 cm range in males and 34.6 cm – 37.2 cm range in females).

The footboard breadth and length measurements correspond to the rider's foot size. It is important to realise that standardly only one foot stands on the board and there is no need to produce the footboard much larger than that in any dimension. During downhill on the road or universal scooter, both feet are either put together diagonally on the footboard or the foot of the standing leg remains on the footboard evenly and the kicking foot is put onto the standing foot additionally (Žďárek, 2005, p. 34). In both cases, it is sufficient the footboard dimensions exceed the foot dimension of just a small value. The footboard breadth should approximately correspond to the breadth of a foot in shoe. The narrower board can cause instability or insecurity of the standing foot. Oppositely, the broader board makes rider to put legs unnaturally apart and push off more distantly from the centre of gravity, which deteriorates balance and fluent ride and may cause the kicked ankles. The dimensions of foot breadth between 25th and 75th quartile in both sexes group varied from 9.7 cm to 10.7 cm. With the shoe put on, the values would increase to about 11 cm.

The footboard length, however, should count with a bigger space reserve. The foot length between 25th and 75th quartile varied from 26.3 cm to 27.8 cm in males and from 23.9 cm to 25.3 cm in females. For the footboard length estimation, it is necessary to calculate with the shoe sagittal dimension and additional space for the foot switch. What is more, the footboard serves as the only connection between the wheels and thus it contributes on scooter riding characteristics as well. Too short wheelbase provided by the short footboard may impair the scooter stability. The 38 cm footboard length, applied by Kickbike (Kickbike.com), is one of the minimal serial-produced footboard lengths, still bestowing a good stability.

The last measurement, the body weight, varied from 71.5 kg to 92.1 kg in males and from 56.2 kg to 63.5 kg in females. The measurement directly corresponds to the scooter load capacity, ordinarily estimated to 100, 120 or 150 kg. All three values, however, are far exceeding the males weight and are even doubling the females weight. Given that load capacity in general bears some weight reserve to sustain a normal treatment, the load capacities estimated in scooters are, within the 25th and 75th quartile, superfluous. On the other hand, the load capacity as such brings no direct negative influence on the scooter ergonomics and the extra capacity can be utilised for additional load, such as a backpack *et cetera*.

On the basis of anthropological-ergonomic findings I propose the scooter producers, in compliance with Horák (2015) and the considerable sexual dimorphism, to construct at least two sizes of scooter models – one standard, corresponding to the 175,5 cm – 184,6 cm quartile variation, the second adapted for shorter riders, corresponding approximately to the 164,0 cm – 169,6 cm quartile variation; with lower scooter height (shorter head tube and stem), shorter footboard, narrower handlebar and, in road scooters, employed 26" front wheel. There already exist a child's scooter model in some producers as a smaller and potentially simplified version of an adult's model. The scooter producers should follow an example already given by bicycle producers (Laios & Giannatsis, 2010; Balasubramanian *et al.*, 2014) and establish one additional scooter size version a priority in a new models development.

Since the road scooter is built even for longer rides, the more its morphology corresponds to the rider's morphology, the better. In universal scooter, the single model size seems sufficient (given that the handlebar is adjustable), yet, many riders spend a considerable time riding such scooters (see the Chart 18). Even these riders can challenge some inconveniences if the scooter is large for them. There will usually be some riders of an extraordinary standing height (both very tall and very short), who will challenge the problem with inadequate scooter dimensions. Such riders, representing extreme values, would need a customised scooter at any rate.

Freshly in the Czech market there is Morxes, a scooter producer offering a model attuned to woman body size. This model disposes of a shorter stem and head tube, more adequate to the lower standing height of women, and the narrower handlebar which better fits narrower biacromial breadth of women (Morxes.com).

I conclude the ergonomic evaluation of the scooter with a statement that an ergonomics is a very relative field accordant also to the fickle user's demands. Let me demonstrate one interesting example. One inspected scooter rider, a mother, described a scooter she has been riding – it had a disproportionally broad handlebar and a footboard oversized to her small feet. Both the mentioned features proved very favourable in her case, as she described she often carries her two children on the scooter to school, standing foot by foot on the huge footboard and holding the broad handlebar palm by palm.

18.2. **Kinematic Recording of Scooter Riding**

18.2.1. SR – Individual Movement Comments

In the Chart 16 there are important situations to comment. A curve of the kicking foot manifests a rich variability in speed; during the PO phase the kicking foot pushes off the ground and has no or very little speed, while during the FS phase the kicking foot swings in front and its speed is saturated with the scooter speed in addition. All this makes the kicking foot the most versatile part of a rider's body. Also, the angle shift in a kicking ankle represents the most rapid angle shift among all inquired joints, as is shown in a Chart 21. This fast angle shift serves as the main propulsion for scooter ride.

As opposed to the kicking foot, the standing foot (or the scooter as such) evinces an increasing speed trend. Nevertheless, the scooter acceleration is not linear, but shifts, as it is shown in the Chart 16. Since the scooter propelling is not linear, but rather periodical, the basic explanation of this shifting is that the scooter accelerates during the PO and consequently decelerates just when the riding resistances outweigh the inertia against deceleration. However, the principle is not that simple. The scooter speed is highest during the PO phase, followed with a deceleration during the BS and FS. Then, in the middle of the FS, surprisingly, occurs another acceleration which is most significant during the K phase. Thereto, this acceleration propels no ground kicking. I presume a conservation of momentum effect being responsible for this phenomenon.

A law of conservation of momentum explains that within a closed inertial system a momentum of two bodies remains constant according to the formula:

$$p_1 + p_2 = m_1 v_1 + m_2 v_2 = const., \tag{12}$$

where p [kg·m/s] stands for momentum, m [kg] stands for mass and v [m/s] stands for velocity (Tarábek *et al*, 2006, p. 30). In this instance, I declare the first body representing a centre of gravity of a scooter and the second body representing a centre of gravity of a scooter rider. As the total momentum within the inertial system remains constant, the acceleration of the first body (scooter rider) results in deceleration of the second body (scooter) and vice versa.

The Chart 22 provides an illustration of the problem. The chart depicts two curves, the first representing a scooter speed as such, the second representing a rider's Chest point (see the Figure 23) velocity in a forward direction in relation to the scooter speed. The Chest here acts as an approximation of the centre of gravity of the scooter rider.

During the FS and the K the Chest decelerates in relation to the scooter (having the common trajectory) and, by that, causes the acceleration of the scooter, according to the law of conservation of momentum. Contrariwise, during the PO and the BS the Chest accelerates in relation to the scooter (having the opposite trajectory) and, by that, causes the deceleration of the scooter, according to the law.

Given that the centre of gravity fluctuates less than the more periphery-situated Chest, the centre, having the shorter trajectory, moves slower in relation to the scooter. Therefore, having the centre of gravity instead of the Chest, the Chest velocity curve in the Chart 22 would evince a lower amplitude, directly corresponding to the law.

Although the explanation of the scooter acceleration during the FS and K is tested only in some individuals within the sample, I expect the congruence in general scooter riding as well.

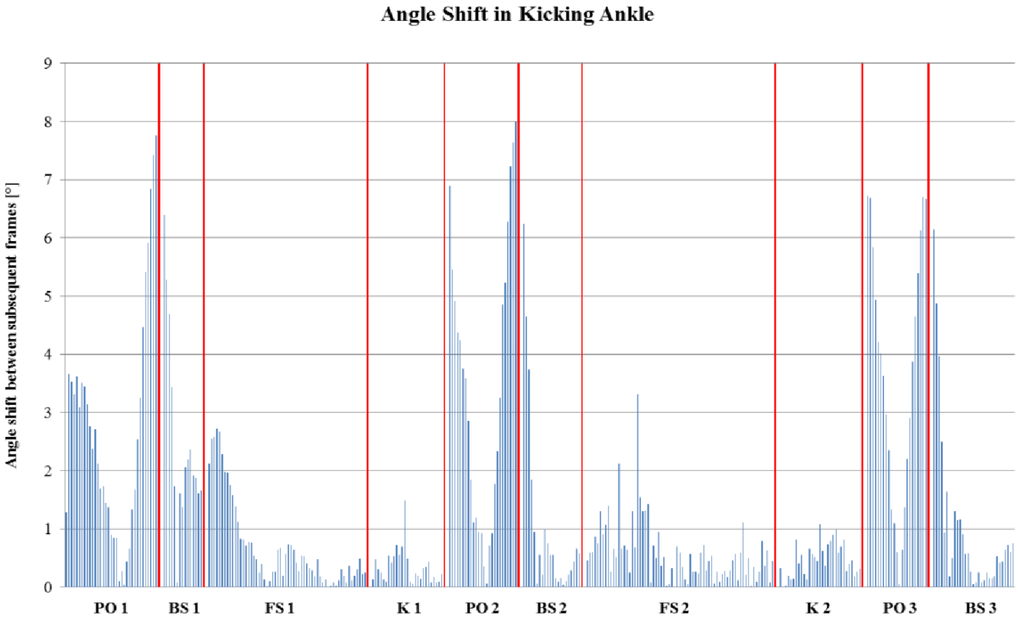

Chart 21: Angle shift in kicking ankle during two and half scooter-propelling cycles. PO – push off, BS – back swing, FS – front swing, K – kick.

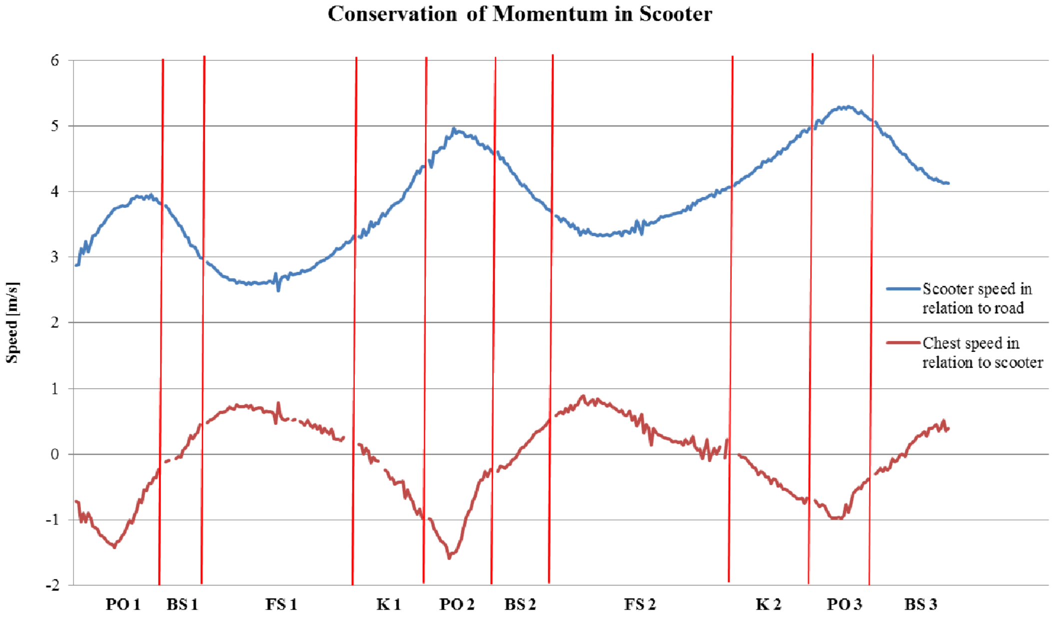

Chart 22: Conservation of momentum in scooter inertial system during two and half scooter-propelling cycles. PO – push off, BS – back swing, FS – front swing, K – kick.

18.2.2. Common Features in SR and NSR

The problem in generalising some results of provided descriptive statistics represents a controversy in a layout of the kinematic recording. Firstly, there was the beforehand mentioned problem of a small size of the recording area, which resulted in not reaching the final and sustainable speed in most participants. The alternative option of setting the scooter in motion before it got into the recording area would help to attain a sustainable and relevant speed was unfortunately not possible for the participant had to be recognized by the cameras within the area and as soon as he or she left it the connection was lost and the new system recognition had to proceed.

Secondly, another controversy was found in the riding style which was designed to be comfortable to the participants. A perception of comfort is, however, too individual, consequently difficult to compare, especially when performed in a short-time scale. Some participants might had attempted to show off, trying to reach the highest speed; some others might had proved just a very little effort.

Nevertheless, the application of the second scooter-propelling cycle as a reference cycle was a correct step. On this cycle, some statements can already be corroborated.

A vast majority of participants had similarly divided scooter-propelling cycle (except for several NSR mentioned above). The FS phase duration was twice as long as the other phases, which had a comparable duration. The whole scooter-propelling cycle lasted slightly above one second.

Although the absolute values of the RelMaxFS (Relative Maximal Front Swing) and the RelMaxBS (Relative Maximal Back Swing) differed in SR and NSR, a fact that the BS reached approximately twice farther than the FS is common for both the SR and the NSR. On the fact several factors contribute. During the BS a whole body normally leans with the movement backwards on the course of the squat. Then, when the kicking leg swings back and forth freely, it already has less momentum to swing in front far up. In a case that the leg is swung in front forcibly there is a handlebar restraining its distant swing in front. That is why a sprint race ride modification makes a racer to overcame the handlebar by lifting the kicking leg up rather than forward, with a knee close to a thorax or even a chin, to achieve a higher potential energy for propelling (Žďárek, 2005, p. 30).

Finally, both SR and NSR had the MaxSq (Maximal Squat) and the MaxStr (Maximal Straightening) occurrence in common, without any significant difference. The MaxSq was generally performed about the PO and BS transition. The MaxStr, was generally performed by the end of the FS. The results were expected since both maxima occurred during the phases optimally corresponding to fluent scooter ride.

18.2.3. SR vs NSR

According to t-test there were many significant differences between SR and NSR, especially in females. To discuss this significance it is however necessary to realise two significance-contributing factors: a small female sample size (9 SR and 13 NSR) and a fact that the female NSR sample coincidentally contained the most of extremely unexperienced riders mentioned in the chapter *17.2.9. NSR – Individual Movement Description*.

Nevertheless, even though the sample size is not perfectly sufficient a number of trends of disparity can be tracked down. Many differences between SR and NSR are possibly being explained by a hypothesis of a cautious ride of NSR. A manifested concomitant of this cautious ride there were restrains in extremities flexions (squats) and extensions (front or back swinging of a kicking leg).

The differences in the RelMaxSq (Relative Maximal Squat), the RelMaxFS and the RelMaxBS are congruent with the cautious ride hypothesis. The NSR squats were shallower, the FS and the BS were shorter.

Another congruence with the cautious ride is evident in differences in speed of KFootMed (see the Figure 23). The cautious NSR dared not to swing the kicking leg swiftly about but rather stood stiff and compact, with extremities close to each other; and propelled slowly. The slow and cautious propelling explains also the lower scooter speed (or SFootMed speed) in NSR which turned to be significant in most cases between SR and NSR.

An angle shift in examined joints, the ankle, knee and hip, seems, on the other hand, to be influenced by the cautious ride only partially. The kicking ankle angle shift evinced no significant difference during the FS and K phase, when the kicking foot swings and consequently falls to push off. However, in females there was an evident difference during the PO and the BS, *id est* during the phases when the kicking foot performs its plantar flexion in order to push off the scooter. This plantar flexion was more distinctive in SR.

In the standing ankle there was no significant angle shift difference between SR and NSR at all. Obviously this joint remains very conservative and evinces no or a very little change provided by experience.

A difference in kicking knee during the PO and the FS in females is a result of lower angle shift in NSR. Again, the compliant explanation is hinged by the cautious ride hypothesis, as the cautious NSR did not dare to extend the knees as wide as the SR did.

A significant difference between female SR and NSR in standing knee ankle shift during the PO probably corresponds to the difference in the RelMaxSq. Additionally, a difference in females standing knee during the FS corresponds to straightening from the squat, which was, as already mentioned, lower in NSR.

Within a hip angle shift the numerous significant differences between SR and NSR were present, especially in a standing hip.

In a kicking hip the angle shift differences during the PO are associated with the squat (the RelMaxSq value and the backward lean of the trunk). The deeper squat occurs and the farther kicking leg reaches, the larger an angle shift in kicking hip is. As the female NSR had both the values smaller, they also had significantly lower values of the kicking hip angle shift during the PO. During the BS the kicking leg swings backwards. Again, the farther kicking leg swings, the larger an angle shift in hip is. The angle shift in kicking hip during the FS and the K showed no statistical difference between SR and NSR. Probably the movements in these phases remain conservative with just a little room to improve in a technique, at least for a comfortable ride.

A hip angle in standing leg is partially a manifestation of squatting knee as a trunk gets closer to it by the squat per se. Moreover, the trunk contributes in a hip angle forming as it leans backwards, enabling an extended squat and consequently extended PO as well. Therefore, the differences in an angle shift of standing hip between SR and NSR during the PO, BS and FS are caused by the shallower squat (for the PO and BS) and the less total straightening (for the FS) in NSR together with the persisting caution and stiffness of the body. The differences during the K can be associated with the stiffness of the trunk during the K in NSR.

18.2.4. Correlations

The three kinematic correlations were based on an assumption of communal relation in scooter speed, RelMaxSq and MaxSq occurrence. I hypothesised that all three variables are based on an experience in scooter riding and they might manifest some communal pattern in presence.

The scooter speed vs the RelMaxSq proved a significant positive communal correlation, meaning the faster scooter rides, the deeper squat accompanies it.

The possible explanation of this correlation is that the deeper squat makes a ride faster. To support this hypothesis, the deeper squat diminishes a frontal area lowering an air resistance. What is more, the deeper squat is, the longer time may a push off last, which would accelerate the scooter for longer time. On the other hand, the deep squat as such would not be sufficient. Not a raw fact that a rider squats deeply would make the ride faster, but since the rider tries to ride faster and puts an effort into speed gain, the deeper squat, as a concomitant, would participate in achieving the higher speed through the diminished frontal area and the extended push off. To support this hypothesis contributes a fact that during setting in motion, when it is crucial to overcome most of resistance, many SR performed the deepest squat in the course of the first or second scooter-propelling cycle, while the subsequent cycles squats were shallower (Chart 12). I presume the deeper squat contributes to achieving the initial, sustainable speed.

An unequivocal correlation between the RelMaxSq and the scooter speed would be proved if discovered in a case of all the participants striving to achieve the top speed, which was unfortunately not possible due to the lack of space. The records of the comfortable ride show at least a positive correlation trend.

From the other variables neither the RelMaxSq vs the MaxSq occurrence nor the scooter speed vs MaxSq occurrence were communally correlated, what was not congruent with the hypothesis that the experience is designing the MaxSq occurrence to any general or ideal position.

18.3. **Visual Inspection of Body Posture**

Within the inspected sample many individuals (both SR and NSR) were assigned an imperfect body posture according to applied methods. Still, only one chi-square association table proved itself significant, the association between the scooter riding experience (either SR or NSR) in males and particular level of the Klein, Thomas, Meyer method.

Although the significant association of the worse body posture with NSR can be simply explained by the sampling paradigm – the SR are rather sportsmen with an active life style, while NSR are more likely sedate with impaired body posture, still there was found no evidence to decline the opposite explanation – that the scooter riding as such corrects the impaired body posture.

On the other hand, what I can state according to the findings, the scooter riding has no significantly harming effect on the body posture.

18.4. **Questionnaire**

Back and Neck Ache

Probably the most remarkable finding was the SR suffered significantly less from the back and neck ache than the control sample (NSR). Alike the body posture, this finding can be attributed to the sampling paradigm, when the SR are sportsmen with an active life style, while NSR are more likely sedate. And again, there is no evidence to decline the alternative explanation that scooter riding remedies the back or neck ache with the complex musculature involvement.

Among the SR there were 4 individuals, who ascribed their back ache to scooter riding specifically. The rest of 20 SR with back ache found no association in back ache and scooter riding.

Skiers vs Athletes

The belief in the different riding style of “skiers” and “athletes” was not proved in analysis. However, some different riding trends can be latent for being very subtle. Since many of inquired variables were based on the kinematic recording of scooter riding, the aforementioned problem with the individual perception of comfortable ride has lasted. The differences in riding trends would be more obvious on the record if the riders had strived to achieve the highest possible speed instead of riding comfortably. Furthermore, an electromyography would help reveal different muscles involvement in “skiers” and “athletes”.

Preferred Leg Association

The hypothesis that the footedness significantly influences the muscle development distribution among standing and kicking leg was not proved by the analysis. The explanation I propose is a regular switching of standing and kicking leg, confirmed by most participants in the questionnaire (see the Chart 19), leading to the even work load in both legs and, consequently, to the even muscle development.

This gratifying conclusion indicates awareness of the riders of a regular leg switch importance for avoiding the unilateral imbalance. A large promotion of leg switch necessity coming from the scooter producers together with the natural fatigue in standing thigh most likely take part on this important awareness.

Additional Findings

Most of additional findings serve as underscoring information for the thesis. Most of results were expected.

There are, however, two results I found interesting to expand further. Firstly, the distributed scooter types showed a surprising uniformity. There were no off-road, mushing, or stunt scooters answered in the questionnaire. Obviously, the distribution of specialised scooter types is still rather scarce or, at least, geographically-based. Almost every SR owned at least one universal scooter. The specialised types (such as road scooter) usually represented the second purchased scooter.

Secondly, the kicked ankles proved to be the most common scooter-related injury. What is more, I expect even the scrapes being related to the kicked ankles. Most commonly, the kicked ankle is caused by the wide rear fork or the rear wheel skewer laterally protruding from the wheel hub. As it was already mention in the ergonomic chapter *15.1.2. Rear Fork*, to protect the kicking ankle it is advisable to employ some additional ankle protection (see the Figure 3), to sink the skewer into the rear fork (Figure 10) or to narrow a rear wheel hub and rear fork (Figure 9). The narrow hub with the sunken skewers became very popular in scooters recently (Lindner, 2012a).

18.5. **Further Topics for Discussion**

Although having a rich history, multiple scooter issues still remain the terra incognita for the majority scooter society. One such unsolved problem testified by experienced riders refers to the scooter shoes. Scooter riding treats the shoes in a harsh way, the kick impact is much more forceful than impact during running; most shoes are usually worn out after a single season. Horák (2013) brings up a solution commonly employed among scooter racers. The racers usually wear home-made shoes with an artificial rubber-supported sole in order to further resist the damage coming out of the kick. The serial produced scooter shoes, based on the Horák's template, are not on the market yet. The second lacking product represents the scooter-adjusted carrier. Usually, when on a scooter, the rider carries the gear either in a backpack, which is inconvenient to squat the extra weight, or in the handlebar bag. There is, however, no clear possibility to carry more touring essentials for longer voyages. The scooter carriers are not serially fabricated (the common bicycle carriers are fastened to seat pillar, which the scooter does not employ). The side panniers are not suitable, as they restrict the fluent back and front swing.

19. Conclusion

The modern scooter conception represents fresh, yet still evolving means of human transport and sport equipment. Scooter riding as such is very dynamic and combines in a specific way two natural movements, squatting and running. Both standing and kicking leg engage specific muscle groups to perform the associated movement. The regular leg switching leads to an even cycling of engaged working muscle groups and non-engaged relaxing muscle groups. Combining squatting and running, almost all lower limb muscles are involved in scooter propelling. This is also evident from the provided thorough scooter-propelling movement description.

As expected, the scooter riders with the rich scooter riding experience are better habituated to more natural and efficient riding, as opposed to the unexperienced non-scooter riders, who ride very carefully with the compact reach of motions. Still, some variables seem to be conservative and equally conformed to the both scooter riders and non-scooter riders (for instance mutual distribution of particular scooter-propelling cycles duration, ankle angle shift in standing leg *et cetera*).

The non-scooter riders demonstrated more impairment in body posture and more pain in back and neck area compared to the scooter riders. Although this result can be advocated by generally different lifestyle between two samples, the alternative explanation of the scooter having the therapeutic effect on the body posture should not be abandoned.

According to the anthropometrical-ergonomic evaluation, I provided several human dimensions to be respected in scooter construction in order to relate the scooter to human. Finally, I propose that the scooter producers fabricate at least two sizes of scooter models, in order to fit variable human dimensions.

To conclude the topic, I expect the scooter popularity will grow even bigger in the following years. A modern lust for originality will discover a large selection of scooter types or announced scooter events and expeditions. Hence, the scooter producers should be well prepared and enhance their assortment with ergonomically corresponding models. Because if the scooter does not fit, the riding feeling never becomes as unique as when riding a fitted scooter. Only the second instance provides the unabridged feeling of joy streaming from the fluent dynamics of scooter riding.

Author's Profile

Ondřej was born on 2nd March, 1991 in the Czech Republic and spent most of his life in the eastern town of Bohumín. There studied at Gymnázium Františka Živného for eight years. After graduating in 2010, he studied in the Department of Anthropology at Faculty of Science, Masaryk University, Brno. After graduating in 2013, Ondřej was conferred the bachelor's degree and initiated the master's degree study at the same place. In 2013/2014 Ondřej spent one year of Erasmus exchange study programme at Universitetet i Bergen, Norway, and in 2015 he absolved a two-month internship at Department of Human Evolution, Max Planck Institute, Leipzig, Germany.

In his spare time Ondřej truly enjoys listening to various music, reading of various books and socialising with various good friends. Six years ago he was given his first scooter, and very quickly became zealously passionate for scooter riding. Since then, the scooter represents another great hobby and a reliable venturing fellow.

Lexicon of Crucial Terms and Names

Anthropology – a scientific discipline concerning a humanity.

Anthropometry – an anthropological method of the measurement of the human individual.

Body posture – the symmetric stand at attention with relaxed but not flabby muscles.

Český svaz koloběhu – the Czech national scooter agent. ČSK organises the Rollo league, co-arranges international scooter competitions and promotes the scooter sport in the Czech Republic.

Ergonomics – a scientific discipline engaged in optimising of human activities, considering the contact objects, workplace, and human mental comfort.

Hannu Vierikko – Finnish scooter rider, a founder of Kickbike Ltd. company.

Jan "Fido" Horák – Czech scooter rider and enthusiast, an author of Jak na koloběžku essay, a non-academic yet erudite complex of scooter-related thoughts and propositions.

Karel Žďárek – Czech master of sports science, an author of the primal scooter-related thesis, Koloběh – Analýza techniky jízdy.

Kickbike – Finnish scooter producer. Probably the most reputable producer in Europe.

Kinematic recording – a technological method of movement recording.

Klein, Thomas, Meyer method – visual method for body posture evaluation.

Kostka – the most successful Czech scooter producer from Hanušovice.

Mibo – important Czech scooter producer from Rožnov pod Radhoštěm.

Petr Lindner – Czech scooter rider, journalist and photographer. He administers the website Přibližovadla.cz, the fun hub of scooter riding.

Scooter – a non-motorised vehicle consisting of a footboard mounted on two wheels and a long steering handle, propelled by resting one foot on the footboard and pushing the other against the ground.

Scooter biomechanics – set of human-made motions performed in order to propel and ride the scooter.

Silhouettographs – visual method for body posture evaluation.

Thijza Brouwer – secretary of Netherlandse Autoped Federatie, former chairperson of International Kicksled and Scooter Association.

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References

Book and Periodical References

Arvonen, S. (2002): *Jäälle - opas retkiluisteluun ja jäällä liikkumiseen*. Helsinki: Edita Prima Oy. 140 p., cited by Žďárek, M. (2005): *Koloběh – Analýza techniky jízdy*. Diploma thesis. Praha: Karlova Univerzita, Fakulta tělesné výchovy a sportu. 58 p.

Auerbach, B. M., Ruff, C. B. (2006): Limb bone bilateral asymmetry: variability and commonality among modern humans. *Journal of Human Evolution* 50: pp. 203–218.

Balasubramanian, V., Jagannath, M., Adalarasu, K. (2014): Muscle fatigue based evaluation of bicycle design. *Applied Ergonomics* 45(2): pp. 339–345.

Bernasconi, P., Kohl, J. (1993): Analysis of co-ordination between breathing and exercise rhythms in man. *Journal of Physiology* 471: pp. 693–706.

Bláha, P., *et al.* (1986): *Antropometrie československé populace od 6 do 55 let. Československá spartakiáda 1985. Díl I, část 1.* Praha: Ústřední štáb Československé spartakiády 1985. 288 p.

Bramble, D. M., Carrier, D. R. (1983): Running and breathing in mammals. *Science* 219(4582): pp. 251–256.

Braun, J., Anderle, P., Haverlík, I. (1978): *Chemie, fyzika, astronomie.* Praha: Albatros. 374 p.

Cibula, K. (2004): *Mechanika jízdního kola*. Praha: Vydavatelství ČVUT. 93 p.

Čermák, J., Chválová, O., Botlíková, V. (1998): *Záda mě už nebolí.* Praha: Nakladatelství Jan Vašut. 144 p.

Dylevský, I., Kálal, J., Kolář, P., Korbelář, P., Kučera, M., Noble, C., Otáhal, S. (1997): *Pohybový systém a zátěž.* Praha: Grada Publishing. 252 p.

Fabre, N., Perrey, S., Arbez, L., Rouillon, J-D. (2007): Neuro-mechanical and chemical influences on locomotor respiratory coupling in humans. *Respiratory Physiology & Neurobiology* 155(2): pp. 128–136.

Falk, H., Torp, A. (1999): *Etymologisk Ordbog over det Norske of det Danske Sprog*. Oslo: Bjørn Ringstrøms Antikvariat. 1089 p.

Garlando, F., Kohl, J., Koller, E. A., Pietsch, P. (1985): Effect of coupling the breathing and cycling rhythms on oxygen uptake during bicycle ergometry. *European Journal of Applied Physiology* 54(5): pp. 497–501.

Gilbertová, S., Matoušek, O. (2002): *Ergonomie. Optimalizace lidské činnosti.* Praha: Grada Publishing. 240 p.

Haladová, E., Nechvátalová, L. (2005): *Vyšetřovací metody hybného systému*. Brno: Národní centrum ošetřovatelství a nelékařských zdravotnických oborů. 135 p.

Halliday, D., Resnick, R., Walker, J. (2000): *Fyzika. Vysokoškolská učebnice obecné fyziky.* Brno: Vutium. 1198 p.

Heitkamp, H. C., Horstmann, T., Mayer, F., Weller, J., Dickhuth, H. H. (2001): Gain in strength and muscular balance after balance training. *International Journal of Sports Medicine* 22(4): pp. 285–290.

Herlihy, D. V. (2004): *Bicycle: the history*. London: Yale University Press. 470 p.

Hoad F. T. (1993): *The Concise Oxford Dictionary of English Etymology*. New York: Oxford University Press. 552 p.

Horáčková, L. (2007): *Anatomie pro antropology I. Pohybový systém.* Brno: Akademické nakladatelství CERM. 169 p.

Kittlerová, Š. (2006): *Aplikace koloběhu pro zrakově postižené.* Diploma thesis. Praha: Karlova Univerzita. Fakulta tělesné výchovy a sportu. 120 p.

Knußmann, R. (1988): *Anthropologie: Handbuch der vergleichenden Biologie des Menschen (4. Auflage des Lehrbuchs der Anthropologie begründet von Rudolf Martin).* Band I und II. Jena – New York – Stuttgart: Gustav Fischer.

Kohl, J., Koller, E. A., Jäger, M. (1981): Relation between pedalling and breathing rhythm. *European Journal of Applied Physiology* 47(3): pp. 223–237.

Kovařík, M. (2011): *Antropometrický výzkum dospělé populace a jeho aplikace v oblasti interiéru a architektury.* Dissertation. Brno: Vysoké učení technické, Fakulta architektury. 78 p.

Laios, L., Giannatsis, J. (2010): Ergonomic evaluation and redesign of children bicycles based on anthropometric data. *Applied Ergonomics* 41(3): pp. 428–435.

Machek, V. (1968): *Etymologický slovník jazyka českého*. Praha: Academia. 868 p.

McBride, J. M., Cormie, P., Deane, R. (2006): Isometric squat force output and muscle activity in stable and unstable conditions. *Journal of Strength and Conditioning Research* 20(4): pp. 915–918.

Mlýnek, T. (2010): *Metodika jízdy na koloběžce na 1. stupni ZŠ.* Diploma thesis. Brno: Masarykova univerzita, Pedagogická fakulta. 96 p.

Oertel, C., Neuburger, H., Sabo, A. (2010): Construction of a test bench for bicycle rim and disc brakes. *8th Conference of the International Sports Engineering Association (ISEA)*: pp. 2943–2948.

Opálková, M., Dvořáková, H., Augustýn, T. (2013): Prevence vadného držení těla u dětí z pohledu fyzioterapeuta. *Česká kinantropologie* 17(4): pp. 35–49.

Pallová, I., Ryšávková, A., Chalupová, M. (2003): Význam rotace obratlů v rámci vývoje prostorové deformity páteře. In: Kirchner, J., Kavalíř, P., Adámková, M. (Eds.): *Nové perspektivy výzkumu a praxe v kinantropologii*. Praha: Univerzita Karlova, Fakulta tělesné výchovy a sportu. pp. 32–33.

Peters, M. (1988): Footedness: Asymmetries in Foot Preference and Skill and Neuropsychological Assessment of Foot Movement. *Psychological bulletin* 103(2): pp. 179–192.

Powell, E. C. (2003): Non-motorized vehicles and walkers: Going for “broke”. *Clinical Pediatric Emergency Medicine* 4(2): pp. 103–111.

Raßler, B., Kohl, J. (1996): Analysis of coordination between breathing and walking rhythms in humans. *Respiration Physiology* 106(3): pp. 317–327.

Riegerová, J., Ulbrichová, M. (1998): *Aplikace fyzické antropologie v tělesné výchově a sportu.* Olomouc: Vydavatelství Univerzity Palackého. 185 p.

Rychter, W. (1979): *Dzieje samochodu.* Warszawa: Wydawnictwa Komunikacji i Łączności. 451 p.

Seliger, V., Vinařský, R., Trefný, Z. (1983): *Fyziologie člověka pro fakulty tělesné výchovy a sportu.* Praha: Státní pedagogické nakladatelství. 429 p.

Soulek, I., Martínek, K. (2000): *Cyklistika*. Praha: Grada Publishing. 112 p.

Švestková, M. (2008): *Hodnocení držení těla žáků mladšího školního věku na vybraných brněnských školách*. Diploma thesis. Brno: Masarykova univerzita, Pedagogická fakulta. 68 p.

Tarábek, P., Červinková, P., *et al.* (2006): *Odmaturuj z fyziky*. Brno: Didaktis. 224 p.

Vargová, L., Páč, L. (2008): *Anatomie pro antropology II. Splanchnologie*. Brno: Akademické nakladatelství CERM. 178 p.

Wilhelm, Z., Bravený, P., Fišer, B., Honzíková, N., Nováková, Z., Šimurdová, M., Štouračová, Y. (2010): *Stručný přehled fyziologie člověka pro bakalářské studijní programy*. Brno: Muni Press. 117 p.

Žďárek, M. (2005): *Koloběh – Analýza techniky jízdy*. Diploma thesis. Praha: Karlova Univerzita, Fakulta tělesné výchovy a sportu. 58 p.

Electronic References

Allmänna Idrottsklubben, AIK (2011): Sparkstötting i AIK:s regi. Retrieved from http://www.aik.se/aikindex.html?/historik/sparkstotting/historik1.html. (28th August 2014)

Bez Pedálů. Seriál amatérského koloběhu. Retrieved from http://www.bezpedalu.cz/. (27th January 2015)

Český svaz koloběhu (2013): Historie koloběžkového sportu. Retrieved from http://www.ceskykolobeh.cz/cs/historie/historie-kolobezkoveho-sportu-2. (19th November 2014)

Český svaz koloběhu: Kluby. Retrieved from http://www.ceskykolobeh.cz/cs/kluby. (27th January 2015)

CNTRL.fr (2012): Ortolang – Outils et Ressources pour un Traitement Optimisé de la LANGue. Retrieved from http://www.cnrtl.fr/etymologie. (26th August 2014)

Doxtor.cz. Zakázková kovovýroba a výroba sportovních potřeb. Retrieved from http://doxtor.cz/fotogalerie/. (22nd March 2015)

E-kolobezka.cz: Internetový specialista na dovoz a prodej koloběžek. Retrieved from http://www.e-kolobezka.cz/cs. (7 th February 2016)

Exion Scooter Sport: Handbuild carbon scooters. Retrieved from http://www.exionscooters.nl/models.htm. (18th February 2015)

Gravity Scooters. Retrieved from http://online-shop.gravityfreescooters.com/. (28th January 2015)

Harper, D. (2014): Online etymology dictionary. Retrieved from http://www.etymonline.com. (13th July 2014)

Horák, “Fido”, J. (2011): *Jak na koloběžku.* 30 p. Retrieved from http://priblizovadla.cz/poctenicko-aneb-kolobezkova-disertacka/. (17th July 2014)

Horák, “Fido”, J. (2013): Čím se dupou závody? Nohama. Ale dobře obutýma! *Přibližovadla.cz*. Retrieved from http://priblizovadla.cz/cim-se-dupou-zavody/. (19th January 2016)

Horák, “Fido”, J. (2015): Prostor pro jezdce aneb geometrie stavby koloběžky z pohledu závodníka. *Přibližovadla.cz*. Retrieved from http://priblizovadla.cz/prostor-pro-jezdce/. (19th January 2016)

IKSA world, International Kicksled and Scooter Association. IKSA Promotional material, Calorie Consumption. Retrieved from http://www.iksaworld.com/. (19th March 2015)

Internationale-worterbuch.com (2016). Retrieved from http://internationale-worterbuch.com/definitions/?german_word=scooter. (27th January 2016)

Intrea – Piko s.r.o. Retrieved from http://www.intrea.cz/default.aspx. (22nd January 2015)

K-bike (a), výroba sportovních koloběžek. Retrieved from http://kolobezka.com/kbike_katalog/katalog_kbike.html. (8th December 2014)

K-bike (b), K-bike, specialista na 12" sportovní koloběžky. Retrieved from http://kolobezka.com/kbike_firma/kbike_firma.html. (22nd January 2015)

Kennedy, E., J. (1990): Yoga Breathing Techniques: Implications for Stress Management, Health, and Psychophysiological Research. *Articles on Yoga.* Retrieved from http://jeksite.org/yoga/resp.htm. (24th January 2016)

Kick your life, kick France – Tour de France by Footbike project. Retrieved from http://www.kickfrance2013.com. (27th February 2015)

Kickbike.com. Retrieved from http://kickbike.com/kickbike-scooters/. (18th February 2015)

Kittlerová, Š. (2009): *Technika jízdy na koloběžce*. 20 p. cited from Kittlerová, Š. (2006): *Aplikace koloběhu pro zrakově postižené.* Diploma thesis. Praha: Karlova Univerzita. Fakulta tělesné výchovy a sportu. 120 p. Retrieved from http://www.kkplzen.cz/technika-jizdy/. (7th December 2014)

Klub koloběhu Lipník nad Bečvou. Lipenští dráčci a draci. Retrieved from http://www.1klubkolobehulipnik.cz/. (27th January 2015)

Koloběžky pro dospělé. Retrieved from http://www.kolobezky-pro-dospele.cz/kolobezky-mestske/. (8th December 2014)

Kostka-kolobka (a). Retrieved from http://cz.kostka-kolobka.eu/#. (8th December 2014)

Kostka-kolobka (b). O společnosti. Retrieved from http://cz.kostka-kolobka.eu/dokumenty/o-spolecnosti/. (20th January 2015)

Lindner, P. (2010): Koloběžka Kostka 28″ Laser star Racer – podrobná recenze. *Přibližovadla.cz*. Retrieved from http://priblizovadla.cz/kolobezka-kostka-28-laser-star-racer-%E2%80%93-podrobna-recenze/. (21st December 2014)

Lindner, P. (2011a): Mibo RaceK – podrobná recenze. *Přibližovadla.cz*. Retrieved from http://priblizovadla.cz/mibo-racek%E2%80%93podrobna-recenze/. (21st December 2014)

Lindner, P. (2011b): Nejoblíbenější značkou koloběžek je… *Přibližovadla.cz*. Retrieved from http://priblizovadla.cz/nejoblibenejsi-znackou-kolobezek-je%E2%80%A6/. (18th February 2015)

Lindner, P. (2012a): Kickbike Race Max 20 – podrobná recenze. *Přibližovadla.cz*. Retrieved from http://priblizovadla.cz/kickbike-race-max-20-podrobna-recenze/. (21st December 2014)

Lindner, P. (2012b): Mibo Tiny – podrobná recenze. *Přibližovadla.cz*. Retrieved from http://priblizovadla.cz/mibo-tiny-podrobna-recenze/. (31st January 2015)

Lindner, P. (2012c): Kickbike Sport Max 18 – první kilometry. *Přibližovadla.cz*. Retrieved from http://priblizovadla.cz/kickbike-sport-max-18-prvni-kilometry/. (20th February 2015)

Lindner, P. (2013): Co jsme viděli na For Bikes 2013? Koloběžky a také skládací kola… *Přibližovadla.cz*. Retrieved from http://priblizovadla.cz/co-jsme-videli-na-for-bikes-2013-kolobezky-a-take-skladaci-kola/. (18th February 2015)

Mibo Ltd. Retrieved from http://www.mibospace.com. (15th July 2014)

Mibo.cz (a). Historie koloběžky a koloběhu. Retrieved from http://www.mibo.cz/podpora/historie-kolobezky-a-kolobehu. (8th December 2014)

Mibo.cz (b). Koloběžky Mibo. Retrieved from http://www.mibo.cz/kolobezky-mibo. (18th February 2015)

Mibo.cz (c). Prodejny. Retrieved from http://www.mibo.cz/prodejny. (20th January 2015)

Micro scooters. Retrieved from http://www.microscooters.com.au/about-us. (9th December 2014)

Micro. Švýcarské skládací koloběžky a odrážedla Micro. Retrieved from http://www.micro-kolobezky.cz/. (9th December 2014)

Morxes. Retrieved from http://www.morxes.com/. (5th March 2015)

Nederlandse Autoped Federatie (2013): NAF (Nederlandse Autoped Federatie). Retrieved from http://www.autoped.nl/home.htm. (28th August 2014)

Nitro scooters. Největší prodejce motokoloběžek v Evropě. Retrieved from http://www.motokolobezky.cz/cs/. (21st December 2014)

Oxford University Press (2014): Oxford Dictionaries. Retrieved from http://www.oxforddictionaries.com. (13th July 2014)

PSP – Klub Koloběhu Plzeň. Retrieved from http://www.kkplzen.cz/. (27th January 2015)

Sciaga.pl (2014): Słownik etymologiczny języka polskiego. Retrieved from http://www.sciaga.pl. (14th July 2014)

Sixteen koloběžky. Retrieved from http://www.sixteen.cz/. (22nd January 2015)

Smithsonian (2012): The Smithsonian Institution. Retrieved from http://smithsonian.tumblr.com. (27th August 2014)

Social Science Statistics (2016): Chi-Square Test Calculator. Retrieved from http://www.socscistatistics.com/tests/chisquare2/Default2.aspx. (18th January 2016)

Sportovní Klub Koloběhu Lipník nad Bečvou. Lipenští draci. Retrieved from http://www.kolobehlipnik.cz/index.php. (27th January 2015)

Suomisanakirja.fi (2013): Suomi sanakirja. Retrieved from http://www.suomisanakirja.fi. (26th August 2014)

Svět koloběžek. Retrieved from http://www.svetkolobezek.cz/. (21st December 2014)

Technor. Technické normy ČSN. Retrieved from http://www.technicke-normy-csn.cz/o-nas.html. (18th February 2015)

Ultima K.Lap Team. Retrieved from http://www.ultimaklapteam.cz/. (27th January 2015)

Vella-Náchod s.r.o. Český výrobce sportovního oblečení a reklamních poutačů. Retrieved from http://www.vellacz.eu/index.php/kolobezky. (22nd January 2015)

Wiktionary.org (2014): Russian-language Wiktionary. Retrieved from http://ru.wiktionary.org. (15th July 2014)

Yedoo scooters & bikes. Retrieved from http://www.yedoo.eu/en/default.aspx. (28th August 2014)

Zkus Kolobku! (2016): Zdravé nadšení z pohybu. Retrieved from http://zkuskolobku.cz/. (27th January 2016)

Other References

Brouwer, T.: personal correspondence. (17th November 2014)

Czech Republic. Road Transportation Act 361/2000 Sb. § 57, subsection 2. Retrieved from http://www.zakonyprolidi.cz/cs/2000-361#cast2. (19th November 2014)

Czech Republic. Technical Competence and Technical Conditions of Traffic on a Road Order 341/2002 Sb., appendix 13. Retrieved from http://www.zakonyprolidi.cz/cs/2002-341. (19th November 2014)

ČSN EN 14619 (2005): Česká technická norma. Kolečková sportovní zařízení - Koloběžky -Bezpečnostní požadavky a zkušební metody.

ČSN EN ISO 7250-1 (2010): Česká technická norma. Základní rozměry lidského těla pro technologické projektování. Část 1: Definice a orientační body tělesných rozměrů.

OptiTrack: NaturalPoint, Inc. [Computer software]. Retrieved from www.optitrack.com.