Step by step analysis of bicycle mounting and dismounting

Strategies and kinematics

Internship Report
Roessingh R&D
June-September 2014
Author: Paul T.C. Straathof
Project: SOFIE

Preface

This internship report is the result of working 3 months at Roessingh Research and Development, and is part of my master studies Biomedical Engineering at the University Twente. It was very interesting and meaningful to participate in the SOFIE project and also to get a good idea how it is be working for a research institute. I enjoyed the amount of freedom I was given, being able to come up with my own ideas and solutions.

I would like to thank all my colleagues for the great and inspiring time I had at RRD, but in special I would like to thank Chris Baten for his technical input with regard to the analysis of the kinematic data.

Most of my thanks go out to my internship supervisor Rosemary Dubbeldam, as she always provided constructive feedback and was able to help me decide what to analyse from the enormous amounts of data available.

Hopefully, with this report in hand, the research of safety for elderly cyclists can be improved, leading to a safer future.

Enschede, October 2014
Paul Straathof

Summary

In The Netherlands, famous for its bicycles and cycling lanes, every year 18000 older cyclists get into a single-bicycle accident severe enough to require medical attention. A considerable part of these accidents happen at low velocities or when mounting and dismounting the bicycle. Contrary to the normal cycling movements, only little is known about the mounting and dismounting of a bicycle and the risks involved for elderly cyclists. This study aims to describe and categorize the various ways a bicycle can be mounted and dismounted and the effects of age and gender are assessed. This is also done for the kinematics and physical and cognitive abilities of the participants.

The participants are split in 2 groups, based on their age: 13 between the age of 18 to 40 years old and 33 above 65 years old. Of the group of older subjects 13 had a bicycle fall history and were considered to be the fall risk group. The kinematic and video data was used from a previous study, which was also part of the SOFIE project at RRD, where the subjects wore 10 wireless inertial measurement units while mounting, cycling and dismounting a bicycle. From these mounting and dismounting phases the video data was used to describe and categorize the various methods used by the subjects. After this a quantitative assessment was made to find a relationship between the kinematic parameters and age, gender and fall risk as well as their cognitive and physical abilities.

From the videos 2 mounting, 3 dismounting, and 2 waiting categories where identified. The largest difference between the mounting and dismounting categories could be seen in which foot was first placed on or removed from the pedal. The older cyclists as well as the female subjects prefer other strategies than the young or male subjects. This can best be seen during mounting where 70% of the young cyclists lift their inner foot through the frame and place it on the outside pedal while 80% of the older cyclists prefer to put their outer foot on the inside pedal which is on the same side of the bicycle as they are. They gain speed by stepping with their inner foot, while the young subjects gain speed by stepping with their outside foot or by pushing their inside foot hard down onto the pedal. Additionally bicycle and cyclist kinematics could be related to age, gender and fall risk, as well as cognitive and physical abilities and the properties of the bicycle itself. The differences and effects found in this study are a start in explaining the high injury risk for older and female cyclists in single-bicycle accidents.

Keywords: *cycling kinematics, elderly, getting on or off a bicycle, mounting and dismounting*

Table of Contents

1 Introduction

This report presents the results of the internship assignment carried out at Roessing Research and Development in Enschede, The Netherlands, and is part of the compulsory internship period for the Biomedial Engineering master at University Twente in Enschede.

1.1 RRD background

Roessingh Research and Development (RRD) exists for more than 20 years and is an internationally recognized research institute as part of the rehabilitation centre Het Roessingh in Enschede, The Netherlands. RRD has a multidisciplinary staff of about 60 employees, consisting of: rehabilitation physicians, (biomedical) engineers, kinesiologists, physiotherapists, and ergotherapists. A clear organisational division is made between telemedicine and rehabilitation research. Both are managed by their own cluster managers who themselves are managed by a small board of directors and the annual general meeting. Each cluster is occupied by senior, postdoc, and junior researchers, and research assistants.

RRD does most of its research in the topics of rehabilitation technology and telemedicine. They are subdivided into research topics of monitoring and diagnostics, and research that is focussed on the development of better treatment programs and methods. For more than 20 years RRD has fulfilled a bridging function between science, rehabilitation and care. In the past few years more and more regional and international companies have become part of their research and development activities program. This has helped them put their developed products into the market, examples of which are the peroneal nerve stimulator and the Freebal trainings robot with Furbalhunt game. Company involvement has also helped projects where RRD was clinically evaluating new and innovative care products. For this purpose RRD has several research facilities where measurements can be done on gait, posture, brain activity, muscle activity, oxygen usage, and much more.

1.2 Assignment background

1.2.1 SOFIE

This internship assignment was part of the SOFIE project [1], which has the goal to develop a "smart and supporting bicycle for the elderly". Cycling is an important and widely accepted means of transportation in The Netherlands and a lot of elderly people cycle as well. Due to the increase in elderly population, as well as the fact that cycling improves their wellbeing, there is an increase in elderly cyclists [2, 3]. This increase also leads to more cyclists getting injured and requiring medical attention: each year 18000 cyclists older than 55 years need medical attention after an accident [2, 4]. The cause of bicycle accidents varies widely, but 75% of the reported accidents were single-bicycle crashes: a type of accident where no other road users are involved [2]. For this type of accident, cyclists who are 65 years or older have a 2-5 times higher risk of getting injured when compared to other adult cyclists [5].

To increase the safety of especially this elderly group of cyclists, the SOFIE project was created. It runs from February 2011 until February 2015 and has INDES and the University Twente as partners. At the university a human-bicycle model is being developed in order to simulate the effects that certain safety measures have on the stability of an elderly cyclist. In addition, an actual bicycle simulator is being build.

Measurements of cyclists will be conducted with regard to their kinematics, and will focus on the differences between young and old cyclists as little is known about these differences. Test protocols will be developed to enable researchers to find out what parameters of cycling affect the stability of a cyclist. This could give a better insight in how to prevent accidents by compensation or prediction measures.

1.2.2 Kinematic research

This kinematic research was executed and reported on by Gengler [6]. A large database of video files was also build to accompany these measurements. These files cover a lot of the different measurements per subject, including their motions when mounting, dismounting, and waiting while stationary. However, no analysis has so far been done on the mounting and dismounting phases as only the data from the cycling phase was used. Distinction between these 3 phases was based on a simple velocity threshold. The conclusions of this research were that there are significant physical and cognitive differences between young and elderly cyclists and that these are related to the differences in kinematics between those groups. Overall, elderly cycle at lower velocities with an increased standard deviation of the roll angle, steer angle, steer angular velocities, and sway angle.

The subjects for this part of the measurements of the SOFIE project were recruited through advertisements in the local newspaper and by spreading flyers at local meeting points. The inclusion criteria encompassed 2 specific groups: young participants between the age of 18 and 40 and older participants aged 65 years or older. Participants in both groups had to cycle regularly in daily life, without the help of any motor support. Exclusion criteria were based on visual or auditory impairments or an indication of high fall risk during measurements based on their fall history. This resulted in 15 young and 33 old participants singing an informed consent. This study was approved by the Medical Ethical Committee Twente, Enschede, The Netherlands and the following demographic data were recorded: gender, age, body weight, height, self-reported medication usage and degenerative diseases, and fall history.

All the kinematic data of the cyclist and the bicycle was recorded using 3D wireless inertial movement sensors (MTw-38A70G20 Xsens, Enschede, The Netherlands) with the FusionTools software (Roessingh Research and Development, Enschede, The Netherlands) built around the Xsens sensor SDK MT 3.81. The cyclist had 8 sensors attached to the following body parts: left foot, right foot, left shank, right shank, left thigh, right thigh, pelvis and sternum. The bicycle had 1 sensor attached to the frame and 1 to the steer. All sensors were attached to the bicycle and cyclist by means of the standard Xsens elastic strap set for wireless sensors. Pre-measurement calibrations were done to facilitate the translation of the sensor orientation data into body segment orientation data by using the magnetic north as point of reference. This was also used to properly align the acceleration and angular velocity data.

1.2.3 Current state

Taking into account the results from the previous research, it can be expected that for mounting and dismounting differences are to be found between young and elderly cyclists. From the available literature it does not become clear what kind of differences are to be expected between mounting and dismounting, nor what parameters might have an effect on safety and stability. Differences in accidents are reported with regard to single bicycle crashed: 22% of the older cyclists had an accident when mounting or dismounting the bicycle while only 8% of the younger adults had such an accident [7]. Scheppers and Klein-Wolt suggested that physical abilities and the choice of mounting or dismounting method can have an influence [8]. This suggestion was partially confirmed by Hagemeister and Tegen-Klebingat as they found that physical abilities are related to mounting and dismounting problems [9].

2 Problems

As was stated in the introduction, not much is known about mounting and dismounting methods, whether there are any differences between young and old cyclist, let alone if there are any reliable indicators for stability. This lack of knowledge and understanding is the main problem that needs to be solved, but which cannot be done by a single analysis of someone mounting a bicycle. Several sub-problems need to be formulated to allow for specific solutions to be applied.

The first problem is the lack of knowledge about the kind of mounting and dismounting methods (MDMs) that are used by cyclists. It is clear from examples in daily life that there are clear differences in the ways people mount and dismount their bicycles, but these differences have never before been described nor categorised in a systematic way. Therefore it is unknown what exact methods are used, their popularity, and possible correlations with subject parameters like age or gender. As long as this remains unknown, it will be impossible to analyse the available kinematic data of the subjects, as the data cannot be subdivided per MDM. This is necessary as MDM differences predominate the results as they are expected to be larger than any intersubject differences.

The second problem is the lack of categorisations. Assuming there are many ways of getting on and off a bicycle possible, a system of categories is needed to reduce the amount of variables introduced by describing the MDMs.

The third problem is related to balance keeping while mounting or dismounting a bicycle. For normal cycling many articles have been written describing various measures of balance control and stability [9-11]. However, not a single article was found about any measure for balance control during the specific movements of mounting and dismounting a bicycle, let alone any age or gender related effects.

In short, the problems can be reduced to:

- No MDM descriptions are available
- No MDM categorisations are known
- No MDM parameters of stability are known

3 Methods

Several methods are proposed to solve the defined problems. Video analysis and MDM visualisation are introduced to describe and categorize the MDMs. Kinematic and subject data analyses are developed to facilitate stability quantification.

3.1 Video analysis

Based on the 3 distinct movements of mounting, dismounting, and waiting, a list of all relevant video files was compiled per subject. This list also includes any unexpected or deviating behaviour. After having gathered a list of relevant video files, they were watched repeatedly and each movement was chronologically divided into separate phases. The movements of the subject and bicycle were noted down per phase, and a video still was saved to accompany each description.

Users, who showed similar movements during the mounting, demounting, or waiting phases, were assigned a method number in order to find out how many different methods were used by the subjects. When all the different methods had been found, they were compared and combined into a fewer amount of categories (MDCs) when they showed large similarities. This reduced the amount of variables and made the analysis much easier.

3.2 Kinematic data analysis

3.2.1 Measurement selection

To support the video analysis, 2 different measurements were chosen that included normal mounting, dismounting, and waiting movements of the subjects:

- Mounting and dismounting when cycling at a normal speed
- Dismounting and mounting while waiting in between

Several other measurements were available as well, but due to the exploratory nature of this research, as well as the results from the video analysis, the chosen measurements were expected to provide the largest kinematic differences.

3.2.2 Movement phase distinctions

To allow for the kinematic data to be analysed for the separate mounting and dismounting phases, a definition was needed as to when these phases actually started and ended. From the videos it was clear that when mounting, a subject always starts by moving one of its legs away from the neutral stance next to the bicycle. Therefore the starting point of the mounting phase was taken to be this first leg movement present in the kinematic data. The end of the mounting phase could not be defined like that, as it was directly followed by another movement phase: cycling.

The biggest difference between mounting and cycling is the change in the movement pattern of both legs. The asynchronous movements of the mounting phase turn into synchronous movements of the cycling phase. The transition between both patterns was decided to mark the mounting phase.

The dismounting phase was defined to start when no synchronous leg movements were discernible anymore. If the subject kept their legs motionless while passively slowing down or actively braking, dismounting was considered to start as soon as the first asynchronous leg activity was showing. The dismounting phase always ended with the subject standing in upright stance next to the bicycle.

Per measurement's mounting and dismounting phase, several other phases were distinguished as well: a foot balance, a vehicle balance, and a stepping phase. The foot balance phase occurred when a subject has one foot on the ground and is moving the other foot towards the bike when mounting, or away from the bike when dismounting. The vehicle balance phase followed the foot balance phase when mounting, or preceded it when dismounting, the bicycle. During the vehicle balance phase, which lasts till the end of the mounting phase or starts from the beginning of the dismounting phase, the subject has to balance the vehicle as well as itself to remain in an upright position. The stepping phase occurred only during the vehicle balance phase while mounting and was characterized by several stepping motions with one leg, in order to gain speed.

3.2.3 Kinematic parameter selection

To be able to analyse the available kinematic data, it is important to first select the most interesting and relevant parameters. Which parameters to choose, would normally be based on the available literature. However, due to the already shown lack of previous research, parameter selection focussed mainly on joint and limb angles, velocities, and accelerations, as those were involved most in the mounting and dismounting movements of the subjects.

Also the vehicle's sway and roll angles, velocities, and accelerations were taken into account, as well as the time and velocity parameters of the various kinematic phases. Based on those preferences the following kinematic parameters were chosen from the measurement data:

- Time required for several parts of the mounting and dismounting phases
- Bicycle longitudinal velocity and acceleration
- Bicycle roll angle, velocity, and acceleration
- Bicycle yaw angle, velocity, and acceleration
- Bicycle steer angle, angular velocity, and angular acceleration
- Outer limb thigh angular velocity and angular acceleration
- Inner limb thigh angular velocity and angular acceleration
- Sternum angular velocity and angular acceleration

3.2.4 Measurement space

In all kinematic data, the 3 axes of translation and rotation were defined as following:

- X-axis: longitudinal (translation) and roll (rotation)
- Y-axis: lateral (translation) and pitch (rotation)
- Z-axis: vertical (translation) and yaw (rotation)

These definitions were used for both the subject's body as well as the bicycle. All rotations of the moving body parts during the calibration phase were assumed to be around the y-axis. The z-axis was found by looking at the acceleration of -9.81 $m \cdot s^{-2}$ due to the earth's gravitational field. The x-axis was then found as it is assumed to be orthogonal to the y-axis and z-axis in Euclidean space. The same was done for the bicycle; except that the y-axis was found by rotating it, while stationary, under an angle with the vertical axis. The steer of the bicycle has its own rotational space, namely a single rotational axis. This can be found by rotating the steer from left to right several times and using the resulting angular velocities to retrieve the rotational axis.

As all measurements were done on a flat parking lot, no large rotations around the y-axis or any vertical accelerations of the vehicle were expected. Any variations that were measured were due to deformations of the bicycle tires when loaded as well as vibrating sensors due to an uneven cycling surface.

3.2.5 Data processing

Loading and calibration

All the measurement data was loaded using the FUSIONtools from the FUSION software package (FUSION version 2013, Roessingh Research and Development, Enschede), which runs under LabVIEW (LabVIEW version 2011, National Instruments, Texas, U.S.). Calibration was required to make sure all the data was presented in the required measurement space. This calibration was done within the FUSIONtools viewer and was based on a set of standard movements that was carried out per subject before the start of each measurement trial. These movements are:

- 5 squats and 5 heel rises
- A minimum of 5 steer rotations in both directions
- 5 bicycle rotations in the x, y, and z axis.

Calibrations had to be done before the data of a subject was loaded for the first time. After a successful calibration, the settings were saved to be used for the calibration of all the datasets per subject. The correctness of the calibrations was checked in several ways:

- Comparing the results with those from the manual
- Using a stick figure to view the movements of the subjects
- Check for physical impossibilities as well as expected values and signal signs

After the calibration the entire dataset per measurement was saved to a tab-delimited file which could be loaded in Excel or Matlab for further viewing, processing, or analysis.

Automated processing script

Matlab (Matlab R2014a, Mathworks, U.S.A) was used to process all the available data. Because 423 measurement files had to be loaded and processed, an automated processing script (APS) was designed that could execute the following steps:

- Load the subject parameters
- Check for missing files or data entries
- Load the calibration and data files
- Check for proper selection windows for the several phases
- Process and analyse the data
- Compile and save the data as Microsoft Excel files

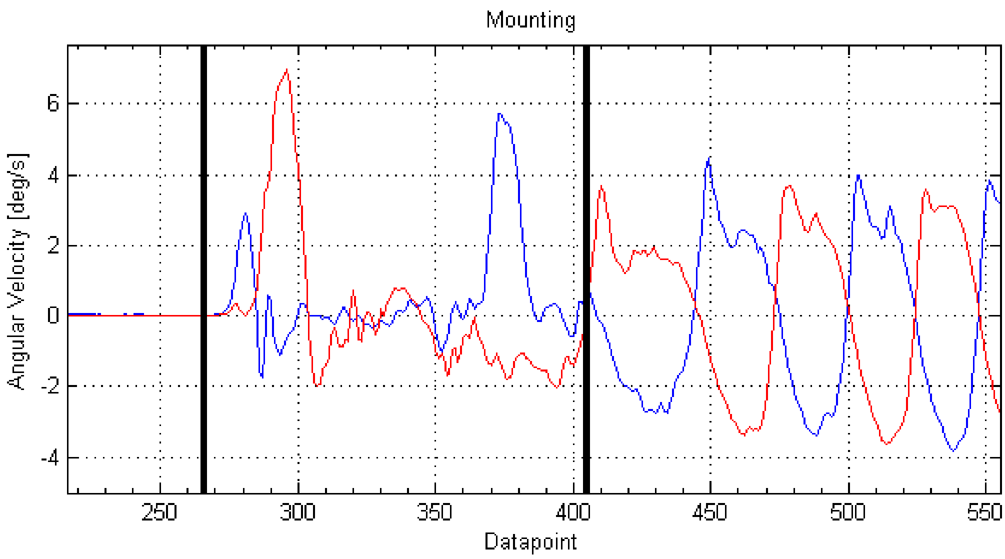
This stepwise approach allowed for reliable analysis of the available data as well as continuity for future use with the same or related projects. Several files were generated that could be used for multiple purposes:

- Subject specific results that can be directly used for the statistical analysis
- Age results per MDM
- Age results per MDC
- Gender results per MDM
- Gender results per MDC

The information from the last 4 files could also be acquired by any statistics program, but this can save time when a quick overview of the results is required.

Phase selection

To find the exact start- and endpoints of the various phases, several methods were adopted. For the mounting and dismounting phases a plot was made for each subject's trial, showing the angular velocity around the y-axis of both knees for the full measurement's duration. From this overview the start and endpoints were clearly discernible, as can be seen from the close ups in Figure 1.



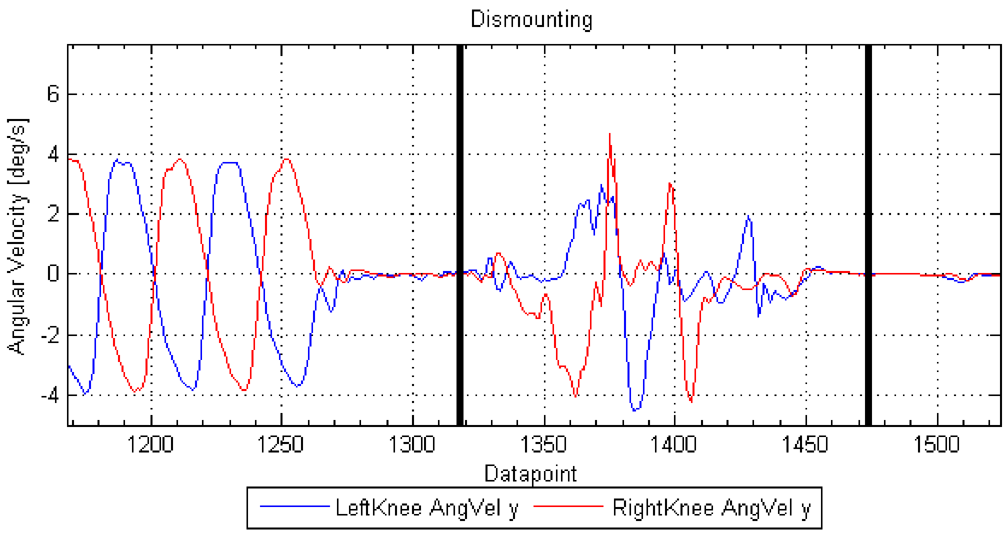


Figure 1. Start and end points close ups mounting (top) and dismounting (bottom) for subject 1 and trial 1.

The transitions from mounting to cycling and back to dismounting were clear in most cases, as can be seen in Figure 1, but when a case happened like that in Figure 2, the closest fit was used.

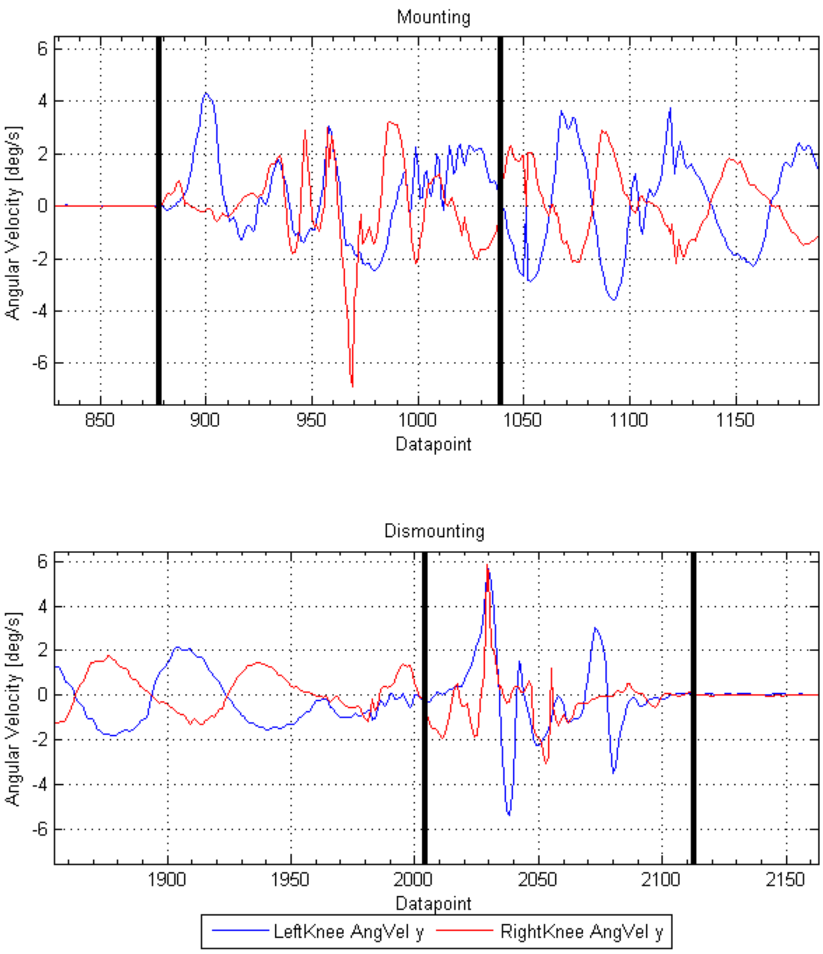


Figure 2. Mounting to cycling point (top) and cycling to dismounting point (bottom) for subject 33 and trial 1.

These difficult cases were also the reason that the window selection had to be done manually per subject and per trial, as no automation was possible to accurately find, for all subjects, the point where mounting becomes cycling and again when cycling becomes dismounting. Other selection parameters were tried, but none of them were as clearly discernible as the knee angular velocities. Using the data from both knees was done to make sure that different mounting and dismounting methods did not lead to misplaced selection windows due to varying levels of knee bending.

The point in time where foot balance changes into vehicle balance can most easily be found by looking at the vertical acceleration of both feet. The moment the stationary balancing foot starts moving i.e. is lifted off the ground, the foot balance phase stops. This transition can be seen in Figure 3. The reverse happens in the dismounting phase.

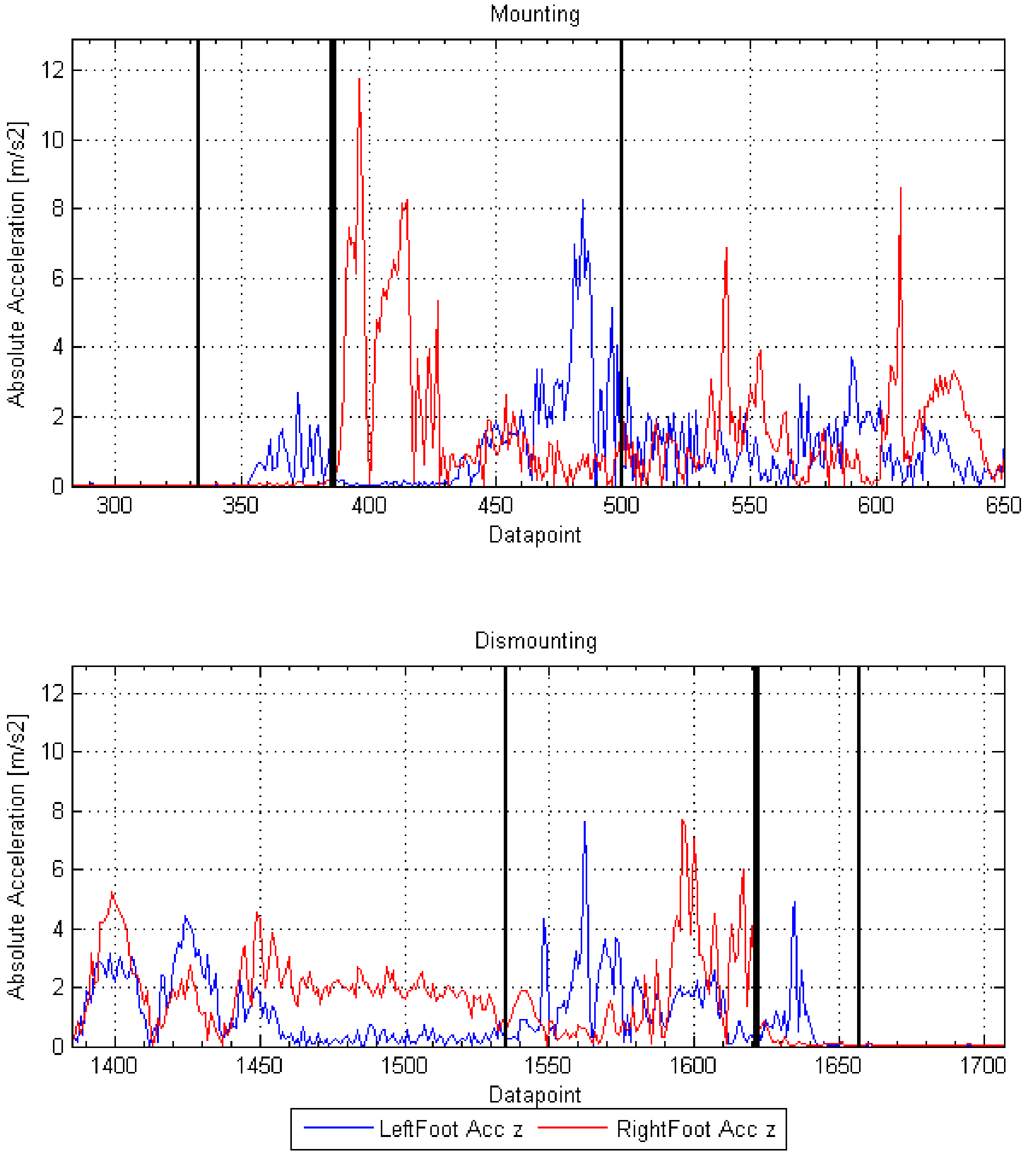


Figure 3. Foot balance end point (top) and foot balance start point (bottom), as thick black line, for subject and trial 1.

The stepping phase selection was the only one who was automated as it showed a very discernible change in several kinematic parameters.

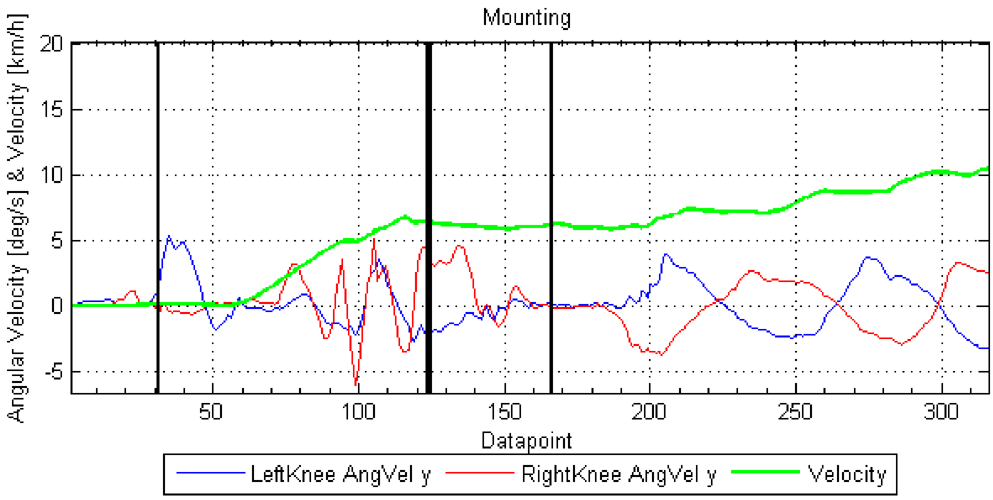


Figure 4. Step phase end point, as thick black line, for subject 22 and trial 1.

Averaging

As each measurement was done 2 times, the results, but not the data, were averaged over these 2 trials. The APS also allowed for averaging over the results of both measurements, effectively creating a single measurement with double the amount of available data. This would only be applicable however if the subjects were to mount in the same way, regardless of the task they had to carry out afterwards. A separate analysis was done to investigate the effects of a full average compared to an intra-trial average.

3.3 Statistical analysis

3.3.1 Subject parameters

Per subject the measurement data for the following physical and cognitive parameters were available:

- Age
- Fall risk
- Gender
- Height
- Weight
- Body Mass Index (BMI)
- Maximal hand grip strength
- Simple reaction time
- Go/no-go reaction time
- Absolute Angular Error (AAE) of the knee during weight bearing
- Berg Balance Scale (BBS), 2 types
- Short term memory
- Dual task performance

All these parameters were used together with the results from the video and kinematic analyses for the statistical analysis.

3.3.2 Data processing

Several statistical analyses were carried out using IBM SPSS (Statistical Packages for the Social Sciences, 19.0 & 22.0; SPSS Inc, Chicago - Illinois, U.S.A.). All the kinetic parameters had their descriptives calculated and two logistic regression analyses were done to see what the effects of age, fall-risk, and gender were on the distribution of the MDCs over these groups.

The relationship between the kinematic and subject parameters, and the age, gender and fall-risk of the subjects were studied using a linear regression analysis. The statistically significant effects ($P < 0.05$) were not adjusted for multiple testing with these 3 factors. Additionally, the confidence intervals of the unstandardized coefficient B were analysed, as well as the statistical power of the significant parameters using an online tool [12].

As part of the statistical results, several scatterplots were made showing the relationships between the statistically significant parameters. The choice of what to plot was based on the statistical significance as well as the power of the parameters. Also the velocity profiles were plotted when averaged over each group, per MDC.

3.4 Case Study

In the case of one subject, the cycling measurements were done both with the RRD test bicycle as well as the subject's own bicycle. Carrying out this separate test was done after initial mounting of the RRD bicycle proved difficult for this subject due to the bicycle's frame being too high to lift the inner foot over. The subject owned a different model bicycle, which had an extra low frame section for easier mounting and dismounting. Results from this case study could give an indication as to what kinematic parameters are influenced mostly by a change in bicycle as well as an increased level of comfort and experience with that specific bicycle.

The measurement sensors were not removed from the RRD test bicycle, but to compensate for the lack of bicycle measurement data one researcher cycled along with the subject, mimicking their bicycle movements as accurately as possible. For now none of the bicycle's kinematic parameters were taken into account for the analysis however and only the subject's kinematic data was used:

- Time required for mounting and dismounting
- Bicycle longitudinal velocity and acceleration
- Outer limb thigh angular velocity and angular acceleration
- Inner limb thigh angular velocity and angular acceleration
- Sternum angular velocity and angular acceleration

4 Results

In this section the following results are presented:

- **MDM description and categorisation, based on the video analyses**
- **MDC-subject correlations, based on the subject parameter analyses**
- **Statistical results, based on the subject and kinematic parameters**
- **Case study, based on the bicycle difference analysis**

4.1 MDM description and categorisation

4.1.1 Introduction

For the video analysis the data of 47 of the 48 subjects was used because one set of videos was no longer available. The following division per age group was made:

- Young subjects: 26.0 ± 3.8 years old (N=14), 6 males and 8 females
- Elderly subjects: 74.6 ± 6.3 years old (N=33), 15 males and 18 females

Of the elderly participants the following division with regard to their fall history was made:

- Normal subjects: 73.9 ± 5.7 years old (N=18), 10 males and 8 females
- Fall history subjects: 75.5 ± 7.1 years old (N=15), 5 males and 10 females

In Appendix I a list of links to representative videos in the database is given. In Appendix II the full description of every movement is given, accompanied by photos for added clarity. The identified methods show similarities, enough so to gather them into broader categories for mounting, dismounting, and waiting while stationary.

The big difference between the mounting categories was seen in the first movement of the subject: the placement of the feet. Which foot was placed first on the pedal strongly determined the rest of the mounting movement.

The biggest differences among the dismounting methods were found in which foot was used to stabilise the bicycle when it had almost or fully come to a halt. This foot choice formed the first 2 categories; the 3rd was formed by the dismounting methods that used both feet for stabilisation.

A clear difference among the waiting methods was seen between 2 groups of subjects: those that did exactly the same when waiting while stationary, compared to their normal dismounting and mounting behaviour, and a group that had chosen a different way of dismounting and mounting. These last subjects usually choose to keep seated or keep 1 foot on both sides of the bicycle.

4.1.2 Category descriptions

Given below is a stepwise description for each category. Each separate step does not necessarily take an equal amount of time, but they are in chronological order. Large movement differences between subjects are given in a bold font and all the differences in the order of some sub-movements are given in brackets.

Mounting category 1 (methods 1 and 4 together):

- Outside foot on the pedal
- Gaining speed by stepping 1 or more times with the inside foot
- Inside foot through the frame || **or** || inside foot over the frame
- Inside foot on the pedal and sitting down

Mounting category 2 (methods 2, 3, 5 and 6 together):

- *In method 6 the outside foot becomes the inside foot, through an extra step, and vice versa*
- Inside foot through the frame and on the pedal (and sitting down)
- Gaining speed by stepping 1 or more times with the outside foot || **and/or** || gaining speed by pedalling with the inside foot
- Outside foot on the pedal (and sitting down)

Dismounting category 1 (method 1 and 3 together):

- Strong braking
- (Off the saddle and) outside foot off the pedal || **or** || outside foot on the ground
- Bicycle comes to a halt (under an angle)
- (Outside foot on the ground)
- (Off the saddle and) inside foot through the frame and on the ground || **or** || off the saddle and inside foot over the frame and on the ground

Dismounting category 2 (method 2 and 6 together):

- Light braking
- Off the saddle and inside foot through the frame || **or** || off the saddle and inside foot over the frame
- Bicycle (almost) comes to a halt
- Inside foot on the ground (in front or, or behind, the outside foot)
- Outside foot on the ground

Dismounting category 3 (method 4 and 5 together):

- Strong braking
- (Off the saddle and inside foot on the ground)
- Bicycle comes to a halt
- Outside foot on the ground || **or** || both feet at the same time on the ground || **or** || both feet one by one on the ground
- (Off the saddle and) inside foot through the frame and on the ground

Waiting category 1 (method 1 and 5 together)

- Strong breaking
- (Off the saddle)
- Both feet on the ground (and standing up) || **or** || one foot on the ground, the other on the pedal (and standing up)
- Bicycle is standing still
- Waiting
- Gaining speed by pedalling with 1 foot (and sitting down) || **or** || gaining speed by pedalling with one foot and stepping 1 or more times with the other foot (and sitting down)
- Other foot on the pedal

Waiting category 2 (method 2, 3, and 4 together):

- No difference with the normal dismounting and mounting behaviour

4.1.3 Overview

Most subjects had a constant choice with regard to what MDM to use. Table 1 shows the popularity of each MDC. The number of users varied because not all of them had video data available, or showed MDMs which were too random to be categorised.

Table 1. The number and percentage of users per MC, DC & WC (mounting, dismounting & waiting category)

	MC 1	MC 2	DC 1	DC 2	DC 3	WC 1	WC 2
Total # of users	47		45			38	
% of users	66%	34%	47%	38%	15%	47%	53%

4.2 MDC-subject correlations

In Appendix V the list of results per subject is given, as well as some relevant information about them. This data was used to find any probable relationship between the subject parameters and their mounting and dismounting behaviour, as can be seen in Table 2.

Table 2. The choice of MDC per subject group.

Movement category	% of >18 & <40	% of >65	% of >65 (normal)	% of >65 (risk)	% of total
Mount 1	29% (N=4)	82% (N=27)	52% (N=14)	87% (N=13)	66% (N=31)
Mount 2	71% (N=10)	18% (N=6)	67% (N=4)	13% (N=2)	34% (N=16)
Dismount 1	84% (N=11)	31% (N=10)	44% (N=8)	14% (N=2)	47% (N=21)
Dismount 2	8% (N=1)	50% (N=16)	44% (N=8)	57% (N=8)	38% (N=17)
Dismount 3	8% (N=1)	19% (N=6)	11% (N=2)	29% (N=4)	15% (N=7)
Wait 1	80% (N=4)	42% (N=14)	56% (N=10)	27% (N=4)	47% (N=18)
Wait 2	20% (N=1)	58% (N=19)	44% (N=8)	73% (N=11)	53% (N=20)

Figure 5 and Figure 6 give a graphical overview of these results. There are clear differences in the MDCs used per subject group and these differences are retained when the subjects only grouped per age and not per fall risk. Especially for the mounting categories, the differences are mirror-like between the young and old subjects.

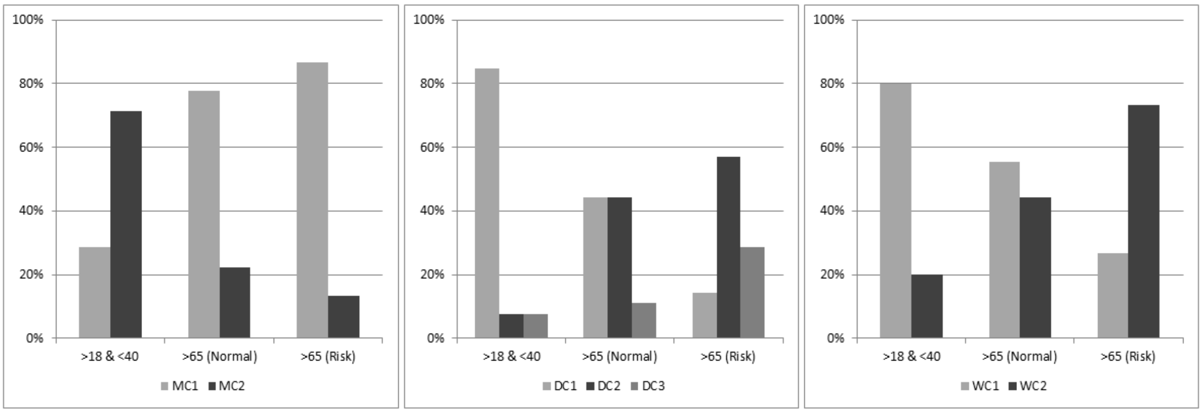


Figure 5. Category per subject group. MC, DC & WC (mounting, dismounting & waiting category)

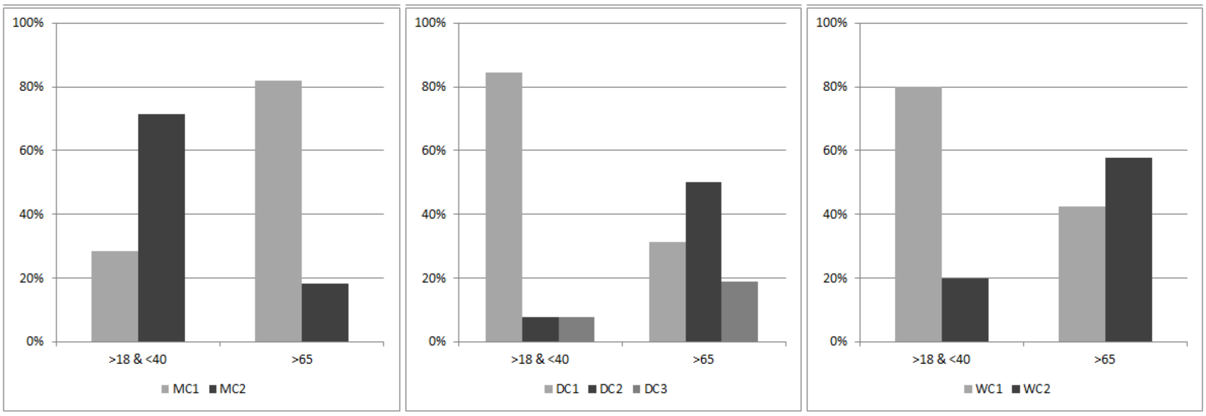


Figure 6. Category per age group. MC, DC & WC (mounting, dismounting & waiting category)

These results show that 71% of the young subjects chose for the mounting category where the inside foot is placed on the pedal first. Contrary to this, 78% of the old subjects used the mounting category where the outside foot is placed on the pedal first. A similar trend was seen in the choice of dismounting strategy, where 84% of the young subjects lift their outside foot of the pedal first, contrary to the older subjects that prefer to lift their inside foot first.

The same can be done when dividing the subjects into their gender groups, see Table 3.

Table 3. The choice of MDC per subject gender.

Movement Category	% of Males	% of Females
Mount 1	57% (N=12)	73% (N=19)
Mount 2	43% (N=9)	27% (N=7)
Dismount 1	65% (N=13)	32% (N=8)
Dismount 2	25% (N=5)	48% (N=12)
Dismount 3	10% (N=2)	20% (N=5)

Movement Category	% of Males	% of Females
Wait 1	71% (N=12)	29% (N=6)
Wait 2	29% (N=5)	71% (N=15)

Figure 7 gives a graphical overview of these results, showing clear differences between male and female subjects.

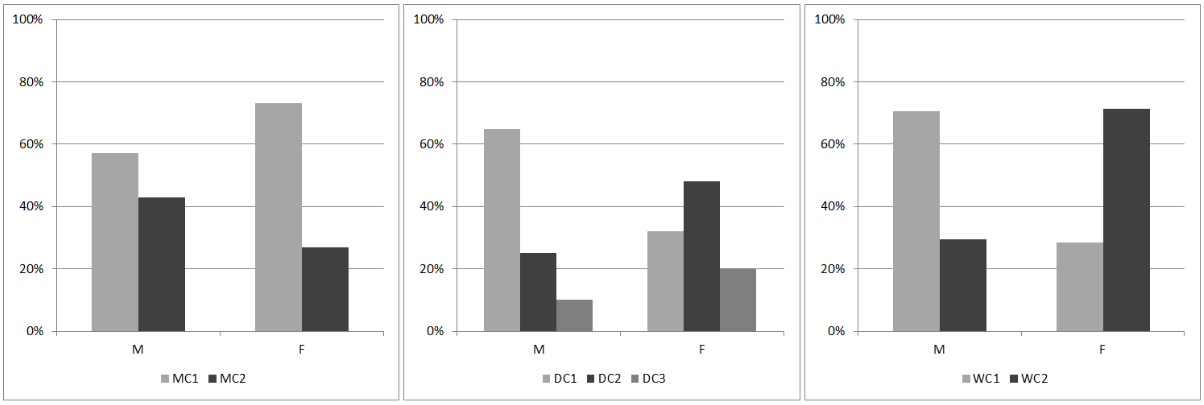


Figure 7. Category per subject gender. MC, DC & WC (mounting, dismounting & waiting category)

Both males and females used all mounting, dismounting, and waiting categories. However, females preferred mounting category 1 where they place their outside foot on the pedal first, and waiting category 2 where they fully dismount the bicycle. Males preferred the dismounting category where they place the outside foot off of the pedal first, and waiting category 1 where they stayed mounted on the bicycle while waiting. There are no clear preferences for a mounting category in the male population, nor for the female population when dismounting.

4.3 Statistics

4.3.1 Introduction

In Appendix V a list is given of the most basic results per subject. The number of subjects with usable data for the statistical analysis was equal to that for the video analysis:

- Young subjects: 26.0 ± 3.8 years old (N=14), 6 males and 8 females
- Elderly subjects: 74.6 ± 6.3 years old (N=33), 15 males and 18 females

Of the elderly participants the following division with regard to their fall history was made:

- Normal subjects: 73.9 ± 5.7 years old (N=18), 10 males and 8 females
- Fall history subjects: 75.5 ± 7.1 years old (N=15), 5 males and 10 females

Even though each subject had a dataset available for analysis, not all of them had all of the measurements recorded, nor were all the available recordings usable. Results that were physically impossible or highly unlikely were removed with the use of the APS or by hand. Unusable or missing data was mostly caused by measurement errors, sensor malfunctions, or processing errors. Of the total 1824 data fields loaded into SPSS for the normal cycling measurement, 96 fields (5.3%) were empty. For the waiting measurement 490 data fields (26.9%) were empty. This large difference is explained by the fact that no measurement data was available for 9 out of the 14 young subjects, simply because those measurements had not been done. The most commonly missing kinematic parameter was the steer data, followed by the other vehicle parameters, both due to sensor failure.

4.3.2 Descriptives

The descriptives were calculated from all the subject and kinematic parameters, based on their age grouping. This data was used to find any probable relationship between the subject parameters and their mounting and dismounting.

Table 4. Descriptives of relevant parameters. OLT = outer limb thigh, ILT = inner limb thigh.

		Young			Old			Old (non-fall risk)			Old (fall risk)		
Parameter	Meas.	Mean	SD	N	Mean	SD	N	Mean	SD	N	Mean	SD	N
Age [year]		26.0	3.8	14	74.6	6.3	33	73.9	5.7	18	75.5	7.1	15
BMI [kg/m2]		23.1	2.9	14	25.8	2.5	33	26.0	2.4	18	25.7	2.7	15
Word score (all)		43.9	5.0	13	24.7	9.2	33	26.6	8.9	18	22.5	9.3	15
Word score (recall)		11.1	2.2	13	5.5	3.0	33	6.1	3.1	18	4.7	2.9	15
BBS 1		56.0	0	14	53.9	3.9	33	54.9	1.6	18	52.6	5.2	15
BBS 2		12.0	0	14	10.7	1.8	33	11.1	1.5	18	10.3	2.1	15
Dual Task		0.92	0.08	14	0.77	0.07	31	0.76	0.05	16	0.77	0.09	15
Muscle force [kg]		39.8	9.6	14	29.4	11.0	33	32.8	13.4	18	25.5	5.2	15
Reaction time [ms]		415	59	14	484	83	33	471	74	18	499	93	15
Go/no-go time [ms]		284	36	14	293	64	33	279	54	18	310	73	15
Time [s]	Normal	4.50	1.25	14	5.61	2.57	32	5.69	3.03	18	5.50	1.94	14
(mounting)	Waiting	3.50	1.41	5	4.50	1.31	33	4.36	1.42	18	4.66	1.19	15
Time [s]	Normal	3.65	0.84	14	4.64	1.79	32	4.79	2.04	18	4.43	1.47	14
(dismounting)	Waiting	2.91	0.92	5	4.37	1.29	33	4.35	1.58	18	4.39	0.89	15
Roll vel. [deg·s^{-1}]	Normal	16.4	6.0	14	20.2	6.3	32	19.7	7.2	18	20.9	5.0	14
(dismounting)	Waiting	15.99	6.32	5	15.84	6.14	30	15.16	7.03	17	16.7	4.9	13
Roll acc. [deg·s^{-2}]	Normal	252	86	14	256	103	32	271	132	18	237	40	14
(dismounting)	Waiting	233	73	5	220	63	30	224	77	17	214	39	13
Yaw [deg]	Normal	4.4	4.8	14	5.6	7.8	32	5.9	9.1	18	5.2	6.0	14
(dismounting)	Waiting	5.42	3.62	5	3.89	1.91	30	4.01	2.37	17	3.73	1.12	13
Yaw vel. [deg·s^{-1}]	Normal	14.5	13.0	14	15.2	11.3	32	15.8	12.2	18	14.3	10.3	14
(dismounting)	Waiting	11.5	3.5	5	11.7	4.8	30	11.8	4.7	17	11.5	5.1	13
Yaw acc. [deg·s^{-2}]	Normal	273	71	14	323	87	32	346	97	18	293	63	14
(mounting)	Waiting	611	692	5	300	71	30	295	79	17	306	60	13
Steer ang. [deg]	Normal	18.6	7.4	12	24.0	8.4	32	24.1	10.0	18	23.8	6.2	14
(mounting)	Waiting	16.3	17.5	4	22.4	12.5	23	18.9	10.9	13	26.9	13.5	10
Steer ang. vel. [deg·s^{-1}]	Normal	73.4	24.0	12	83.1	27.0	30	83.8	30.0	17	82.2	23.5	13
(mounting)	Waiting	80	34	4	77	23	26	76	26	15	79	17	11
OLT ang. vel. [deg·s^{-1}]	Normal	164	41	14	176	44	32	187	36	18	163	51	14
(mounting)	Waiting	169	31	5	164	50	33	162	49	18	166	52	15
OLT ang. vel. [deg·s^{-1}]	Normal	122	40	14	144	54	32	140	63	18	150	43	14
(dismounting)	Waiting	103	37	5	126	50	33	119	45	18	136	56	15

		Young			Old			Old (non-fall risk)			Old (fall risk)		
OLT ang. acc. [deg·s^{-2}]	Normal	1984	801	14	2132	630	32	2241	650	18	1992	598	14
(mounting)	Waiting	1867	795	5	1868	687	33	1746	655	18	2016	717	15
OLT ang. acc. [deg·s^{-2}]	Normal	1712	449	14	2618	1619	32	2509	1787	18	2757	1429	14
(dismounting)	Waiting	1826	680	5	2038	1093	33	1788	1023	18	2339	1132	15
ILT ang. acc. [deg·s^{-2}]	Normal	1909	992	14	2736	1391	32	2737	1617	18	2734	1094	14
(dismounting)	Waiting	1490	1106	5	2092	1499	33	1991	1835	18	2212	1010	15
Strn. ang. vel. [deg·s^{-1}]	Normal	51.2	9.9	14	57.7	18.9	32	52.3	15.5	18	64.6	21.0	14
(mounting)	Waiting	51.8	4.5	5	52.3	17.6	33	47.1	13.9	18	58.4	19.9	15
Strn. ang. acc. [deg·s^{-2}]	Normal	927	315	14	1123	372	32	1014	316	18	1263	403	14
(mounting)	Waiting	945	346	5	1086	475	33	1003	483	18	1186	462	15
Veh. vel. [m·s^{-1}]	Normal	1.84	0.41	14	1.79	0.40	32	1.78	0.36	18	1.81	0.46	14
(mounting)	Waiting	2.40	0.85	5	1.82	0.51	31	1.93	0.34	17	1.69	0.65	14
Veh. acc. [m·s^{-2}]	Normal	3.12	0.84	14	2.63	0.70	32	2.74	0.67	18	2.48	0.74	14
(mounting)	Waiting	3.59	1.01	5	2.71	0.66	30	2.65	0.58	17	2.79	0.78	13
Veh. acc. [m·s^{-2}]	Normal	3.39	0.93	14	3.28	1.17	32	3.18	1.15	18	3.40	1.24	14
(dismounting)	Waiting	3.48	1.00	5	2.72	0.68	30	2.69	0.48	17	2.77	0.90	13

As can be seen from the descriptives, the differences between mounting before normal cycling and mounting after waiting are larger than 5% for most of the parameters and the same goes for dismounting.

4.3.3 Logistic regressions

To analyse the independent contribution of age, gender and fall-risk to the mounting, dismounting, and waiting strategies, logistic regressions were performed, and the confidence intervals (CI) are presented in Table 5.

Table 5. The 95.0% confidence intervals (CI) of B per MDC for age, risk, and gender.

	Mounting		Dismounting		Waiting	
	lower bound	upper bound	lower bound	upper bound	lower bound	upper bound
Age	-0.80	-0.19	0.08	0.98	0,19	0.78
Risk	-0.40	0.24	-0.22	0.72	-0.21	0.52
Gender	-0.30	0.25	0.15	0.96	-0.04	0.66

These confidence intervals indicated that age was related to the mounting strategy, while both age and gender were related to the dismounting strategy. No significant relations could be found for the waiting strategy, though gender may play a role.

4.3.4 Significance and power

In Table 6 the P-values and statistical powers can be found of the normal cycling measurement parameters that had P-values around or lower than 0.05. The same is done for the waiting measurement in Table 7.

Table 6. The P-values and power for significant kinematic parameters with normal cycling. (M) = mount, (D) = dismount.

Parameter	P-value	Power
ILT ang. acc. (M)	0.002 (age) 0.013 (gender)	0.99 (age) 0.89 (gender)
OLT ang. vel. (D)	0.003 (gender)	0.97 (gender)
Stermum ang. vel. (M)	0.007 (risk) 0.043 (gender)	0.58 (risk) 0.26 (gender)
Bike yaw acc. (M)	0.017 (age)	0.79 (age)
Bike yaw vel. (D)	0.026 (gender)	0.61 (gender)
Sternum ang. acc. (M)	0.028 (risk)	0.79 (age)
Steer ang. vel. (M)	0.029 (gender)	0.61 (gender)
OLT ang. acc. (D)	0.034 (gender) 0.062 (age)	0.84 (gender) 0.93 (age)
OLT ang. vel. (M)	0.036 (risk)	0.51 (age)
Time (D)	0.047 (age)	0.82 (age)
OLT ang. acc. (M)	0.052 (gender)	0.41 (gender)
Steer ang. acc. (M)	0.053 (age)	0.79 (age)

Table 7. The P-values and power for significant kinematic parameters with waiting.

Parameter	P-value	Power
OLT ang. vel. (D)	0.000 (gender)	1.00 (gender)
Bike yaw (D)	0.001 (gender)	0.96 (gender)
OLT ang. acc. (D)	0.001 (gender)	1.00 (gender)
ILT ang. acc. (D)	0.002 (gender)	1.00 (gender)
Bike yaw vel. (D)	0.004 (gender)	0.93 (gender)
Bike roll acc. (D)	0.008 (gender)	0.85 (gender)
Steer angle (M)	0.010 (risk)	0.45 (risk)
Bike yaw acc. (M)	0.013 (age)	0.26 (age)
Bike lat. acc. (M)	0.020 (age)	0.60 (age)
Steer ang. vel. (D)	0.028 (gender)	0.85 (gender)
OLT ang. vel. (M)	0.035 (gender)	0.68 (gender)
Bike lat. vel. (M)	0.037 (age)	0.44 (age)
Time (D)	0.039 (age)	0.93 (age)
Bike lat. acc. (D)	0.046 (age)	0.50 (age)
Bike roll vel. (D)	0.048 (gender)	0.74 (gender)

All these parameters were found statistically significant, or almost statistically significant, as well as represented by a powerful enough dataset. Other results were also found significant, but did not have enough statistical power. It is clear that mostly angular accelerations and angular velocities are included in the results and that age related mounting kinematics are mostly present in the results for the normal cycling task, while gender related dismounting kinematics were mostly present in the waiting task results.

In Table 8 the P-values can be found of the statistically significant kinematic parameters when analysed using physical and cognitive parameters instead of age, gender, and risk.

Table 8. The P-values for significant physical and cognitive parameters per measurement.

Param.	Meas.	Time (M)	Time (D)	Time (S)	Yaw ang. vel (D)	Yaw ang. acc. (M)	Steer ang. (D)	OLT ang. acc. (M)	ILT ang. acc. (M)
BMI	Normal	-	-	-	-	-	-	-	-
	Waiting	0.060	-	0.014	-	-	0.016	-	-
Word score (all)	Normal	-	-	-	-	-	-	-	0.056
	Waiting	0.003	-	-	-	-	-	-	-
Word score (recall)	Normal	-	-	-	-	-	-	-	-
	Waiting	0.035	-	-	0.067	-	-	-	-
BBS 1	Normal	0.050	0.026	0.006	-	0.087	-	-	0.076
	Waiting	-	-	-	0.035	-	-	0.022	-
BBS 2	Normal	0.000	0.000	0.000	-	0.006	-	-	0.001
	Waiting	0.038	-	-	-	-	-	0.004	0.026
Muscle force	Normal	-	-	-	-	-	-	0.015	-
	Waiting	-	0.045	-	0.001	-	-	-	-
Reaction time	Normal	-	-	-	-	-	-	-	-
	Waiting	0.031	-	0.065	-	-	0.079	-	-
Go/no-go reaction t.	Normal	-	-	-	-	-	-	-	0.026
	Waiting	0.013	-	0.033	-	-	0.059	-	-

It is clear that although there are significant physical parameters, the cognitive parameters are almost 3 times more common. The most significant results were found in the BBS 2 ($P < 0.001$), the muscle force ($P < 0.001$) and the word score ($P < 0.003$). Also the waiting task had more significant results than the normal mounting and dismounting measurements.

4.3.5 Kinematic data

Based on the kinematic parameters that were found significant and powerful enough, several scatter plots were made using SPSS. They were color-coded based on whether the gender or risk group had the strongest statistical influence.

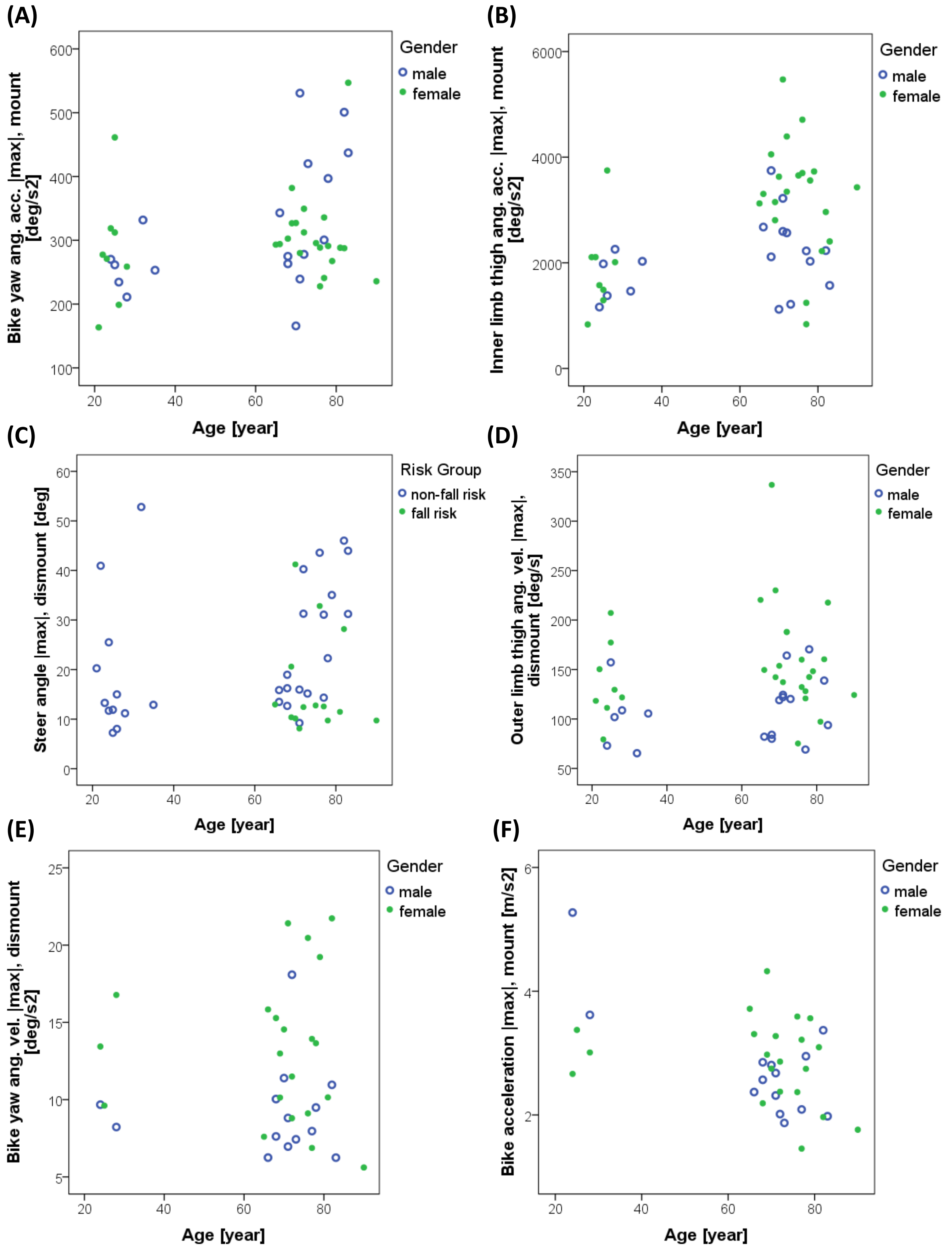


Figure 8. Effect of age, fall-risk and gender on the kinematic parameters. Figures (A) and (B) are from mounting tasks, (C) and (D) are from dismounting tasks and (E) and (F) are from waiting tasks.

In Figure 8 (A) increasing age is shown to be related to a higher bicycle yaw angular acceleration during mounting: 323 deg·s^{-2} vs. 273 deg·s^{-2}. Additionally, the older cyclists tended towards a higher maximum steer angle: 24 deg vs. 19 deg, as well as a higher steer angular acceleration: 1002 deg·s^{-2} vs. 805 deg·s^{-2}. Figure 8 (B) shows that age and gender were related to the inner limb angular acceleration: 1816 deg·s^{-2} for young subjects vs. 2907 deg·s^{-2} for old subjects, and 2087 deg·s^{-2} for males vs. 2889 deg·s^{-2} for females. Furthermore, males demonstrated a higher steer angular velocity and sternum angular velocity compared to females: 90 deg·s^{-1} vs. 73 deg·s^{-1} and 59 deg·s^{-1} vs. 54 deg·s^{-1}. Fall risk was related to both the maximum sternum lateral angular velocity and acceleration: 65 deg·s^{-1} vs. 52 deg·s^{-1} and 1263 deg·s^{-2} vs. 1014 deg·s^{-2} for older fall risk and older non-fall risk group, respectively.

From Figure 8 (C) it is clear that the fall risk was related to lower maximum steer angles when dismounting: 17 deg for fall risk vs. 25 deg for non-fall risk older subjects. Older cyclists had a longer dismount time than the young subjects: 4.6 sec vs. 3.6 sec. For the bicycle yaw velocity a gender effect was visible with the males having a higher velocity: 20 deg·s^{-1} vs. 12 deg·s^{-1}. The outer limb angular accelerations shown in In Figure 8 (D) were lower for males: 1768 deg·s^{-2} vs. 2711 deg·s^{-2}, as well as the angular velocities: 110 deg·s^{-1}. vs. 155 deg·s^{-1}, when compared to the female subjects.

When looking at the results of the waiting task, gender was the most influential parameter. Compared to the female subjects, the male subjects showed lower values for the bicycle yaw angle: 2.8 deg vs. 5.0 deg, angular velocity as shown in Figure 8 (E): 9.22 deg·s^{-1} vs. 13.27 deg·s^{-1}, roll angular acceleration: 191 deg·s^{-2} vs. 241 degs^{-2}, and steer angular velocities: 30 deg·s^{-1} vs. 44 deg·s^{-1}. Also the outer leg angular velocities: 84 deg·s^{-1} vs. 147 deg·s^{-1} and angular accelerations: 1264 deg·s^{-2} vs 2446 deg·s^{-2}, as well as the inner leg angular accelerations: 1893 deg·s^{-2} vs. 2861 deg·s^{-2} where lower for the males.

Another important factor was age, as the older subjects needed more time to dismount than the young subjects: 4.4 sec vs. 2.9 sec. Also their maximum bicycle deceleration was lower: 2.7 m·s^{-2} vs. 3.5 m·s^{-2}. After the waiting period was over and the subjects mounted their bicycles again, the older subjects also had a lower maximum bicycle accelerations: 2.7 m·s^{-2} vs 3.6 m·s^{-2}, as shown in Figure 8 (F), and did not reach the same velocity at the end of the mounting phase as the young cyclists: 1.8 m·s^{-1} vs. 2.4 m·s^{-1}. The fall risk subjects showed higher maximum steer angles during mounting: 27 deg vs. 19 deg. The maximum outer limb angular velocity was related to the gender of the subjects: 144 deg·s^{-1} for males and 177 deg·s^{-1} for females.

Differences between the various mounting and dismounting methods and categories were also investigated. Due to the lack of subjects for some of the methods an extensive comparison was not possible. The results given in Figure 9 for the angular accelerations of the inner and outer leg thighs for the mounting and dismounting movements give clear differences between the methods and categories. For the movement of the inner leg thigh during mounting category 1 (MC1) has a much higher angular acceleration than MC2: 2951 deg·s^{-2} vs. 1798 deg·s^{-2}. For the outer leg the differences are much smaller: 2130 deg·s^{-2} for MC1 vs 1999 deg·s^{-2} for MC2. For dismounting the differences between DC1, DC2, and DC3 are: 2160 deg·s^{-2} vs 3085 deg·s^{-2} vs 1962 deg·s^{-2} for the inner leg and 1901 deg·s^{-2} vs. 2595 deg·s^{-2} vs. 1948 deg·s^{-2} for the outer leg. DC2 clearly requires higher angular accelerations to execute when compared to DC1 and DC3.

Method differences can also be seen, especially between method 1 and 4 for the mounting movement of the inner leg. Differences between the other methods are much harder to discern due to the lack of subjects for some methods.

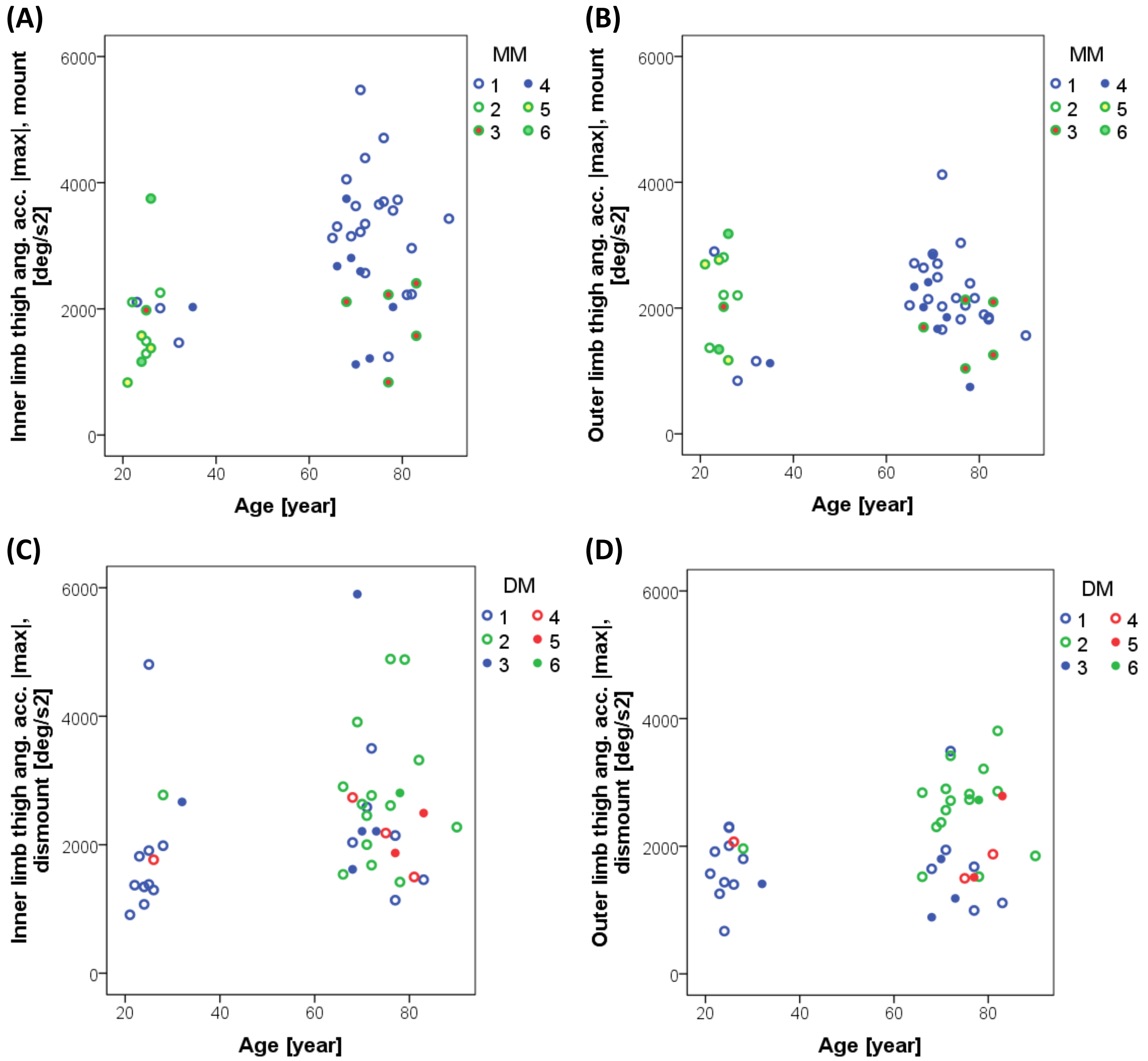


Figure 9. Kinematic differences per category and method. Figures (A) and (B) are for mounting, the numbers are per method: blue for C1 and green C2. Figures (C) and (D) are for dismounting, the number are per method: blue for C1, green for C2, and red for C3.

A comparison of the actual kinematic data between groups was successfully done for the velocity profiles by assuming that every mounting and dismounting movement shows the same, but time-scaled, version of a general movement. Each subject's velocity profile was interpolated to fit within the same time span and the means and standard deviations per age group and gender are presented in Figure 10 and Figure 11. These plots are not represented by any of the statistical results as only the bicycle velocity endpoints were taken into account for that and not the actual profiles.

It is clear that the similarities in maximum velocities do not have to coincide with similar velocity profiles. Clear mean velocity profile differences can be seen between the age groups in MC1, the genders in MC2, and the genders and age groups in DC2. Differences in the standard deviations from the mean profiles are the most clear for both gender and age groups in MC1, the gender group in MC2 and DC1. Velocity profile differences between categories are very clear for the mounting phase, but much less clear for the dismounting phase. Not all categories had enough data to create standard deviations due to the lack of subjects using that method and having data available. For the same reason the waiting data was not plotted.

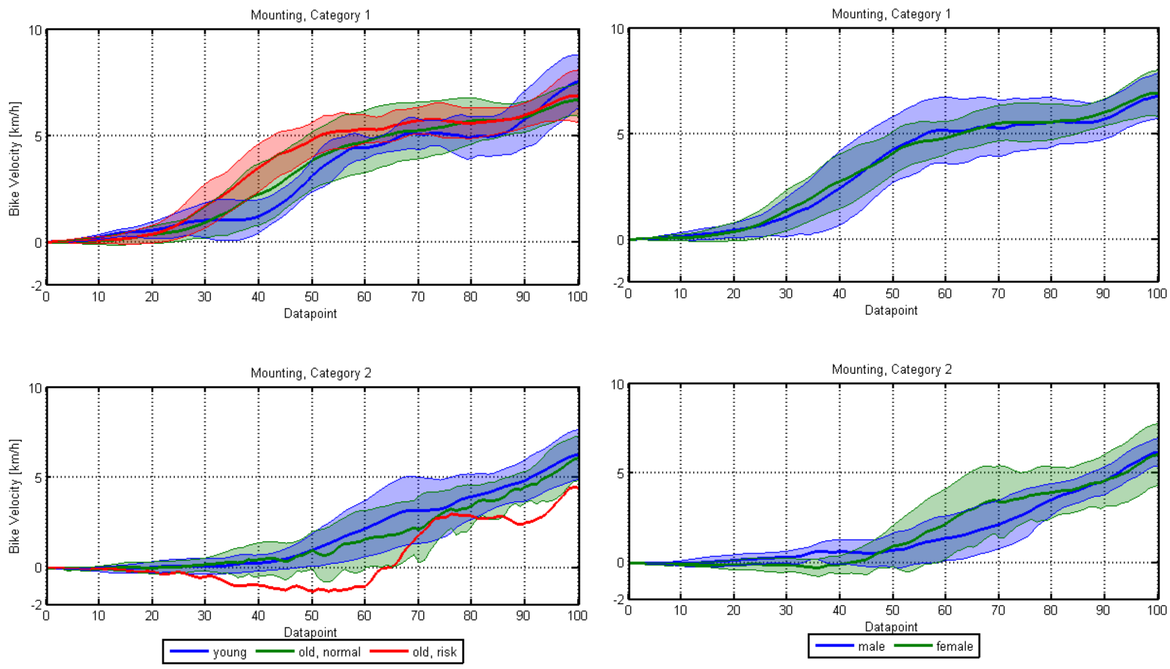


Figure 10. Velocity profile of mounting per group for normal cycling. Thick lines are the means, the areas are the standard deviations. Groups with 1 subject only had their means plotted.

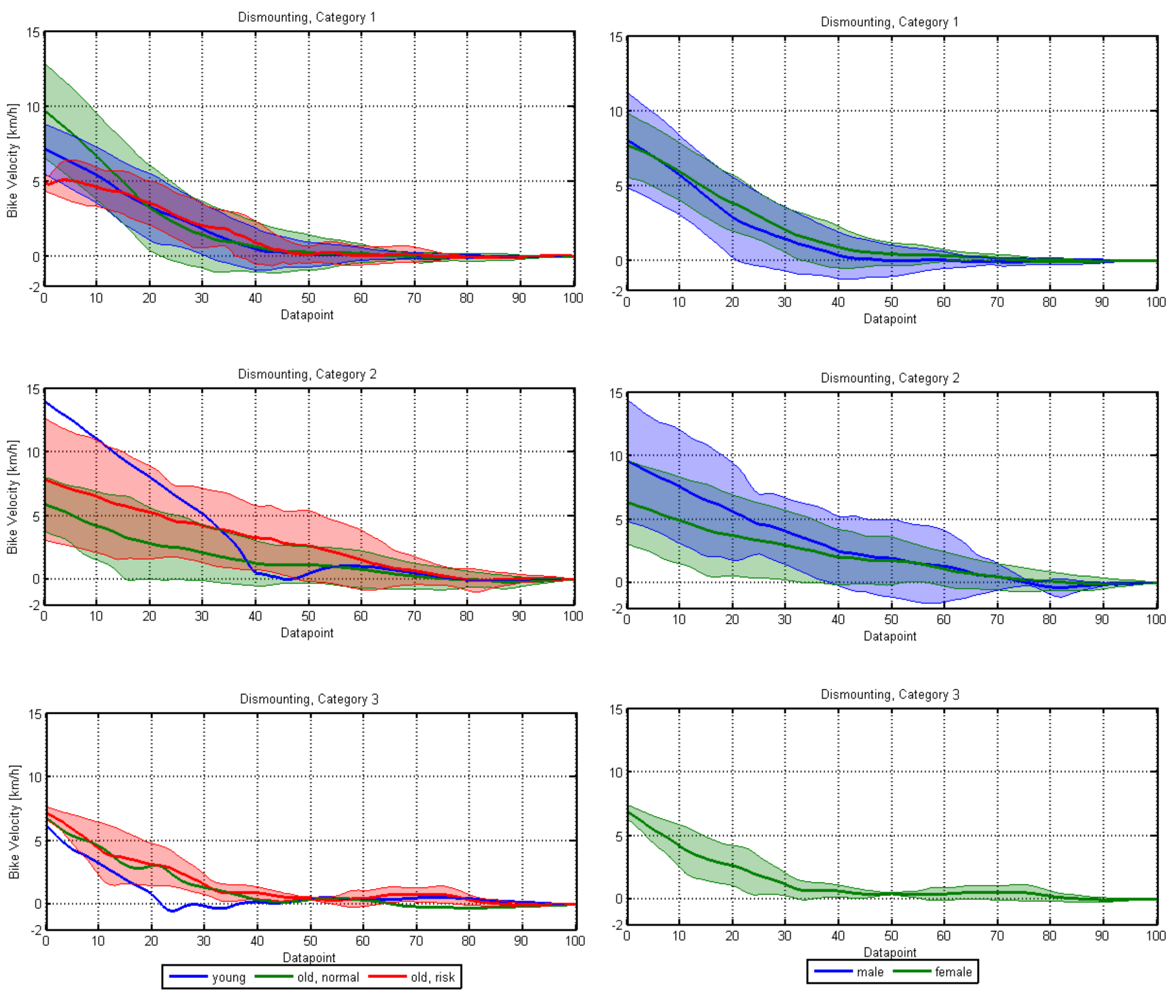


Figure 11. Velocity profile of dismounting per group for normal cycling. Thick lines are the means, the areas are the standard deviations. Groups with 1 subject only had their means plotted.

4.3.6 Cognitive and physical data

Based on the cognitive and physical subject parameters that were found significant and powerful enough, several scatter plots were made using SPSS. They were color-coded based on whether the gender or risk group had the strongest statistical influence.

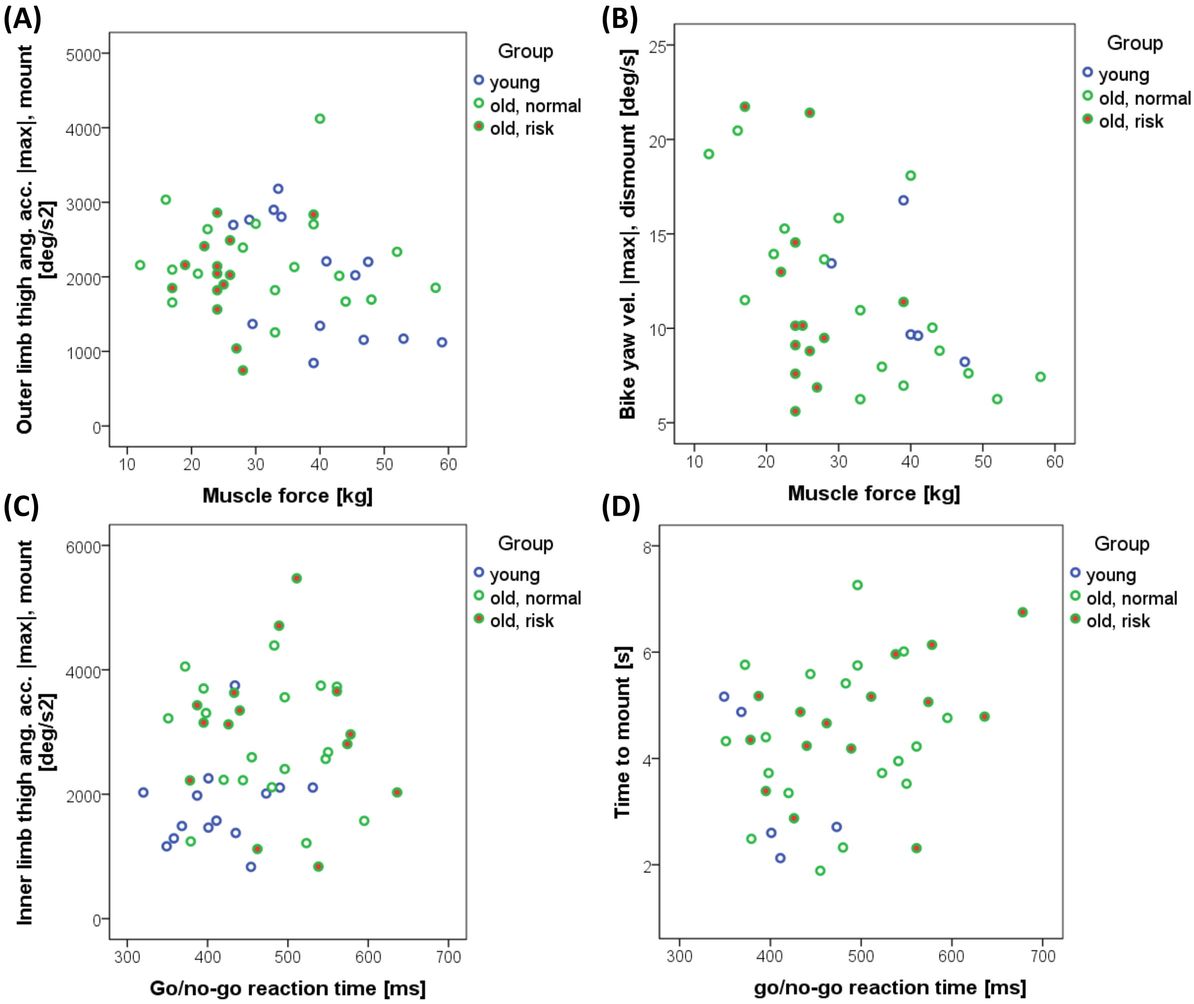


Figure 12. Effect of muscle force and go/no-go reaction time on the kinematic parameters. Figures (A) and (C) are for normal cycling, (B) and (D) are for the waiting task.

From Figure 12 (A) and (B) it can be seen that both the outer limb thigh angular acceleration during mounting and the bicycle yaw angular velocity during dismounting scale with the hand grip force that can be produced per subject group. The scale is however inverted, as higher accelerations are found with subjects who cannot produce high muscle forces. This is most clear for the young and old subjects with a non-fall risk. The fall risk group is clustered too closely to say anything about their muscle force scaling. In Figure 12 (C) and (D) the differences for both the inner limb thigh angular acceleration during mounting and the time to mount when waiting are influenced by the go/no-go reaction time of the subjects. These effects are most clear in both cases for the older subject groups.

4.4 Case study

The subject used for the case study was a member of the fall-history group, female and 82 years old at the time of the measurements. The bicycle provided by the subject is shown in Figure 13, alongside the RRD bicycle. The frame difference is clearly visible and facilitated a much easier mounting and dismounting due to the larger space to move in. This could be seen on the videos and was reported by the subject as well.

Figure 13. Personal bicycle (in front) vs. the RRD bicycle (behind).

The results of the kinematic data analysis are presented in Table 9 and show large differences between the usage of both bikes.

Table 9. case study

Parameters	Mount RRD	Mount Own	%Δ	Dismount RRD	Dismount Own	%Δ
(Dis)mount time [s]	7.51	3.76	-50%	5.51	5.50	0%
Outer limb thigh θ |max| [deg]	59	57	-3%	51	51	0%
Outer limb thigh $\dot{\theta}$|max| [deg·s^{-1}]	153	202	24%	160	159	0%
Outer limb thigh $\ddot{\theta}$|max| [deg·s^{-2}]	1850	2338	21%	3808	2437	-36%
Inner limb thigh θ |max| [deg]	73	66	-10%	66	71	7%
Inner limb thigh $\dot{\theta}$|max| [deg·s^{-1}]	163	179	9%	184	178	-3%
Inner limb thigh $\ddot{\theta}$|max| [deg·s^{-2}]	2962	2844	-4%	3318	3007	-9%
Sternum roll θ |max| [deg]	21	21	0%	19	12	-37%
Sternum roll $\dot{\theta}$|max| [deg·s^{-1}]	57	44	-23%	50	42	-16%
Sternum roll $\ddot{\theta}$|max| [deg·s^{-2}]	1473	585	-60%	1095	1570	30%
Vehicle acc. |max| [m·s^{-2}]	2.29	2.46	7%	2.83	1.91	-33%
Vehicle velocity max [m·s^{-1}]	1.52	1.58	4%	2.13	2.78	23%
Sternum y-acc. |max| [m·s^{-2}]	4.30	3.93	-9%	4.64	3.87	-17%

The mounting time was halved while the dismounting time stayed the same. And there are more differences between the mounting and dismounting movements. The sternum roll angular acceleration decreased when mounting but increased when dismounting. It is the other way around for the outer limb thigh angular acceleration. The inner limb movements, which are expected to be mostly related to the change of frame as the foot has to be lifted higher, showed only very small (max. ±10%) changes. The maximum angle is indeed lower for the inner leg thigh when the subject mounts her own bicycle compared to the RRD bicycle: 66 deg vs. 73 deg, showing that a lower frame results in a lower maximum angle. The outer leg though showed differences up to 36%, which seems to be countered by changes in the sternum roll parameters, possibly as a measure of stability control.

5 Discussion

Based on the reported results, several points will be discussed with regard to mounting and dismounting categorisation, strategies, kinematics, and safety.

To solve the problem of not knowing what strategies people use to mount and dismount their bicycles, a collection of descriptions was made and categorised based on a large set of video data. Several different mounting and dismounting methods were identified and categorized into 2 mounting, 3 dismounting, and 2 waiting categories. The choice of strategy was both influenced by age and gender.

When mounting, younger subject start pedalling after having put their inside foot on the pedal on the other side of the bicycle frame. This is the opposite of what the older subjects do as they place their outside foot on the pedal on the same side of the bicycle and then start pedalling with their inside foot also on that side of the bicycle. They continue doing this until they reach enough speed to be able to move their inside foot to the pedal on the other side of the frame. This clear difference cannot easily be explained, as several causes are possible. It may be based on the way older subjects were brought up and thought to mount and dismount a bicycle in different ways than the younger subjects. It is also possible that the older subjects had to change their mounting and dismounting strategies to compensate for changes in balance capabilities and joint stiffness.

A change in tactics with increasing age might also be guided by the stability properties of bicycles themselves. Bicycle stability increases when speeds up [10, 11], so reaching a higher velocity more towards the start of the mounting phase could compensate for the decreased stability of the cyclist. This idea is supported by the velocity profile of MC1 from Figure 10 where the fall risk group gains the most speed early on in the movement. The young subjects show such an increase in velocity much later on in the movement and the non-fall risk subjects show intermediate behaviour. To a lesser extent the same can be sad of the female subjects for MC2. Whether these velocity profiles can be interpreted this way remains uncertain however, as making a time-independent superposition of kinematic parameters is not a regular analysis method. The clear group differences do suggest that the method is viable, but it’s possible that it only works for general parameters like velocity.

The choice in foot-lifting order, and thus which mounting category, can also be influenced by an increase in hip joint ante-flexion or knee joint flexion stiffness in older subjects. When the inner foot is lifted through the frame first, larger angles are required, which might not be as easy anymore for some subjects. This was clearly shown in the case study where the subject had difficulty mounting the RRD bicycle compared to her own bicycle.

Dismounting a bicycle is clearly not a reverse movement of mounting one, but there are however large similarities. The young subjects tend to brake strongly and place their outside foot on the ground first. This was contrary to most older subjects as they only brake lightly and when still moving lift their inner foot through the frame and on the ground, all the while slowing down further. Sometimes the subject had to walk alongside the moving bicycle to come to a complete standstill. This resulted in longer dismounting times as well as velocity profiles with higher average velocities as can be seen in Figure 11 for DC2. This higher bicycle velocity, when lifting their feet through the frame, could again help the older subjects in increasing their overall stability.

Gender differences are also present for the dismounting movements, as the male subjects tended to keep seated while slowing down to a full standstill, contrary to the female subjects. This could be explained by the difference in body height between the genders as the male subject were on average taller. This increases the ease to remain seated on the bicycle, without having the need to dismount for added stability.

Also the kinematic data was analysed, showing large differences between age, risk, and gender groups. Such differences were for example present in the bicycle yaw angular acceleration as function of age and the thigh angular velocities as function of age and fall-risk indication. The older or female subjects showed higher inner limb thigh velocities and accelerations while mounting and higher outer limb thigh velocities and accelerations while dismounting, when compared to the younger or male subjects. These differences, combined with the lower muscle strength in older people, could explain the higher risk of injury in single bicycle accidents for older and female cyclists.

While the kinematic differences between some groups could reach up to 80%, the spreading could be very large within a group as well. This results in a large overlap between groups with regard to their kinematics. At least half of the older subjects had the same kinematics as the young subjects for both mounting and dismounting movements. It is very well possible that the older subjects had physical and cognitive abilities sufficient enough to mount and dismount in the same way as the young subjects, or at least compensate enough when they lacked in a specific ability [8].

The older cyclists with a fall-risk indication that were included in this study, might not have received this indication correctly. The same could be said of the older cyclists without such an indication, as their behaviour and resulting kinematics might very well belong to that of a fall-risk group subject. Some of the subjects admitted having actively adapted their behaviour after having been involved in a cycling accident, or already before the occurrence of an incident. The only subjects that could be put in the fall-risk group are those who have had multiple accidents in a short space of time, but those have mostly stopped cycling at all or cannot take part in such a research as the risk of injury is too high.

Large similarities were found for the time to mount and the velocity reached at the end of the mounting phase for all age and gender groupings. Only the young subjects were able to reach that about 1 sec earlier than the older subjects. This maximum velocity was approximately 6.5 km/h with a standard deviation of 1.4 km/h for all age groups. This leads to a minimum velocity of 5 km/h to be able to start with the harmonic cycling phase and these values are in accordance with Moore et al. [10].

The analysis of the physical and cognitive data of the subjects together with their kinematic data shows that there are significant connections between them, especially with regard to muscle force, balance capabilities, and reaction times. These findings are also supported by research done on the effects of cognitive and physical abilities during gait and stance [13].

These factors are normally not taken into account when analysing cycling motion or doing accident studies. To increase the understanding and accuracy of such studies, cognitive and physical parameters should be included. Also not taken into account in such studies are the bicycle parameters. This study however clearly shows that differences are present and can be very large and in emergency cycling situations this could mean the differences between falling or keeping balance. Additionally mounting and dismounting movements should be considered as 2 different movements, which is contrary to what has been done in bicycle accident analysis studies [4, 8] so far.

The dependence on the physical and cognitive state of the subject as well as the properties of the bicycle involved should be taken into consideration when executing such studies, especially now that e-bikes are getting more and more popular which might be accompanied by an increasing amount of people who are not able to adjust for the change in dynamics that are required for safe mounting and dismounting [7].

6 Conclusions

From the reported results, several conclusions can be drawn.

This report is the first to describe, categorize, and analyse the possible strategies that young and old cyclists use to mount and dismount their bicycles. A limited amount of mounting and dismounting movements were found to be used and some were clearly more popular than others. In future accident and bicycle safety studies, these classifications can be used to further specify the results and gain more knowledge about the cyclists behaviours.

The bicycle and subject kinematics varied per mounting and dismounting category as well as between age, risk and gender subject groups. A cycling velocity of at least 5 km/h at the end of the mounting phase was required for each subject, regardless of age, risk indication or gender. A change of bicycle will influence the mounting and dismounting behaviour of a subject. What these changes exactly depend on is unknown, but bicycle dimensions are at least one such parameter. Differences were also observed between the mounting data of one task, normal cycling, and that of the waiting task. These differences were however very large, leading to the conclusion that both cannot be averaged to increase the effective amount of measurement data. Whether this is true for all task remains to be shown.

From the power analysis it’s clear that not all the parameters have enough statistical power to allow for conclusions to be drawn. Most however do, or are very close to it, which means that the research population was adequately chosen. Whether the divisions between fall risk and non-fall risk was correctly done is uncertain.

Finally it can be concluded that mounting a bicycle is not the same as dismounting one and that in any research that focusses on these phases of cycling a distinction between both should be made to improve their validity.

7 Recommendations

With regard to future research, as part of SOFIE or on its own, several recommendations can be made. These recommendations mostly cover the areas of extensions to the current research, or as applications that follow from the current results.

The current research was very extensive, resulting in a lot of data not yet having been analysed. The kinematic data should be corrected for changes in MDM for separate trials. This allows other kinematics to be averaged in the same way as was done with the velocity data, creating a profile over time. Maximum values of kinematic parameters should also be compared to those from the actual cycling phase. A principle component analysis (PCA) could also be done in the same way as Moore et al. have done [10].

Even though the statistical power of most kinematic parameters was high enough, a more extensive research would allow for a better division of the kinematic parameters with regard to mounting and dismounting categories or even methods. This could also result in the discovery of more MDMs. Such research could also be done by using video materials from archives to see if there have been changes in the teaching of certain mounting or dismounting methods.

A separate research could be done by tracking peoples performances over time to see whether they adapt to changes in their physical or cognitive abilities. Such changes could be used to try and find fall risk predictive parameters. Subjects could also be forced to use a certain MDMs and then have their performances tracked over time to see if certain MDMs are better suitable for the need for adaptability. This is a realistic scenario as people buy new bicycles, of which some do not allow all MDMs to be used as successfully as before.

Any future research should at least include arm and head data, as well as force measurements. Any energy conservation strategies will be expressed through such forces. Position tracking of the moving body parts and bicycle could also be done, but will limit it to a laboratory environment. This is however not a big restriction for mounting or dismounting measurements as they require a lot less space compared to actual cycling measurements. A laboratory setting would also allow to test under varying conditions for mounting and dismounting. Such conditions could include causes of falls: wrong gears, steep elevations, pedal slips, or extra heavy bicycles. Sensory data acquisition has to be improved however, although the lower reliability for wireless sensors outweighs the increased performance of wired sensors due to the added movement freedom, which is especially helpful when performing complex movements such as mounting or dismounting.

Literature

1. *SOFIE*. [cited 2014 26-10]; Available from: http://www.rrd.nl/projects/cluster_rehabilitation_technology/sofie/.
2. *Fietsongevallen bij ouderen (55+)*. 2011, VeiligheidNL: Amsterdam, The Netherlands.
3. *Mobiliteit per regio naar geslacht, vervoerswijzen en persoonskenmerken*. 2007, Centraal Bureau voor de Statistiek: The Hague, The Netherlands.
4. *Enkelvoudige fietsongevallen bij 55 plussers*. 2010, VeiligheidNL: Amsterdam, The Netherlands.
5. Berveling, J. and H. Derriks, *Opstappen als het kan, afstappen als het moet*. 2012, KiM Netherlands Institute for Transport Policy Analysis.
6. Gengler, D.M., *To bike or not to bike*, in *Construerende Technische Wetenschappen*. 2014. p. 56.
7. Kruijer, H., et al., *Fietsongevallen in Nederland*. 2013, VeiligheidNL: Amsterdam, The Netherlands.
8. Scheppers, P. and K. Klein-Wolt, *Single-bicycle crash types and characteristics.* Cycling Research International, 2012. **2**: p. 119-135.
9. Hagemeister, C. and A. Tegen-Klebingat. *Cycling habits of older cyclists in Germany*. in *International Cycling Safety Conference*. 2013. Helmond, The Netherlands.
10. Moore, J.K., et al., *Rider motion identification during normal bicycling by means of principal component analysis.* Multibody System Dynamics, 2010. **25**(2): p. 225-244.
11. Schwab, A.L., J.P. Meijaard, and J.D.G. Kooijman, *Lateral dynamics of a bicycle with a passive rider model: stability and controllability.* Vehicle System Dynamics, 2012. **50**(8): p. 1209-1224.
12. *Statistical Power Calculators*. [cited 2014 26-10]; Health Care Research Calculators]. Available from: https://www.dssresearch.com/KnowledgeCenter/toolkitcalculators/statisticalpowercalculators.aspx.
13. van Schoor, N.M., et al., *Different cognitive functions in relation to falls among older persons.* Journal of Clinical Epidemiology, 2002. **55**(9): p. 855-862.

Appendices

I - Video links

From the video material, 6 different methods were identified. The following videos represent a relevant selection from the database, as they give a clear example of the various methods used, or show subjects deviating from these methods.

Note: the links can only be accessed from within the RRD intranet and with the correct authorisation.

Mounting video links

Method 1:

- L:\Sofie\Video\2013 11 13 VB1985\GOPR0005.MP4 (smooth)
- L:\Sofie\Video\2013 09 20 CK1935\GOPR0005.MP4 (off-balance)
- L:\Sofie\Video\2013 10 04 ZW1931\GOPR0004.MP4 (off-balance)
- L:\Sofie\Video\2013 10 16 GR1931\GOPR0003.MP4 (too slow)

Method 2:

- L:\Sofie\Video\2013 08 02 RG1991\GOPR0002.MP4 (smooth)

Method 3:

- L:\Sofie\Video\2013 08 23 RK1988\GOPR0009.MP4 (smooth)
- L:\Sofie\Video\2013 10 16 IR1930\GOPR0002.MP4 (very slow)
- L:\Sofie\Video\2013 09 25 EV1935-fiets\GOPR0004.MP4 (very slow)
- L:\Sofie\Video\2013 09 20 FZ1945\GOPR0010.MP4 (too slow)

Method 4:

- L:\Sofie\Video\2013 09 11 AT1947\GOPR0014.MP4 (smooth)
- L:\Sofie\Video\2013 09 30 HL1935\GOPR0012.MP4 (4 steps)

Method 5:

- L:\Sofie\Video\2013 09 04 SK1989\GOPR0004.MP4 (smooth)

Method 6:

- L:\Sofie\Video\2013 08 02 IH1987\GOPR0016.MP4 (smooth, back)
- L:\Sofie\Video\2013 08 28 TH1989\cam2\GOPR0006.MP4 (smooth, front)

Dismounting video links

Method 1:

- L:\Sofie\Video\2013 09 20 FZ1945\GOPR0009.MP4 (smooth)
- L:\Sofie\Video\2013 10 18 AB1941\GOPR0004.MP4 (not smooth)
- L:\Sofie\Video\2013 08 26 FM1985\GOPR0011.MP4 (not used to female bicycle)
- L:\Sofie\Video\2013 09 25 WV1936\GOPR0004.MP4 (stuck behind pedal)

Method 2:

- L:\Sofie\Video\2013 10 02 AP1942\GOPR0003.MP4 (smooth)
- L:\Sofie\Video\20131014 TS1937\GOPR0012.MP4 (almost off-balance)
- L:\Sofie\Video\20131014 TS1937\GOPR0004.MP4 (almost off-balance)

Method 3:

- L:\Sofie\Video\2013 09 20 RR1945\GOPR0004.MP4 (smooth)
- L:\Sofie\Video\2013 10 04 PT1944\GOPR0016.MP4 (very large bicycle angle)

Method 4:

- L:\Sofie\Video\2013 10 14 TK1938\GOPR0002.MP4 (smooth)

Method 5:

- L:\Sofie\Video\2013 11 13 WH1926\GOPR0001.MP4 (smooth)
- L:\Sofie\Video\2013 10 16 IR1930\GOPR0001.MP4 (difficulties with foot trough the frame)

Method 6:

- L:\Sofie\Video\2013 09 30 HL1935\GOPR0003.MP4 (smooth)

Waiting while stationary video links

Method 1:

- L:\Sofie\Video\2013 09 20 FZ1945\GOPR0013.MP4 (smooth, sitting)
- L:\Sofie\Video\2013 09 25 WV1936\GOPR0006.MP4 (smooth, standing)

Method 2:

- L:\Sofie\Video\2013 09 27 HZ1923-fiets\GOPR0009.MP4 (smooth)
- L:\Sofie\Video\2013 08 30 JD1945-fiets\GOPR0016.MP4 (dismounted too fast)

Method 3:

- L:\Sofie\Video\2013 10 04 PT1944\GOPR0008.MP4 (smooth)
- L:\Sofie\Video\2013 10 04 PT1944\GOPR0011.MP4 (foot off the pedal)
- L:\Sofie\Video\2013 09 23 TC1943-fiets\GOPR0007.MP4 (bicycle not stationary)

Method 4:

- L:\Sofie\Video\2013 10 14 TK1938\GOPR0006.MP4 (smooth)

Method 5:

- L:\Sofie\Video\2013 11 13 WH1926\GOPR0006.MP4 (smooth)
- L:\Sofie\Video\2013 10 16 IR1930\GOPR0011.MP4 (too slow)

II - Mounting method descriptions

Method 1

Phase	*Subject*	*Bicycle*	*Photo*
1	**Outside** foot on the pedal	Straight	
2	Gaining speed by stepping with the **inside** foot 1 or multiple times	Leaning outwards	
3	**Inside** foot through frame	Leaning outwards	

4	**Inside** foot on the pedal and sitting down	Straight	

Method 2

Phase	***Subject***	***Bicycle***	***Photo***
1	**Inside** foot through the frame and on the pedal	Leaning inwards	
2	Gaining speed by stepping with the **outside** foot 1 or multiple times	Leaning inwards	

3	**Outside** foot on the pedal and sitting down	Straight	

Method 3

Phase	*Subject*	*Bicycle*	*Photo*
1	**Inside** foot through the frame and on the pedal, and sitting down	Leaning inwards	
2	Gaining speed by pedalling with the **inside** foot and stepping 1 or more times with the **outside** foot	Leaning inwards	

3	**Outside** foot on the pedal	Straight		

Method 4

Phase	*Subject*	*Bicycle*	*Photo*
1	**Outside** foot on the pedal	Straight	
2	Gaining speed by stepping 1 or more times with the **inside** foot	Leaning outwards	

3	**Inside** foot over the frame	Leaning outwards	
4	**Inside** foot on the pedal and sitting down	Straight	

Method 5

Phase	*Subject*	*Bicycle*	*Photo*
1	**Inside** foot through the frame and on the pedal	Straight	

2	Gaining speed by pedalling with the **inside** foot	Leaning outwards	
3	**Outside** foot on the pedal and sitting down	Straight	

Method 6

Phase	***Subject***	***Bicycle***	***Photo***
1	**Inside** foot through the frame and on the ground	Straight	

2	**Outside** foot on the pedal	Leaning outwards	
3	Gaining speed by pedalling with the **outside** foot and stepping 1 or more times with the **inside** foot	Leaning outwards	
4	**Inside** foot on the pedal and sitting down	Straight	

III - Dismounting method descriptions

Method 1

Phase	*Subject*	*Bicycle*	*Photo*
1	Strong braking	Straight	-
2	**Outside** foot off the pedal (and off the saddle)	Straight	
3	Bicycle comes to a halt	Straight	-
4	**Outside** foot on the ground	Leaning inwards	

5	(Off the saddle and) **inside** foot through the frame and on the ground	Straight	

Method 2

Phase	***Subject***	***Bicycle***	***Photo***
1	Light braking	Straight	-
2	Off the saddle and **inside** foot through the frame	Leaning outwards	
3	Bicycle (almost) comes to a halt	Straight	-
4	**Inside** foot on the ground (in front of, or behind, the **outside** foot)	Leaning inwards	

5	**Outside** foot on the ground	Straight	

Method 3

Phase	***Subject***	***Bicycle***	***Photo***
1	Strong braking	Straight	-
2	**Outside** foot on the ground	Leaning inwards	
3	Bicycle comes to a halt (under an angle)	Leaning inwards	-
4	Off the saddle and **inside** foot over the frame and on the ground	Leaning inwards	

Method 4

Phase	*Subject*	*Bicycle*	*Photo*
1	Strong braking	Straight	-
2	Off the saddle and **inside** foot on the ground	Straight	
3	Bicycle comes to a halt	Straight	-
4	**Outside** foot on the ground	Straight	
5	**Inside** foot through the frame and on the ground	Straight	

Method 5

Phase	*Subject*	*Bicycle*	*Photo*
1	Strong braking	Straight	-
2	Bicycle comes to a halt	Straight	-
3	**Both** feet off the pedals	Straight	
4	**Both** feet at the same time, or one by one, on the ground	Leaning inwards	
5	Off the saddle and **inside** foot through the frame and on the ground	Leaning inwards	

Method 6

Phase	*Subject*	*Bicycle*	*Photo*
1	Light braking	Straight	-
2	Off the saddle and **inside** foot over the frame	Straight	
3	Bicycle comes to a halt and **inside** foot on the ground	Straight	
4	**Outside** foot on the ground	Straight	

IV - Waiting method descriptions

Method 1

Phase	***Subject***	***Bicycle***	***Photo***
1	Strong breaking	Straight	-
2	(Off the saddle)	Straight	
3	**One** foot on the ground, the other on the pedal	Leaning	
4	Waiting	Leaning	-

5	Gaining speed by pedalling	Straight	
6	**Other** foot on the pedal	Straight	
7	Sitting down	Straight	-

Method 2

Phase	***Subject***	***Bicycle***	***Photo***
1.1	Light braking	Straight	-
1.2	Off the saddle and **inside** foot through the frame	Leaning outwards	
1.3	Bicycle (almost) comes to	Straight	-

	a halt		
1.4	**Inside** foot on the ground (in front of, or behind, the outside foot)	Leaning inwards	
1.5	**Outside** foot on the ground	Straight	
2.1	Waiting	Straight	-
3.1	**Outside** foot on the pedal	Straight	

3.2	Gaining speed by stepping with the **inside** foot 1 or multiple times	Leaning outwards	
3.3	**Inside** foot through frame	Leaning outwards	
3.4	**Inside** foot on the pedal and sitting down	Straight	

Method 3

Phase	*Subject*	*Bicycle*	*Photo*
1.1	Strong braking	Straight	-
	Outside foot on the ground	Leaning inwards	
1.2	Bicycle comes to a halt (under an angle)	Leaning inwards	-
1.3	Off the saddle and **inside** foot over the frame and on the ground	Leaning inwards	
2.1	Waiting	Straight	-
3.1	**Outside** foot on the pedal	Straight	

3.2	Gaining speed by stepping 1 or more times with the **inside** foot	Leaning outwards	
3.3	**Inside** foot over the frame	Leaning outwards	
3.4	**Inside** foot on the pedal and sitting down	Straight	

Method 4

Phase	***Subject***	***Bicycle***	***Photo***
1.1	Strong braking	Straight	-

1.2	Off the saddle and **inside** foot on the ground	Straight	
1.3	Bicycle comes to a halt	Straight	-
1.4	**Outside** foot on the ground	Straight	
1.5	**Inside** foot through the frame and on the ground	Straight	
2.1	Waiting	Straight	-

3.1	**Outside** foot on the pedal	Straight	
3.2	Gaining speed by stepping with the **inside** foot 1 or multiple times	Leaning outwards	
3.3	**Inside** foot through frame	Leaning outwards	

3.4	**Inside** foot on the pedal and sitting down	Straight	

Method 5

Phase	*Subject*	*Bicycle*	*Photo*
1	Strong breaking	Straight	-
2	**Both** feet on the ground	Straight	
3	Bicycle is standing still	Straight	-
4	Waiting	Straight	-

6	Gaining speed by pedalling with **one** foot and stepping 1 or more times with the **other** foot	Straight	
7	**Other** foot on the pedal	Straight	

V - User data

Table 10. Subject data and results for the MDM categorisations. Differences in the cases where mounting and dismounting differs when waiting.

ID	Group	Gender	Length (m)	Weight (kg)	BMI	Mounting	Dismounting	Waiting	Diff.
AB1941_F39	>65	F	1.57	55	22.3	M1 (C1)	M1 (C1)	M1 (C1)	Yes
AP1942_F37	>65	M	1.78	72	22.7	M1 (C1)	M2 (C2)	M2 (C2)	No
AR1943_F40	>65 (risk)	F	1.61	86	33.2	M1 (C1)	M2 (C2)	M2 (C2)	No
AT1947_F20	>65	M	1.79	86	26.8	M4 (C1)	M2 (C2)	M1 (C1)	Yes
BK1981_F08	>18 & <40	M	1.78	85	26.8	M1 (C1)	M3 (C1)	-	-
BW1947_F17	>65	F	1.65	71	26.1	M1 (C1)	M2 (C2)	M2 (C2)	No
CK1932_F25	>65 (risk)	F	1.71	73	25.0	M1 (C1)	M4 (C3)	M1 (C1)	Yes
CK1935_F22	>65	F	1.63	67	25.2	M1 (C1)	M2 (C2)	M2 (C2)	No
DG1988_F01	>18 & <40	F	1.78	78	24.6	M2 (C2)	M1 (C1)	- (C1)	Yes
EH1944_F42	>65 (risk)	F	1.62	71	27.1	M1 (C1)	M2 (C2)	M2 (C2)	No
EV1936_F23	>65 (risk)	M	1.76	78	25.2	M3 (C2)	M5 (C3)	M5 (C1)	Yes
FM1985_F12	>18 & <40	M	1.76	65	21.0	M2 (C2)	M1 (C1)	M1 (C1)	Yes
FZ1945_F24	>65	M	1.83	76	22.7	M3 (C2)	M1 (C1)	M1 (C1)	Yes
GP1942_F36	>65 (risk)	F	1.67	67	24.0	M1 (C1)	M2 (C2)	M2 (C2)	No
GR1931_F44	>65 (risk)	F	1.68	72	25.5	M1 (C1)	M2 (C2)	M2 (C2)	No
HD1940_F18	>65	M	1.90	94	26.0	M4 (C1)	M3 (C1)	M1 (C1)	Yes
HK1987_F06	>18 & <40	M	1.84	73	21.6	M5 (C2)	M1 (C1)	-	-
HL1935_F31	>65 (risk)	M	1.76	82	26.5	M4 (C1)	M6 (C2)	M1 (C1)	Yes
HZ1923_F38	>65 (risk)	F	1.62	62	23.6	M1 (C1)	M2 (C2)	M2 (C2)	No
IH1948_F34	>65 (risk)	F	1.69	71	24.9	M1 (C1)	-	M2 (C2)	-
IH1987_F10	>18 & <40	F	1.63	63	23.7	M6 (C2)	M4 (C3)	-	-
IR1930_F45	>65	F	1.59	73	28.9	M3 (C2)	M5 (C3)	M5 (C1)	Yes
JD1945_F16	>65	F	1.62	65	24.8	M1 (C1)	M4 (C3)	M2 (C2)	Yes

ID	Group	Gender	Length (m)	Weight (kg)	BMI	Mounting	Dismounting	Waiting	Diff.
JH1988_F07	>18 & <40	F	1.74	57	18.8	M2 (C2)	M1 (C1)	-	-
JJ1930_F26	>65	M	1.80	86	26.5	M3 (C2)	M1 (C1)	M1 (C1)	Yes
LG1990_F05	>18 & <40	F	1.78	68	21.5	M1 (C1)	M1 (C1)	-	-
LN1992_F04	>18 & <40	F	1.72	79	26.7	M5 (C2)	M1 (C1)	-	-
ML1978_F09	>18 & <40	M	1.78	58	18.3	M4 (C1)	-	-	-
MS1941_F41	>65 (risk)	F	1.70	63	21.8	M1 (C1)	M2 (C2)	M2 (C2)	No
PB1942_F33	>65	M	1.82	82	24.8	M4 (C1)	M1 (C1)	M1 (C1)	Yes
PT1944_F27	>65 (risk)	M	1.80	91	28.1	M4 (C1)	M3 (C1)	M3 (C2)	No
RB1937_F19	>65	F	1.64	84	31.2	M1 (C1)	M2 (C2)	M2 (C2)	No
RD1934_F21	>65	F	1.69	86	30.1	M1 (C1)	M2 (C2)	M2 (C2)	No
RG1991_F11	>18 & <40	F	1.78	58	18.3	M2 (C2)	M1 (C1)	-	-
RK1988_F13	>18 & <40	M	1.86	76	22.0	M3 (C2)	M1 (C1)	-	-
RR1945_F29	>65	M	1.86	93	26.9	M4 (C1)	M3 (C1)	M3 (C2)	No
SK1989_F02	>18 & <40	F	1.74	77	25.4	M5 (C2)	M1 (C1)	M1 (C1)	Yes
TC1943_F30	>65 (risk)	M	1.88	86	24.3	M4 (C1)	M3 (C1)	M3 (C2)	No
TH1989_F14	>18 & <40	M	1.92	90	24.4	M6 (C2)	M1 (C1)	M1 (C1)	Yes
TK1938_F46	>65 (risk)	F	1.70	63	21.8	M1 (C1)	M4 (C3)	M4 (C2)	No
TS1937_F32	>65 (risk)	F	1.57	63	25.6	M1 (C1)	M2 (C2)	M2 (C2)	No
TT1941_F28	>65	M	1.57	64	26.0	M1 (C1)	M2 (C2)	M2 (C2)	No
VB1985_F15	>18 & <40	F	1.70	65	22.5	M1 (C1)	M2 (C2)	M2 (C2)	No
WH1926_F48	>65 (risk)	M	1.83	77	23.0	M3 (C2)	M5 (C3)	M5 (C1)	Yes
WT1975_F03	>18 & <40	M	1.85	73	21.3	-	-	-	-
WV1936_F35	>65	F	1.68	68	24.1	M1 (C1)	M1 (C1)	M1 (C1)	Yes
WV1936_F47	>65	M	1.77	80	25.5	M3 (C2)	M1 (C1)	M1 (C1)	Yes
ZW1931_F43	>65	M	1.77	85	27.1	M1 (C1)	M2 (C2)	M1 (C1)	Yes