

---

SAARLAND UNIVERSITY

Faculty of Natural Sciences and Technology I  
Department of Computer Science  
Related Work Summary



# Interactive Technology for Slackline Training

Christian Murlowski

Master's Program of Media Informatics  
March 2018

---



**Reviewers:**

Prof. Dr. Antonio Krüger, German Research Center for Artificial Intelligence  
Saarland Informatics Campus  
Saarbrücken, Germany

Prof. Dr. Jürgen Steimle, Human-Computer Interaction Lab  
Department of Computer Science  
Saarland Informatics Campus  
Saarbrücken, Germany

**Advisors:**

Felix Kosmalla, German Research Center for Artificial Intelligence  
Saarland Informatics Campus  
Saarbrücken, Germany

Dr. Florian Daiber, German Research Center for Artificial Intelligence  
Saarland Informatics Campus  
Saarbrücken, Germany

**Submitted**

28<sup>th</sup> of March, 2018

Saarland University  
Faculty of Natural Sciences and Technology I  
Department of Computer Science  
Campus - Building E1.1  
66123 Saarbrücken  
Germany

**Eidesstattliche Erklärung**

Ich erkläre hiermit an Eides Statt, dass ich die vorliegende Arbeit selbständig verfasst und keine anderen als die angegebenen Quellen und Hilfsmittel verwendet habe.

**Statement in Lieu of an Oath**

I hereby confirm that I have written this thesis on my own and that I have not used any other media or materials than the ones referred to in this thesis.

Saarbrücken, 28<sup>th</sup> of March, 2018

**Einverständniserklärung**

Ich bin damit einverstanden, dass meine (bestandene) Arbeit in beiden Versionen in die Bibliothek der Informatik aufgenommen und damit veröffentlicht wird.

**Declaration of Consent**

I agree to make both versions of my thesis (with a passing grade) accessible to the public by having them added to the library of the Computer Science Department.

Saarbrücken, 28<sup>th</sup> of March, 2018

## **Acknowledgements**

I want to thank all people that helped me actively and passively for making this thesis possible.

In the first place I want to express my gratitude to my advisors Felix Kosmalla and Dr. Florian Daiber for providing me with helpful and competent advises for this topic, arranging all the hardware I needed, preparing the conducted study, proofreading my thesis, and lastly for supporting me in every situation during the entire time. Further, I want to thank Prof. Dr. Antonio Krüger for the opportunity to work on this interesting topic and I also want to thank Dr. Jürgen Steimle for having interest in this thesis and for being my second supervisor.

I also would like to specially thank Tobias Walter and Maximilian Mock for supporting me in every way during all the time, reviewing my thesis, and all the helpful discussions. In addition, I want to thank Patrick Schuck for his helpful advises concerning the statistical analysis of the study.

A thank goes to all people that participated in the study.

Lastly, I especially thank my family and friends who have supported, understood, and motivated me throughout the entire period.

While the following examples, arguments, and descriptions apply equally to both genders, for the sake of ease of reading, only the female pronouns are used in this thesis.

## **Abstract**

Combining sport activities with interactive technology, for example with the Kinect for Windows, guide the user through exercises for keeping herself fit or learning new sports. Slacklining is a balancing sport on which the user walks over a narrow ribbon. The common methods of learning this sport are repetitive trials or having an intermediate slacker as a personal human trainer. However, this comes with several constraints. The beginner needs to know someone, who has fundamental knowledge about slacklining. Further, she is dependent on the knowledge of this person. A trainer cannot give constant real time feedback about all the necessary performance parameters of the slacker. In this thesis I present an intelligent interactive slackline training system that provides constant real time feedback and independency of any external help. Furthermore, it can be used to store the progress of specific exercises and train several people with the same system. A user study was conducted to compare the interactive slackline training system to a personal trainer and should show whether the system can compete against the common training method. The measurements included the time stood on the line, number of steps on the line and the distance walked on the line for the left and right foot. The results showed no significant interaction effects for group x time and no main effects for the group without considering the time. Significant main effects for the time, without considering the group have been found. However, a semi-structured interview showed that all participant had fun and enjoyed the training with the interactive slackline training system. In conclusion the system can be used as an playful and effective alternative to common training methods.



---

# Contents

<b>1</b>	<b>Introduction</b>	<b>1</b>
1.1	Motivation . . . . .	1
1.2	Research Questions . . . . .	3
1.3	Outline . . . . .	4
<b>2</b>	<b>Related Work</b>	<b>5</b>
2.1	Slackline Specific Training and Effects to the Human Body . . . . .	5
2.1.1	Exercises During Slackline Training . . . . .	6
2.1.2	Slackline Specific Training Effects and Application Scenarios	8
2.2	Interactive Technology . . . . .	9
2.2.1	Comparison of Tracking Technologies . . . . .	9
2.2.2	Accuracy of the Microsoft Kinect . . . . .	10
2.2.3	Implementation in Balance Training Scenarios . . . . .	12
2.3	Feedback and Interaction Methods . . . . .	13
2.3.1	Restricting Cognitive Load . . . . .	14
2.3.2	Motivating Factors for Skill Acquisition . . . . .	15
2.3.3	Approaches and Techniques for Providing Feedback . . . . .	16
2.4	User Interface Design . . . . .	18
2.4.1	User Interface Design for Appropriate Feedback . . . . .	18
2.4.2	Kinect for Windows - Human Interface Guidelines . . . . .	19
2.5	Conclusion . . . . .	23
<b>3</b>	<b>Introduction into Slacklining and Slacklining Learning Techniques</b>	<b>25</b>
3.1	Introduction into Slacklining . . . . .	25
3.2	Slacklining Variations and Categorizations . . . . .	26
3.3	Slackline Learning Techniques . . . . .	28
3.3.1	Methods for Slackline Skill Acquisition . . . . .	28
3.3.2	Levels and Exercises of Learning Slacklining . . . . .	31
3.4	Conclusion . . . . .	33

<b>4 Concept</b>	<b>35</b>
4.1 Basic Principles . . . . .	35
4.1.1 Ten Heuristic Principles for Interaction Design . . . . .	36
4.1.2 System Specific Basics . . . . .	37
4.2 Interaction . . . . .	38
4.3 Levels . . . . .	38
4.4 Exercises . . . . .	38
4.5 Feedback System . . . . .	39
4.6 Summary . . . . .	40
<b>5 System Implementation</b>	<b>41</b>
5.1 Hardware . . . . .	41
5.1.1 Components . . . . .	41
5.1.2 Kinect and Slackline Positioning . . . . .	43
5.2 Data Model . . . . .	45
5.3 Movement Recognition . . . . .	46
5.3.1 Heuristics vs. Visual Gesture Builder . . . . .	46
5.3.2 Workflow for Building Gestures . . . . .	47
5.4 Frontend . . . . .	48
5.4.1 Unity3D and Kinect SDK . . . . .	48
5.4.2 Implementation . . . . .	49
5.5 Summary . . . . .	52
<b>6 Study</b>	<b>55</b>
6.1 Introduction and Research Questions . . . . .	55
6.2 Participants . . . . .	56
6.3 Method . . . . .	57
6.3.1 Conditions of Slackline Training . . . . .	57
6.3.2 Procedure . . . . .	58
6.3.3 Design and Independent & Dependent Variables . . . . .	60
6.4 Results and Analysis . . . . .	60
6.4.1 Single Leg Stance Performance . . . . .	61
6.4.2 Walked Steps Performance . . . . .	62
6.4.3 Walked Distance Performance . . . . .	62

6.4.4	Observations of the User Study . . . . .	64
6.4.5	Rating of Exercise Difficulty . . . . .	65
6.4.6	Semi-Structured Interview . . . . .	66
6.5	Discussion . . . . .	66
<b>7</b>	<b>Conclusion and Future Work</b>	<b>73</b>
7.1	Conclusion . . . . .	73
7.2	Limitations and Future Work . . . . .	74
<b>Appendices</b>		
<b>A</b>	<b>Questionnaires of the User Study</b>	<b>79</b>
<b>B</b>	<b>Statement of the Ethical Review Board</b>	<b>85</b>
<b>List of Abbreviations</b>		<b>87</b>
<b>List of Figures</b>		<b>91</b>
<b>List of Tables</b>		<b>93</b>
<b>Bibliography</b>		<b>100</b>

---

---

# Chapter 1

## Introduction

### 1.1 Motivation

With the release of the Microsoft Kinect in 2010 a new area of game interaction has been released. Already existing interaction devices like the Nintento Wii or PlayStation Move provide a remote control with motions sensors as the controlling device. However, the Microsoft Kinect followed another approach by tracking the entire body of the user with an infrared sensor. This resulted in various interaction possibilities, since no controlling device is needed and the full body could be tracked. Especially fitness applications with exercises in which the user is in need of both hands or should not be disturbed by any other device benefited from this (see Figure 1.1).



Figure 1.1: Ingame screenshot of the *Nike+ Kinect Training*<sup>1</sup>Application. A virtual avatar demonstrates the exercise on the left side. The user can see herself mirrored on the right side of the screen.

---

<sup>1</sup><https://marketplace.xbox.com/de-DE/Product/Nike-Kinect-Training/66acd000-77fe-1000-9115-d8024d53090f>

Combining exercises that are implemented in a video game or a gamified environment and tracking the body movement of the user with an appropriate device originated in a new genre named *exergames* [6, 58]. Nowadays the uprising modern sedentary way of life , through more and more sitting jobs or watching television at home, leads to insufficient movement throughout the day. Exergames can bring more contrast into their daily routine if implemented effectively [53]. Several studies point out that such applications can improve the physical activity level, increase the engagement of the user, promote exercises, and provide an enjoyable experience [23, 28, 62]. Further works have also shown that interactive system applications with an exergame approach can improve and train sport specific skill acquisition, e.g. in trampoline or climbing [5, 12, 30, 32, 35].

Slacklining is a more specific form of sport that relies on the balance of the user. She has to walk over a narrow ribbon, which is in general tensed between two static end points and about the height of 50 cm. The length of the line varies from 3 up to 100 meters and more. In general, a beginner learns to balance on a slackline on her own with repetitive trials. This can be frustrating and dangerous because she has to learn it by herself without any knowledge about the correct movements and body position. Another approach is to learn it under experienced guidance with a well known expert. However, the trainee must know such a person and is also dependent on her.



Figure 1.2: Person standing on a slackline and balancing out his sway

These problems can be solved by an interactive slackline learning system. The system presented in this thesis provides specific exercises as well as real-time support and feedback for beginners to learn slacklining. Building a constructive predefined exercise routine with an appropriate difficulty level teaches the trainee how to stand and walk on a slackline from the ground up. A detailed introduction with a preview of the exercise execution provides her with the appropriate

knowledge for the ongoing exercise. During the execution she gets audiovisual feedback about her execution in real-time with the help of several indicators. Lastly, showing several performance parameters to summarize her learning progress of the exercise execution.

## 1.2 Research Questions

The research questions of this thesis are divided into four parts and will be further described in the following.

**Has slacklining a positive training effect and what has to be considered to build an appealing interactive learning system?**

First, the usage of slacklining and its training effects to the human body will be shown by several works. Further, several interactive tracking devices and applications in balance training will be compared. It is also important to provide appropriate feedback and design an appealing application in the context of balance sport training to support and motivate the user. This helps to get an idea on how to design the application for the SLS and which factors should be considered to motivate the trainee as well as to provide an adequate user experience. Several learning methods exist to train beginners on a slackline. Mainly the investigations of Thomann [63] and Kroiß [38] are used to provide an appropriate training method and exercises.

**How can a conceptual design of a prototypical interactive slackline learning system be elaborated?**

The conceptual design will be described on the basis of related work and slackline exercises. To provide a more general conceptual elaboration the used tracking technology was not taken into account for it. Hence, the concept provides the possibility to adapt it for other tracking systems. Basic interaction design principles, specific basics for the system regarding slacklining, structuring of the exercises, and the feedback system are discussed.

**Which technical architecture and hardware are necessary for developing such a system?**

The system implementation process consists of the technical development part based on the conceptual elaboration for the study afterwards. In general, it describes hardware components, apparatus, data management, movement recognition, and user interface. Special attention will be paid to the positioning of the slackline related to the Kinect as tracking device. The coherence of the Kinect with the development platform Unity are also part of this.

**Can the slackline learning system compete with a common learning method and show a learning progress on users that trained with the system?**

A user study will be conducted to show the suitability of the system, its strengths and weaknesses, and whether the SLS shows positive effects on the learning progress of beginners on a slackline. To explore if such a system can compete with a common learning method it will be compared to a personal trainer. Therefore, participants are divided into two groups in which one group trains with the SLS and the other with a personal trainer. The performance parameters of single leg stance on the slackline, how many steps they can walk with each leg, and the distance they walk on the line will be measured before and after the training. With this the learning progress of the users' balance ability can be shown. Lastly, an interview should reveal the participants experience with the training method after the training.

### 1.3 Outline

The structure of the thesis is outlined in the following. As a groundwork the *Related Work* chapter discusses sections of *Slackline Specific Training and Effects to the Human Body*, a comparison of interactive tracking devices in *Interactive Technology, Feedback and Interaction Methods*, as well as aspects of *User Interface Design*. The chapter *Introduction into Slacklining and Slacklining Learning Techniques* gives an overview on this sport and how to learn slacklining appropriately in section *Slackline Learning Techniques*. The conceptual design is described in chapter *Concept* with general interaction design principles, interaction with the system, and how to build an appropriate structure related to the slackline exercises elaborated in the previous chapter. Details of the system implementation are further described in chapter *System Implementation*, which is divided into the sections *Hardware*, *Data Model*, *Movement Recognition*, and *Frontend*. The study structure, methods, results, and discussion can be found in chapter *Study*. Lastly, chapter *Conclusion and Future Work* comprises the findings of the thesis and gives approaches and recommendations for future work.

---

---

# **Chapter 2**

## **Related Work**

This section presents related work to a slacklining assistance system with an interactive technology approach. Topics covered in this section are how to provide exercises and feedback approaches for beginners on a slackline, further called slacker, with the Microsoft Kinect v2 as a tracking device. Hence, it is necessary to have an understanding of instructive teaching methods for beginners. Already existing approaches and studies have been investigated to build an appropriate foundation and point out several application scenarios. Also the user interface should motivate the slacker for the training scenario and lead to a proper user experience.

At first, related concepts concerning slacklining show how to build learning techniques for beginners, the efficacy in balance training, and areas of application. Next, current tracking technologies are compared for tracking the human body on the slackline, which follows by a discussion why the Microsoft Kinect v2 seems like the appropriate tracking device. The system should also be aware of the cognitive load and motivating aspects, which can be challenging with repetitive exercises. Several applications show, where problems occur with different feedback and interaction methods. Lastly design opportunities for guiding the user through the learning process are demonstrated by various approaches.

### **2.1 Slackline Specific Training and Effects to the Human Body**

As in other sport activities it is important to have a concrete baseline about which exercises and tips are useful for early beginners. Mainly to have a good knowledge of the basics, which results in a faster learning process, but also to prevent

injuries from the beginning. In the following, several slackline learning techniques will be discussed, which are then be implemented in the SLS afterwards. Prior research indicates the applicability of slackline training for areas like sport medicine and rehabilitation training. It shows why slacklining could be used as an alternative to classical balance training and how the body swift affect these. Donath et al. [15] found in his meta-analysis significant improvements in the postural control after slackline training, which indicates the efficacy of this sport. This subsection shows several application scenarios in which a slackline can be implemented and improve the training effect.

### 2.1.1 Exercises During Slackline Training

For beginners it is often difficult to walk or even stay on a slackline. The uncontrollable swift of the narrow line result in unfamiliar movements that cannot be handled at the very beginning. Therefore they should learn to concentrate, build up motoric basics and trust into the line, as well as manage their body behaviour.

Thoman [63] differentiates two basic methods for the learning process on a slackline. First, teaching a slacker without any external help or second, with systematic external assistance. The investigation of Kroiß [38] resulted in no significant difference between both methods. However, there is a trend regarding providing methodological aid, like human support or physical objects as nordic walking sticks or a bar, can help to improve the learning effect (see Figure 2.1). Therefore, it is a good advise for beginners to learn the fundamentals of standing and walking on the slackline to build up a groundwork. Several basic techniques and tips are useful to support her in this way. For example focusing on a specific point in front of her, stretching out the arm, raising the hands over the shoulder level, turning the palms to the top, going slightly in the knees, having the feet straight with the line, and so on [37, 38].

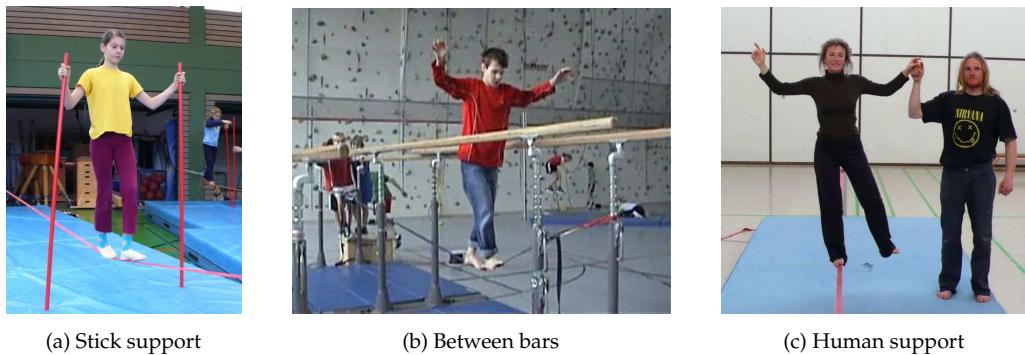


Figure 2.1: Supportive exercises [38]

With further progress, the external help, if given, should be reduced. The slacker can now try to stay and walk on the line on her own. It is recommended to begin with the practice of a basic start, to stay with both feet, and one feet on the slackline since these are basic techniques (see Figure 2.2). Staying with both

feet seems easier in the beginning but only the hips and hands can be used for balancing. With just one feet on the line, the slacker can use the other one as an additional extremity for balancing purposes.

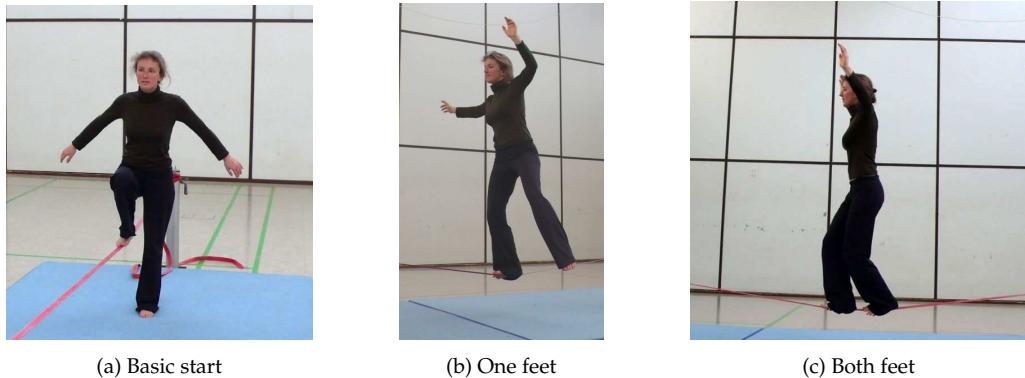


Figure 2.2: Basic exercises [38]

Advanced training should be practiced in a more dynamical way [63]. Like seen in several research works [13, 14, 24, 36, 47] this can be from crossover start (see Figure 2.3a), turning on the line, hands on hips or behind the back (see Figure 2.3b), walk sideways or backwards up to catch and pass a pall, kicking a football, bouncing a basketball, or a kneel down on the slackline (see Figure 2.3c).

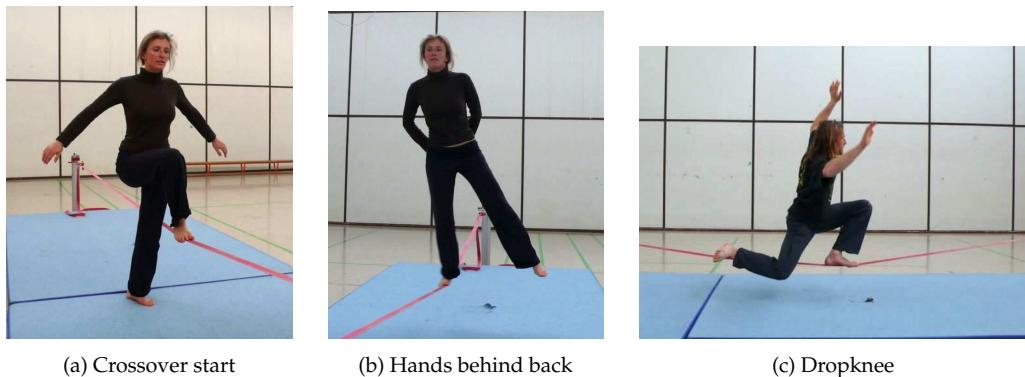


Figure 2.3: Advanced techniques [38]

Additional cognitive load is caused by unfamiliar exercises and simultaneous balancing on the line. This conjunction can lead to impairments. Even more difficult exercises can be carried out in further sessions like standing up from a sitting position, juggling, two people on the same line, reading a newspaper, closing eyes while balancing, vertical jumps, or rope skipping. Due to the higher difficulty of constraints, it results in a more unstable movement of the line.

Changes directly on the slackline itself, like varying the tension and length, have also an influence on the stability of the human body on the line [36, 47, 48]. A short and tight line results in a relatively small vibrating area, where the slacker

has to outbalance short unpredictable movements on point. Given a longer and loose line, it results in a more swinging behaviour that she has to counteract [38].

The slacklining assistance system should mainly train and support beginners to walk on the slackline. With those approaches in mind, a foundation is set to build helpful exercises for the system. Because the focus relies especially on beginners, this information serves as a guideline for supporting them with effective and efficient methods. Now is the question, what effect has slacklining on the human body and in which application areas can it be applied? This is part of the next subsection.

### 2.1.2 Slackline Specific Training Effects and Application Scenarios

Donath et al. [13] elaborated the effects of slackline training on regular balancing, jump performance, and muscle activity with young children in school sport. The slackline specific balance has improved. Also the dynamic sway and muscle activity for the lower limb is reduced. However, there were no effects regarding jump performance. The children enjoyed the slackline training. In comparison to classical balance training, it can be more fun for the children and at the same time serve as an effective training method.

A further study of Donath et al. [14] investigated slackline training with seniors from an age between 59 to 69 to measure effects on slackline specific balance and neuromuscular performance. They found significant differences between pre- and posttests during all slackline stance conditions. In addition, the trunk and limb muscle activity were reduced after the training phase. With this in mind slacklining can be provided as an alternative balance training method for seniors. Regular balance training can help to reduce the fall risk, which can be an useful therapy for seniors when keeping in mind that 30% of seniors suffer from fall injuries once a year.

Keller et al. [36] examined the improvement of the postural control regarding the Hoffmann-Reflex after slackline training and whether adaptations can be found regarding classical balance training. The H-Reflex (Hoffmann-Reflex) is used to assess and quantify stretch-reflex responses due to electrical stimulation. The measurements show that these were significantly reduced as well as slackline specific balance were improved. Therefore slackline training and classical balance training have at least similar effects on the postural control.

Pfusterschmied et al. [47] found significant effects regarding stable stance after slackline training and even more effects were found for perturbed leg stance. This is because slacklining is a high dynamic movement activity and there is more need of regaining equilibrium as in perturbed stance than for maintaining balance as in a stable leg stance condition. The velocity in medio-lateral and anterior-posterior center of gravity, knee and hip joint is reduced as well as the range motion in knee and hip joint. No changes in medio lateral direction for the stable surface or joint kinematics for both have been found.

Another study of Pfusterschmied et al. [48] shows effects on lower limb joint motion and muscle activation. They found a decrease in platform velocity and improvements in corrective action in the knee joint. Also enhanced activation of the muscle activity in rectus femoris (upper leg) was measured.

Granacher et al. [24] investigated the impact of slackline training for balance and strength promotion and found contradictory results compared with the studies described above. Static and dynamic postural control were analysed as well as the isometric and dynamic muscle strength. There were no effects regarding the postural control, maximal torque, and jumping height. The results can be explained due to the assessment of other recorded variables, usage of different methods for analysing the data, and the relatively short slackline training time than in other studies [47]. Therefore this study can be seen as an exceptional case.

Those investigations show that slacklining is indeed an effective method for improving the postural control. Hence many application scenarios can be thought of to implement a slacklining assistance system. For example it can be used as a training approach in school sport, preventative activity for seniors, and rehabilitation alternative. Furthermore, it can be used as a supportive training method for athletes in sport activities like skiing or skating, that require a good body balance. Interactive technologies can be used to support training in such scenarios. The next section provides an overview about state of the art technologies, compares them, and show several implementations in balance scenarios.

## 2.2 Interactive Technology

To build a real time feedback assistance system, a tracking device is needed that supports the slacker in an appropriate way and that won't interrupt her. The Microsoft Kinect v2 seems like a suitable tracking system in this context, because the user doesn't need any further devices to be tracked as it will be discussed in the following. Further, advantages and drawbacks of comparable systems like the Nintendo Wii, Playstation Move, and motion capture systems will be discussed. Lastly, several studies show how accurate and precise the Microsoft Kinect v2 is, if it can be applied for balancing purposes, and if it gives the user appropriate feedback or useful analysis data for specialists like therapists.

### 2.2.1 Comparison of Tracking Technologies

The Nintendo Wii consists of a sensor bar with infrared sensors that estimates the position of the Wiimote controller in 3D. Further, an accelerometer is integrated in the Wiimote to detect its motion. Thus the user can interact with the console, based on predefined gestures [5, 60]. Gesture recognition is an essential aspect of the slacklining assistance system for giving appropriate feedback regarding the executed exercise. Schröder et al. [56] analysed the gesture recognition of the Wii and found an error rate between 5% and 15%.

A similar approach with a handheld controller is followed by the PlayStation Move. It consists of a RGB camera called Move Eye that is used for tracking the 3D position of a glowing sphere attached on the handheld device named Move wand. The controller contains an accelerometer, gyro sensor and geomagnetic sensor to track the rotation. Further, it also supports position tracking. In this way more accurate tracking is possible than with the Nintendo Wii [5, 60].

Both systems are suitable devices if the controller itself can be replicated as a virtual device like for example in golf or tennis. However, they do not track the body movement and the user is bound to her handheld devices to interact with the system. In the slacklining system they could disturb user standing on the slackline. Moreover accurate feedback from the whole body is wanted and thus it should be the actual controlling device. Therefore they seem not to be appropriate devices for the slacklining system.

With a motion capture suit, like *Xsens MVN* [42] or *OptiTrack* [45], sensors or markers have to be attached on the user's body for tracking her body motion and rotational data. This makes it the best method for high accuracy and precision body tracking. Problems with the suite are that it is very expensive and the setup takes relatively long time because of the marker attachment and the positioning of the tracking cameras. The biggest drawback is the uncomfortable bulky equipment that could interfere the user during the performance [5, 7, 44]. This makes it an inappropriate device for user tracking on a slackline.

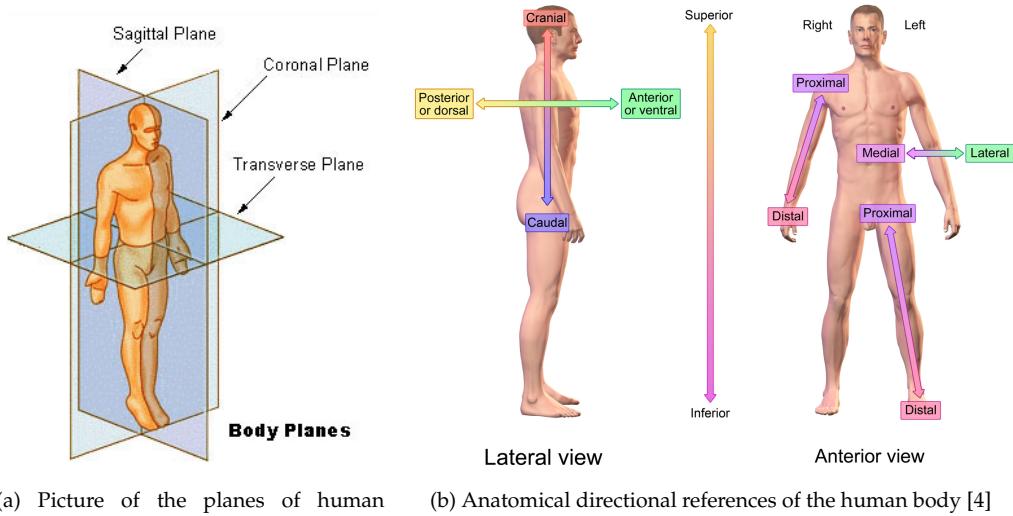
The Microsoft Kinect is a static device that includes a RGB camera and depth sensor. Because the body joints and player position are recognised by these, the user is free in her movement without any further controller. Another advantage is the low price in comparison to the motion control suite, and the low setup time because only the device itself is needed. Problems occur with occlusion of body parts that results in glitches and flawed tracking [34, 61]. To the user they can be hidden, e.g. by only showing the output of the depth cam [30]. This problem can also occur in the slacklining case because the feet overlay with each other while walking on the line. Therefore a technical feasibility evaluation have been conducted to show if this is a bigger problem or can be neglected.

With this in mind, the Microsoft Kinect v2 seems like the most suitable device. The recognition of the whole body, freedom of movement, short setup time, and relatively low cost make it the best system out of the considered systems.

### 2.2.2 Accuracy of the Microsoft Kinect

In the field of balance training it is necessary to give appropriate feedback for the patient that reveals errors in the performance and support a proper execution. With this in mind user tracking should be good enough to fulfil this criteria. Since Microsoft Kinect is used as the tracking device the accuracy and precision should be assessed.

Lim et al. [40] assessed the accuracy of the Kinect with a 3D motion capture system as a reference system. For further understanding please review Figure 2.4 regarding expressions to body planes and anatomical directional references. The participants had to execute balance training with complex aperiodic movements in the body planes (see Figure 2.4a). Similar characterization of movements are provided by the Kinect in comparison to the 3D motion capture system. The correlation analysis showed that the Kinect and the 3D motion capture system are highly correlated for the flexion and extensions in the medio-lateral-axis (x-axis) but not on the anterior-posterior-axis (y-axis) and the cranial-caudal-axis (z-axis) (see Figure 2.4b). This is because the Kinect determine joint locations based on the depth image data and the data input is limited to the depth camera view. Therefore recognition of joint angles in the sagittal and transverse plane is not optimal (see Figure 2.4a). Also the primary goal of the Kinect is to measure the dynamic movements in the coronal (frontal) plane for gaming reasons. It is indeed an effective system to characterize changes in center of mass and movements in the frontal plane during balance training. But it would not be suitable in balance training that require in-depth analyses of joint motions, which is not needed with the slackline assistance.



(a) Picture of the planes of human anatomy [31]

(b) Anatomical directional references of the human body [4]

Figure 2.4: Anatomical terms of location

Chang et al. [7] focuses mainly on the tracking performance of the Microsoft Kinect as a rehabilitation device in comparison with a high fidelity motion capture system called OptiTrack. In their application the user has to move objects from one side of the screen to the other. Five correct and incorrect movements have been realised and both systems successfully identified them. In trajectory comparison the results of the hand and elbow by the Kinect are very close to the OptiTrack system. Tracking of the shoulder movements are moderate because it involves rotation that the device does not recognizes well. The timing perfor-

mance comparison shows that the OptiTrack system is negligible faster than the Kinect.

Woolford [68] compared the accuracy and precision of the Kinect v2 with the Qualisys motion capture system for the usage in healthcare applications. He describes that accuracy is the amount of how close a measured quantity to the actual value is. Precision is the similarity of repeated measurements (see Figure 2.5). For example the Kinect skeleton tracking methods are accurate because the average joint position data is very close to the actual physical position. Regarding his definition of precision, the joint position data is not always precise because the data spreads in its position of the frame. The results show that the Kinect V2 is accurate but imprecise for body parts whose center of mass cannot be easily identified like the shoulder. For smaller body parts as well as between two body parts such as elbow or wrist the accuracy and precision is very high.

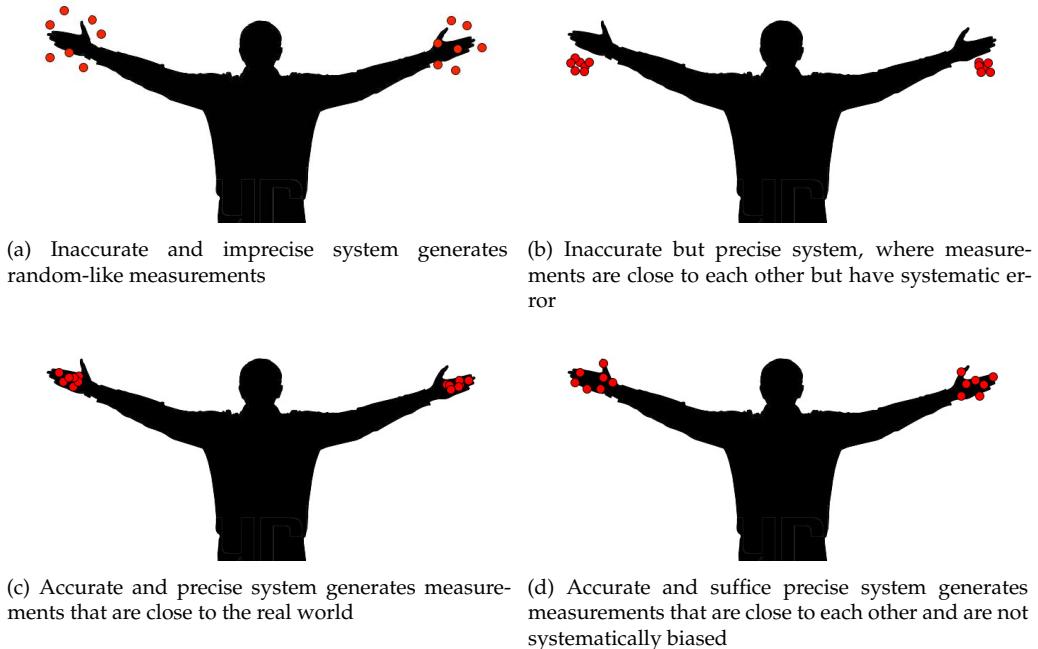


Figure 2.5: Definition of accuracy and precision [68]

The Microsoft Kinect v2 can indeed be compared with high performance tracking devices. If no detailed analysis is needed, it provides reliable and appropriate data. For the assistance system it should provide sufficient data to track the user and give useful feedback

### 2.2.3 Implementation in Balance Training Scenarios

Like already stated Chang et al. [7] not only assessed the accuracy of the Microsoft Kinect but also if it could fit as an alternative training device in rehabilitation

training. The results show that it provides enough usable feedback to the therapists to be an appropriate device for medical uses. Woolford [68] state that the Microsoft Kinect is a useful device for monitoring such exercises. The setup is relatively easy and the tracking is appropriate for exercises in a healthcare environment. Lim et al. [40] investigated the usage of Microsoft Kinect in the field of falling risk. They tracked characterizing movements and found that it is an useful device for balance training. Ustinova et al. [65] used the Kinect to improve the postural control as well as coordination deficits from chronic traumatic brain injury patients. It resulted in improvements of postural stability, movement performance and motoric coordination. The participants were also very satisfied whereas normal exercises have been stated as boring. Pisan et al. [49] used the device to investigate the prediction of the loss of balance for elderly users with a step training program. The user preferred doing exercises with the system and the tests matched also the expectation of the researcher. An integration in promoting the postural control for parkinson disease with

Kinect games were elaborated by Pompeu et al. [50, 51]. The results affirm that the patients improve in balance purposes and motoric movements with this help.

Furthermore, Estapa et al. [16] and Freitas et al. [18] collected data of execution from patients for medical reviews. Both developed a motor rehabilitation game. It is used to support therapeutic exercises and evaluate biomechanics of the patients. This allows subsequent analysis of the performance data for the therapist.

This approach of data analysis was also integrated by Garrido et al. [22] but in addition, they elaborate if the Kinect can serve as a rehabilitation home assistance. Many patients are thrown out of their daily life environment for accessing traditional rehabilitation training in a medical center. The patient incorporate the system into their daily life and avoid such trips. The medical stuff gets all relevant parameters due to the transmission of the recordings from the exercises to the medical center. Beside this they get more time because nobody has to observe the training.

Keeping the stated results in mind shows that the Microsoft Kinect is a promising system for balance exercises that provides sufficient accurate and usable feedback. It can be embedded in a variation of fields as rehabilitation system, home assistance, or preventative technique. The aspect to motivate patients with an exergame approach and enjoyable user interface can also lead to successful exercise execution, which is part of the next section.

## 2.3 Feedback and Interaction Methods

Cognitive load plays an important role if skill acquisition is a major factor. In slacklining the user has to focus on multiple things simultaneously that increases the mental pressure. Several studies show why and how the cognitive load should be restricted. Another important fact is that repetitive exercises can

lead to a boring and demotivating user experience. For that reason several methods, systems and game approaches can be used as an inspiration to build a system with a motivating and joyful environment. At last the integration and visualisation of feedback and interaction methods should be well thought out. Various techniques have been elaborated on how to provide this appropriately.

### 2.3.1 Restricting Cognitive Load

As a baseline Paas et al. [46] describes that the acquisition of new skills is in conjunction with cognitive load. By adjusting this the learning effect can be eased or hardened. Three types of cognitive loads exists that handle the working memory of a person regarding the learning process. Intrinsic load is the inherent complexity that is caused by the topic itself. It is also important in which manner information is given to the user. If this is unnecessary, repetitive, or interferes her it is called an extraneous cognitive load and increases the burden of the user. The last type is germane cognitive load, which describes also how information is given to the user but by supporting her in that way. This is brought by activating and automating already existing patterns or generating new ones in the working memory to enhance a learning process. Regarding this several applications have been evaluated that are also relevant to the slacklining supporting system.

Van der Spek [66] evaluated how to deal with the right complexity in serious games. He describes in his mental model construction (see Figure 2.6) that interference can be avoided by information regulation and focus attention. Improving is encouraged by predictability and reflection of the tasks. The attention of the user should be focused to relevant material by regulating the information given to her. Since a serious game like approach should be developed this is an important reference for building an effective learning process to the user.

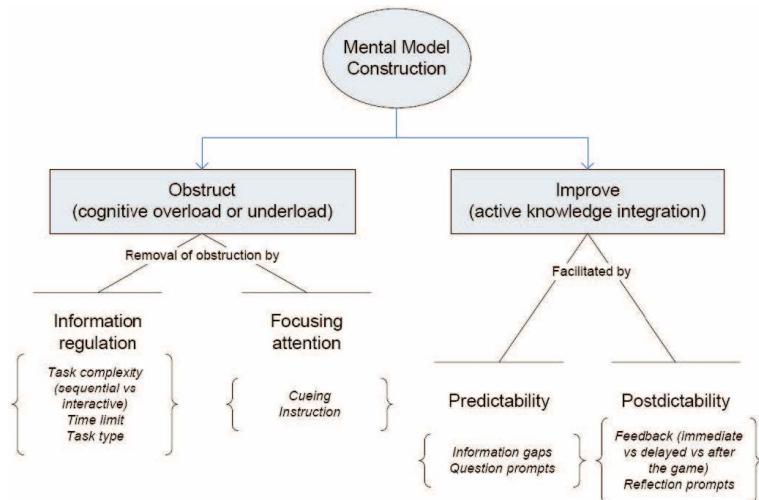


Figure 2.6: Guideline for enhancing the cognitive load [66]

Pisan et al. [49] evaluates the user risk of falling with cognitive loading exercises. They executed two stroop tests, where the participant had to name the correct color of the word. High and low cognitive load can be measured by differentiating the meaning and color of a word. In the next challenge she has to answer different maths problems provided by the system. The results show that the reaction time due to cognitive load is much larger with users that have a higher risk of falling than for users that have a lower risk. This could be explainable due to the fact that user with higher falling risk are not that good in terms of switching the cognitive focus from the balancing action into other actions.

Training on a slackline provides cognitive load to the user because of several simultaneously things she has to be aware of. Hence feedback given on how to behave in a situation should be provided in an appropriate manner to support the slacker. The system has to be aware of this and restrict the cognitive capability in the right way. Next to cognitive load the system has to ensure that the user stays motivated for the training, which is part of the following subsection.

### 2.3.2 Motivating Factors for Skill Acquisition

Several rehabilitation and sport training programs can be elaborated for motivating factors because the skill acquisition in slacklining resembles with them. The training procedure is a process of repetitive exercise execution. For mastering new skills and extending herself the user must have the willingness and commitment for practicing, which can be described as motivation. The self-determination theory by Ryan et al. [54, 55] describes several types of motivational factors. First the intrinsic motivation, which is caused by interest to an action and satisfies the own psychological needs for self-determined behaviour. This is the fundamental stimulus for high valuable learning and practicing. Second the extrinsic motivation that is performing an activity because of an external output. The user can hereby feel externally propelled due to compliance with external regulations or she can be self-endorsed due to willingness and acceptance by the value of the practice.

Johnson et al. [33] stated concerning rehabilitation training that if exercises and the user herself provide negative factors like boredom, repetition or long execution time it results in a discouragement. Enhancing the interaction with this trainings can lead to effective training. Pisan et al. [49] says that video games can help to motivate the patients through their physical training. The participants in his user tests found the games that he developed engaging. They preferred doing the exercises with the system.

Several researchers involved the motivational aspect of video games in their system. Ustinova et al. [65] developed four custom virtual video games to elaborate the efficacy for postural deficits. First a virtual teacher where the subject has to copy its movements strictly. Second a virtual challenger that is divided into a skateboard, courtyard and an octopus game with specific exercises

in which the movements of the user are more flexible. Successfully completed performance will be rewarded with a number of points. Overall the user were strongly satisfied with the gaming part of the therapy and moderate with the virtual teacher part.

Freitas et al. [18] focused on user centred development of a physiotherapeutic game that supports motor rehabilitation exercises. A plane represented the user and she has to fly through rings in the air and avoid obstacles. The patients were strongly satisfied with the game. An important factor here is the good user interface that affects the user motivation, visually presented scenario and playing technique in a positive way.

Estepa et al. [16] evaluates three developed exergames involving different psychophysical rehabilitation exercises. A virtual avatar represents the patient and orders are giving via an auditive or visual stimuli. The first two games are a series of oncoming balls placed at desired angles that the patient has to avoid with her trunk or, in the second game, with her feet. In the third exercise she has to step forward to a colored line between starting and goal position. All games were easy to understand and provide necessary feedback. The patients had a considerable interest to use the system.

Kajastila and Hämäläinen [34] encourages monotonous parts of climbing training by adding goals and supporting the social collaboration of the participants. Hence they are making it overall more enjoyable. Six prototypes were developed. Prototypes that rely more on a training part are an easy route builder, automatic route generator and instant video feedback. For the user those were the most useful ones. The exercises that consists of a more playful part, such as a chasing animated saw that the climber has to avoid, shifted the focus away from the training part.

With this in mind a useful training device should be considered that includes an enjoyable virtual environment. A good balance between these both is the key for successful and motivating skill acquisition. Another part of the system should also provide useful feedback to the slacker. What methods can be used for this will be discussed in the following.

### **2.3.3 Approaches and Techniques for Providing Feedback**

Several technological advances like video feedback, virtual environments, and auditive information can be applied for providing feedback in sport activities. Liebermann et al. [39] evaluated those regarding their field of application. With video information costs are relatively low, it is easy accessible, and portable. It can be repetitively replayed in real-time or superposition of two video. Training in 3D virtual environments can help to improve or to familiarize with a real world skill acquisition. The user can pre-practice a skill in simulated unknown conditions like pilots in a simulated airplane. Providing appropriate auditive information can also have a relatively high impact on performance enhancement.

Also the Microsoft HCI-Guidelines state that implementing audio is a good way if the user need to be notified, and to indicate states of changing behaviour [9]. For example in balance training a warning signal can indicate that the current pose is not the desired one. If the user corrects her posture in the right way, the signal should then transform into an more comfortable signal. All of these allow qualitative and meaningful feedback in their application context. The user can review the execution, pre practice in a virtual environment, or be supported by audio warning signals. With this she can discover failure in her performance.

Feedback has to be provided in an appropriate manner for improving new motor skill acquisition. Especially for starting to learn a new technique it is important to have immediate feedback sources on which the user can rely on [29, 67]. Therefore it should be easy to understand for enhancing the learning process.

Hämäläinen [27] developed applications for a camera output in front of the user. An automated motion controlled approach starts and stops the recording if the motion exceeds a certain threshold. Second a speech and last a gesture control prototype. Both consists of four commands to record, play, stop and delay the recording. The user test ranked the automation the worst because it reacted to unintentional motions, which ends in unwanted command recognition. The speech system ranked the best but only worked well if the participant speaks near the microphone. Some mentioned that the gesture approach were more intuitive and natural, which could be a good compromise out of the three approaches.

Holsti et al. [30] investigated delayed video feedback and a platform jumping game in trampoline sport. The former records the performance execution and shows it repetitive to the user. In the second the player has to jump back- and forwards on virtual platforms. They tested it with athletes and beginner. The delayed video feedback was ranked useful for nearly all athletes. Overall the platform jumping game was ranked the best.

Kajastila and Hämäläinen [34] project graphics on an artificial climbing wall. A feasibility study showed that graphic information is best located near holds where the focus of the climber goes naturally. This can be adapted to slacklining since the slacker has to focus usually a specific point in front of her. It would be useful to provide information in the peripheral view. Next to other prototypes he has implemented an instant delayed video feedback. This is rated as one of the most useful ones because the user can immediately analyse her performance. Also a gaming approach is developed as an animated saw that chases the climber and has to be avoided. User state that it moves the focus away from the training, but it could be an enjoyable alternative to kids for getting them used to the sport.

Based on the results of the last paper Kajastila et al. [35] developed two games and a route creation application. User emphasize the versatility and excitement of the games. They also forget the fear of heights due to time limits and forcing them to focus and achieve a goal. User stated that playing and spectating is also more fun due to implemented sound and visual effects.

Like already stated, a delayed video feedback is a good approach to learn new skills. Combining this with a gaming approach can simultaneously lead to a joyful experience with training aspects. Also adding audio signals can further improve this experience for the user as well as for spectators. A well suited interaction mechanism and a good looking environment can help to create an effective system and motivate the user for training purposes.

## 2.4 User Interface Design

The user interacts with the system through the provided interface. This should contain all relevant information, which are necessary to achieve a specific goal and support her on the way to reach this goal. General user interface approaches from exergame like related work approaches should be compared. Therefore the subsection *User Interface Design for Appropriate Feedback* gives an overview on which elements can be used for guiding the user through the system and how feedback can be visualized properly. After that in subsection *Kinect for Windows - Human Interface Guidelines* shows how to enhance the user experience on a kinect application based on guidelines provided by Microsoft.

### 2.4.1 User Interface Design for Appropriate Feedback

Important feedback information during the exercise should be placed in the users' peripheral view, which surrounds her focus point. Directing her the correct movement can be done in several ways. Basic information about the execution should be given prior to the user for exercise preparation. Surrounding objects can be displayed as arrows, flashing notifications or weighting scale, like seen by Garrido et al. [22] in Figure 2.7a. Additional informations like the current exercise and state can be displayed outside of the focus space. They should be designed to not distract the user. A feedback summary after the execution can give an useful recap about the exercise for reflection (see Figure 2.7b).

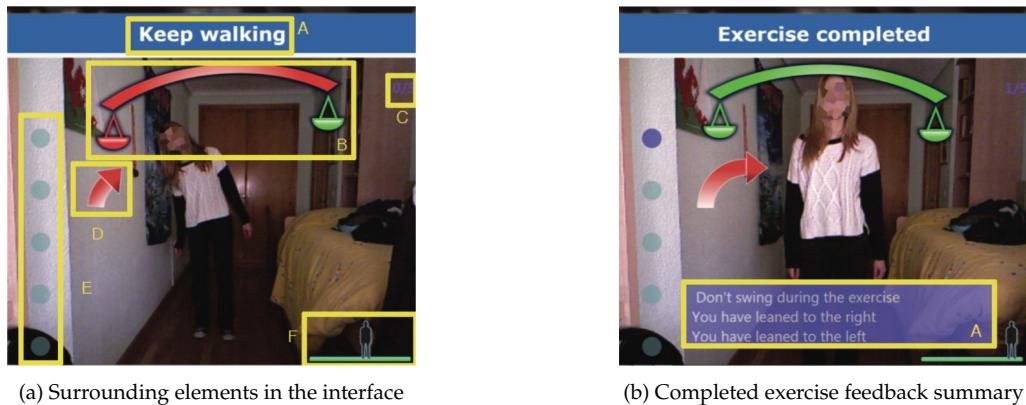


Figure 2.7: Interface of a rehabilitation training application [22]

Another method is to show the user herself or an avatar that demonstrates the correct performance of the current exercises like in Figure 2.8 and 2.9. Holsti et al. [30] implemented such a user integration and in user testing they endorse to see themself performing in real time.

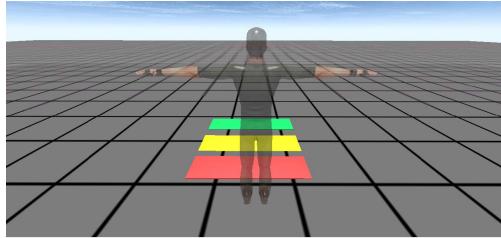


Figure 2.8: 3D Model as avatar [16]



Figure 2.9: Rail-time user representation [30]

The task about the execution has to be clarified. Chang et al. [7] provide real time feedback on the performance quality due to a visualised path. If the performance is correct, the path will turn green. However, if the user moves outside the range, the path turns red and an arrows guides her into the correct position. Instructions and highlighting objects can help to complete an exercise successfully (see Figure 2.10). If she performs something wrong during the performance e.g. in the slacklining case corresponding body parts could be highlighted.



(a) Instruction to the game



(b) Green indicator for correct performance

Figure 2.10: User interface of a rehabilitational application [7]

## 2.4.2 Kinect for Windows - Human Interface Guidelines

Microsoft itself offers Human-Interface-Guidelines (HIG) for developer and designer that describes several techniques of certain areas for developing a kinect application [9]. It provides a quick introduction into the Kinect itself, design principles for interactions regarding gesture and voice, techniques on teaching complex gestures, and how to visualize appropriate feedback. Also which interactions should be used for a specific action. Therefore developer may follow this general standard to support their end-user. In the following general principles of the guideline will be discussed on which the interactive slackline system will rely on to enhance the user experience.

## Basic Design Principles

Context-awareness delivers the best user experience, e.g. controls should be placed where user would expect them to be and interactions should be appropriate for the environment. It is important that the user feels confident. This can be achieved by designing interactions to be simple and easy to learn. The user will choose an input that takes the least effort for the given goal. Therefore the input method should match its purpose, be reliable, consistent, and convenient. Conducting user test helps to improve the system. Not each person will use the system the same way and minor adjustments can make a huge difference in the understanding of the usage.

## Visual and Audio Feedback

Providing constant feedback helps to display the current status of the system. In general, appropriate feedback should show if the sensor is ready, the user is visible and engaging with the Kinect, and so on (see Figure 2.11a). Regarding this a combination of visual as well as audio feedback results in a better experience, e.g. clicking a button changes its visual state and provides an audio signal (see Figure 2.11b).

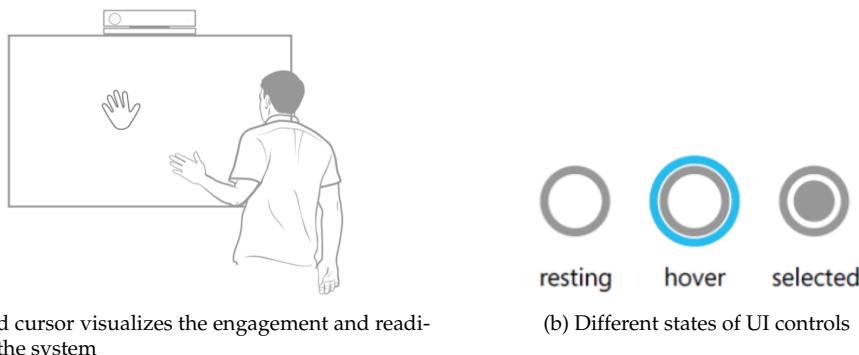


Figure 2.11: Feedback methods [9]

The most important part for complex gestures is the progress indicator described in this guideline. It supports the user if she has to hold a position, as well as if an amount of frequent repetitions have to be performed. Clear and prominent visuals should be used to show the entire progression (see Figure 2.12a). If a user has to copy a specific movement, an avatar or animation before or during the movement can be shown, like in Figure 2.12b.

## Clarification

The user may interpret interactions with the system differently from others. Therefore the system should explain clearly what the user has to do, e.g. "Raise

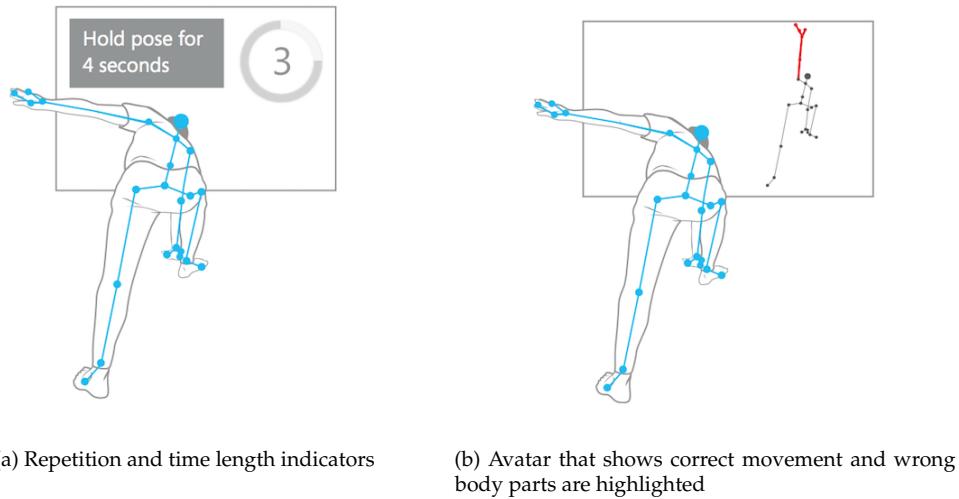


Figure 2.12: Feedback indicator and movement visualization as an avatar [9]

*one hand above your head*" instead of just "*Raise your hand*". The cognitive load of the user should be kept low and not exceed a number of six gestures, such that she easily remembers the actions. The system has a set of three basic interaction techniques, which fits in this range.

### User Viewer

A small scene viewer shows the range in which the user can move and is recognized by the Kinect. It displays a mirror like view in which the user can see a silhouette of herself and the constraints of the Kinect device, like in figure 2.13.

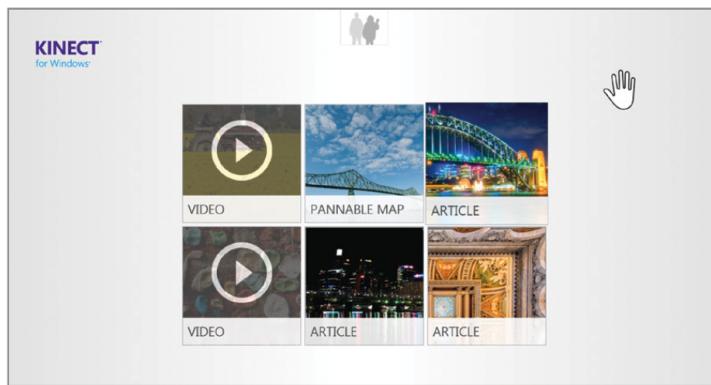


Figure 2.13: User Viewer on top [9]

### Learning Interaction Methods

An introduction tutorial should teach the user how to properly interact with the application from the beginning. The interaction itself should rely on the real world, which can help the user to be more familiar with the product than learning unknown gestures (see Figure 2.14). Also bilateral interaction support should be applied to cover both possibilities for left- and right-handed people.

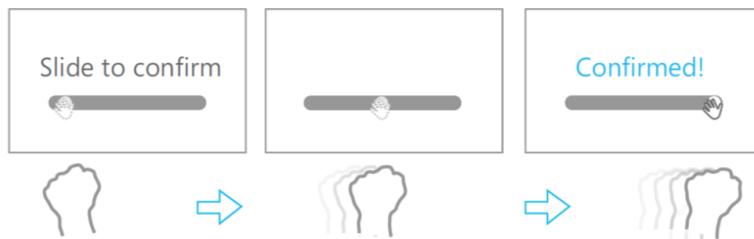


Figure 2.14: Direct manipulation of a slider with intuitive interaction [9]

### Teaching Complex Gestures / Exercises

Executing gestures is a core functionality in the slacklining assistance system. For new gestures, especially complex ones, the application should provide a tutorial that teaches and shows the user on how to execute or accomplish the gesture properly. When performing the gesture a visual indicator (a hint, animation, or notification) should acknowledge if the gesture is executed and when it is completed. (see Figure 2.15).

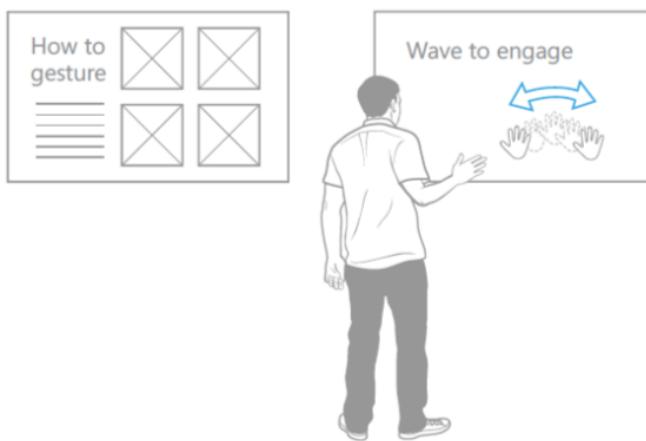


Figure 2.15: Teaching new gestures [9]

### Element Sizing

The system will rely on the guidelines and match the button sizing regarding the screen resolution to keep reliability on interaction. This is a size of 208 by 208px in a resolution of 1920x1080 pixel. As recommended a tile button style will be used which are a good baseline where the user can hit them accurately and read the button text.

### Physical Interaction Zone

This zone ensures that the user is able to reach anything in a comfortable range. In the application it is constrained by the joints of the shoulders to the hips of the opposite site of the interaction hand. It is designed to have a better understanding, like seen in figure 2.16.

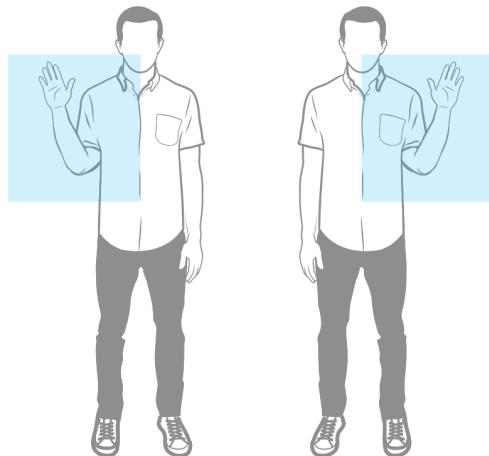


Figure 2.16: Physical interaction zone [9]

Summarizing the user interface should not distract the slacker but support her. Only necessary and useful information have to be displayed during the exercise. Providing an introduction and useful tips can help to give an understanding of the exercise. An avatar or animation is a good alternative to make clear how to perform an exercise. The system should also rely on Microsoft human interface guidelines, which provides design tips and serves as a reference to build user friendly applications.

## 2.5 Conclusion

With the stated related work a foundation is given to build a slacklining assistance system. Especially for beginners it is important to get familiar with the slackline to learn it. The assistance system should provide appropriate and structured exercises as well as tips, which build a foundation for further training.

Several application scenarios show that slacklining can replace balance training in rehabilitation environment, as prevention system, in school sport or as an home assistance. This can be combined with interactive technology, which helps patients to fulfil their exercises and provide the medical stuff with sufficient analysis data.

As interaction device the Microsoft Kinect v2 seems like the best choice out of the available technologies. It provides sufficient useful and accurate data analysis, if no in-depth analysis is needed. More advantages are the low cost, short setup time and the freedom of the movements for the user. Several studies indicate also that the Kinect can be embedded in balance training scenarios and increases the training efficacy while motivate patients.

A problem that occurs with more complexity in the exercises is the raising cognitive load. The system should therefore provide appropriate feedback and be aware of the cognitive load of the slacker. Motivating the slacker for further exercise execution can be done with a well defined interaction mechanism, an enjoyable but challenging virtual training environment, and an user friendly interface. This can be realised especially with the help of human interface guidelines provided by Microsoft, which include several design tips for developing a Kinect application.

---

---

# **Chapter 3**

## **Introduction into Slacklining and Slacklining Learning Techniques**

The following section *Introduction into Slacklining* gives an understanding of the evolution, philosophy, and basics of this sport. Further, an overview about the diversity of slacklining and application scenarios can be found in section *Slacklining Variations and Categorizations*. The last section *Slackline Learning Techniques* elaborates teaching methods and exercises, which will be used as a basis for designing the concept and will be integrated into the system.

### **3.1 Introduction into Slacklining**

The term *slackline* has its origin in the 1980's. In contrast to the existing balance activity tightrope, where you balance on a steel rope, some climbers balanced on a tubular webbing. Therefore they used the term *slack wire* that later transformed into *slackline*, which means loose line [70, 2, 41].

Hence slacklining comes from the climbing sport and can be compared with ropedancing in a broader sense [37]. The line itself is made out of a nylon ribbon. Unlike in ropedancing the ribbons width is between 2.5 and 5 cm and very flat. It has to be tensed between two stable fixation points like trees, stable pillars, fixation systems on the ground, so called *A-Frames*, or on a rock with a bolt hanger and carabiner. Mostly this is done with a tension device, which is in general a ratchet or pulleys depending on the fix points [37]. Because of the nylon texture the line will expand under pressure once someone stands on it. Given this elasticity makes it very dynamic and the slacker has to outbalance every sway [38]. To be in control of her body behaviour she has to act very calm, which makes slacklining in general a quiet and meditative sport activity. Besides

walking one can also e.g. bounce, bob, or swing on the line. As a result various fields of application arose from this variability, which is further described seen in the next section.

## 3.2 Slacklining Variations and Categorizations

Several slackline variations originated from combining and modifying the core components of a slackline, which are the height, length, and tension [37, 41, 64]. Regarding the height of the slackline fixation one can differentiate between a *lowline* (see Figure 3.1a) and a *highline* (see Figure 3.1b). A lowline describes a height in which a person can safely jump off the line. On a highline this is not possible. Here the slacker has to make safety precautions like e.g. a separate rope above or under the regular line in which the person can hook herself into [37]. Hence, the majority of the lines are categorised as a lowline.

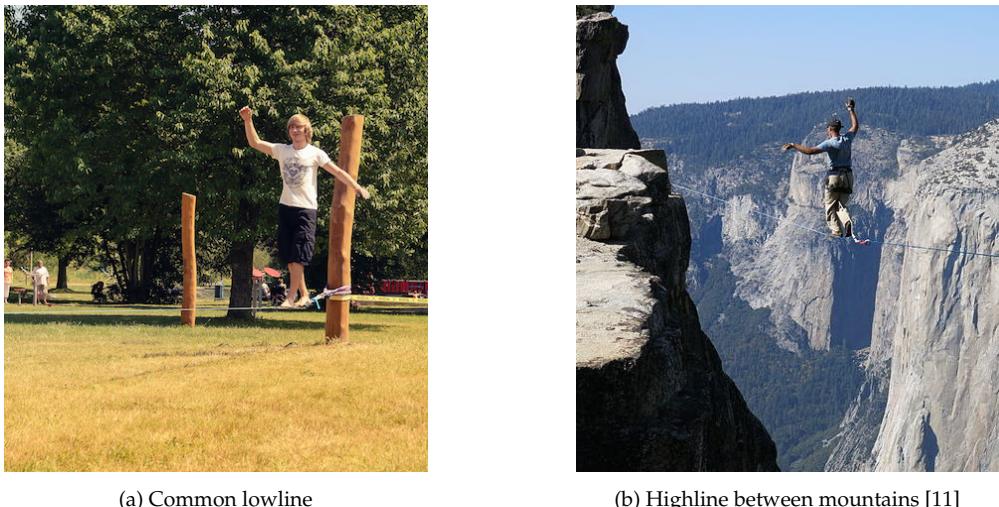


Figure 3.1: Main categories of slacklines

The following terms describe some fine granular variations as well as categorizations of the slackline in different application scenarios. They are not strict, which means they can differ in its scenario or can be combined with each other. A common slackline is also named *trickline* (see Figure 3.2a). It is tensioned a bit loose in about the height of the knees and has a length up to 30 m. A *jumpline* (see Figure 3.2b) is stronger tensioned to simplify jumps on the line. It has a length of 8 - 14 m and is a bit higher than the trickline. With a *rodeoline* the line is more slacked and has the highest amplitude, like seen in figure 3.2c. It is a relatively short line with a length of 5 - 8 m and the fixation points are in about 2 m such that if a person stays in the middle of the line it is just above the ground and she can swing on it sideways. Slacklines beyond 30 m are called *longline* (see Figure 3.2d). The goal here is to walk as far as possible without falling off the line.

Beside these there exist some terms that describe a categorization or environment where a slackline can be applied. For example a *waterline* is a line set up over a pool, sea, or a river like in figure 3.3a. *Urbanlining* can be found, like already implied in its naming, in urban areas. Manmade buildings or structures are then used to tension the line in between, like in figure 3.3b.



(a) Handstand on a trickline [25]



(b) Backflip on a jumpline [37]



(c) Slacker walking on a rodeoline in Graz [19]



(d) Alexander Schulz on a 340 m longline [59]

Figure 3.2: Slackline variations



(a) Waterlining over the Sulm in Austria [20]



(b) Urbanlining in Rillieux-la-Pape [52]

Figure 3.3: Categorization of slacklining

The disadvantage of these lines is the inevitable usage of static fixation points. In the case of the SLS this would result in a constraint of variability regarding developing, testing, and study purposes. Since the focus of this thesis is mainly on beginners the slackline must not be very long. Therefore the choice fell on a mobile slackline device, which provides the needed mobility and is further described in section *Kinect and Slackline Positioning*.

### 3.3 Slackline Learning Techniques

Section *Exercises During Slackline Training* of chapter 2 showed that systematic help is not essentially necessary to learn slacklining. The user of the interactive learning system should be able to learn it by herself without any further external help. In the following section *Methods for Slackline Skill Acquisition* differentiates between two learning concepts, the methodical routine and differential methodic, on which the interactive learning system relies. Further, section *Levels and Exercises of Learning Slacklining* describes the categorization of specific slackline exercises in the system that are used for structuring the learning flow of the user.

#### 3.3.1 Methods for Slackline Skill Acquisition

Thomann [63] designed two learning procedures for slackline skill acquisition. One approach is the *methodical routine* which follows a more strict procedure and guides the trainee through more and more difficult exercises. The second approach is the *differential methodic*. It follows a more dynamical model where big stimulus differences are given to the trainee. In the following both methods are discussed in more detail.

### Methodical Routine

A methodical routine can be integrated in almost every sport activity. It consists of a series of exercises, whose difficulty increases with further practice. The selected exercises should base on methodical principles that can be scaled by e.g. easy to difficult, known to unknown, or simple to complex [17]. Größing [26] describes the general procedure as follows: at the beginning of a methodical routine the trainee will perform warm up exercises. This is useful to prepare her for the training. After that preliminary exercises will be provided, which are more specific regarding the actual exercises. With this she will learn the general motoric basics and train the movements that are needed to perform the activity. Further, it ensures a smooth transition to the main exercises.

The methodical routine by Thomann [63] is specifically designed for slackline skill acquisition. It contains various approaches with different elements to reach the goal of learning slacklining. However, the integration of these elements are more strict to guide the trainee through a constructive exercise procedure (see Figure 3.4). The routine starts with an introduction and preliminary exercises. This is followed by material and security where the lines' dynamic, how to jump off, and controlling of the line is covered. Further, the learning of the oscillation behaviour should be implemented with or without methodical help, e.g. human support. Afterwards the user can decide to execute balance training either with help and therefore directly balance on the line, or without any further help, with which she can decide to first sit, step, or balance on the line independently. The trainee can then decide if she wants to train static or dynamic balance, which follows by the option for more variable exercise execution like walking forwards on the line, walking backwards, with eyes closed, and so on. After this the trainee must first learn to stay with her feet orthogonal on the line. It is a necessary prerequisite for learning tricks, which can be found at the very end of the routine, and has to be learned beforehand.

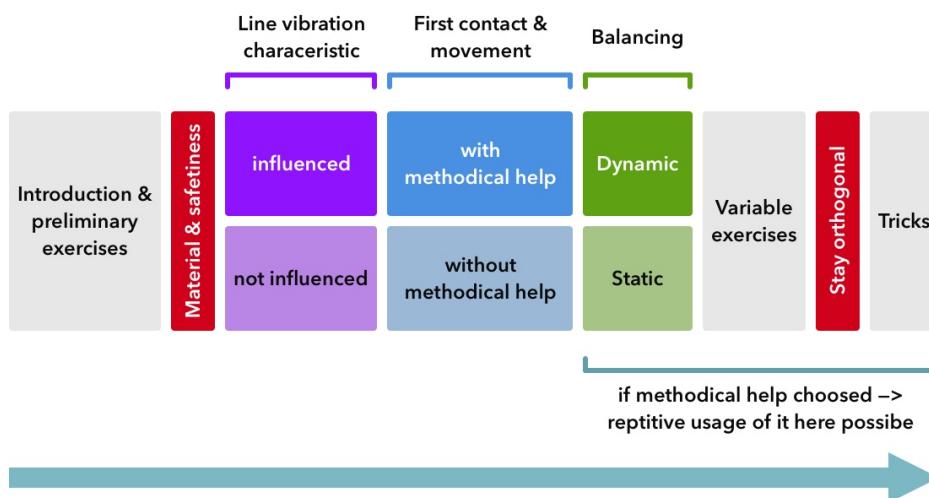


Figure 3.4: Methodical routine, adapted from Thomann [63]

### Differential Method

The differential or dynamic method follows another approach. It is in coherence with an open learning situation [63]. This means it depends on several factors, which in slacklining would be line type and length, tension, environment, etc. Considering the interplay of these factors each trainee can construct her own training set. A dynamic method is a practical usage for this [3, 57]. This inherits the model of stepping stones. In general, it describes that many ways can lead to the same goal. Each potential way has therefore its own level of difficulty. This results in a more modular way to reach a specific goal. In comparison to the methodical routine it leads to bigger differences in stimulus and provides more variability in the movement execution, like compared in Figure 3.5.

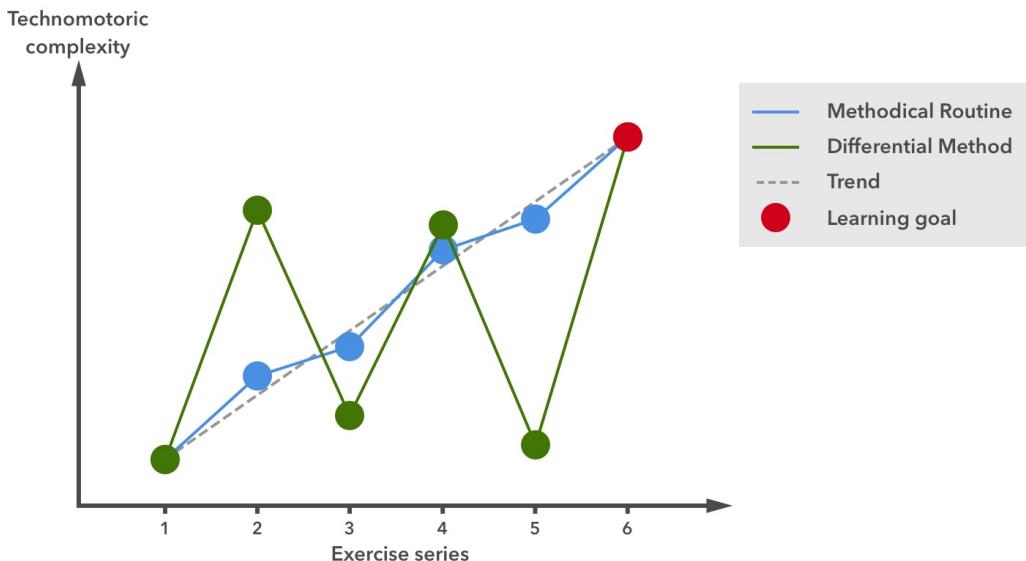


Figure 3.5: Comparison methodical routine vs. differential method, adapted from Thomann [63]

To make use of the differential learning method, the trainee can follow a methodical principle, like seen in the methodical routine. If she reaches a certain skill level, more dynamic procedures can then be involved in the actual learning process.

The usage in slacklining can be integrated like described and visualized by Thomann [63] (see Figure 3.6). He divided exercises regarding to five learning stages and their coordinative demands and complexity. The main goal is to master controlled and complex movements on the line. The trainee has to choose an amount of various exercise of all stages. More complex exercises can either be supported by methodical help or the trainee can return to the lower stage to learn the movement for the specific exercise. Each trainee can therefore create her individual training path. Modification and integration of more useful exercises are allowed. Structured examples can be seen in Figure 3.6. The purple arrows visualize a way for more skilled people that are more coordinative, more venture-

some, or have background knowledge. In contrast, the green arrows visualize a path for more novice people that are less coordinate, less venturesome, or have no background knowledge in slacklining.

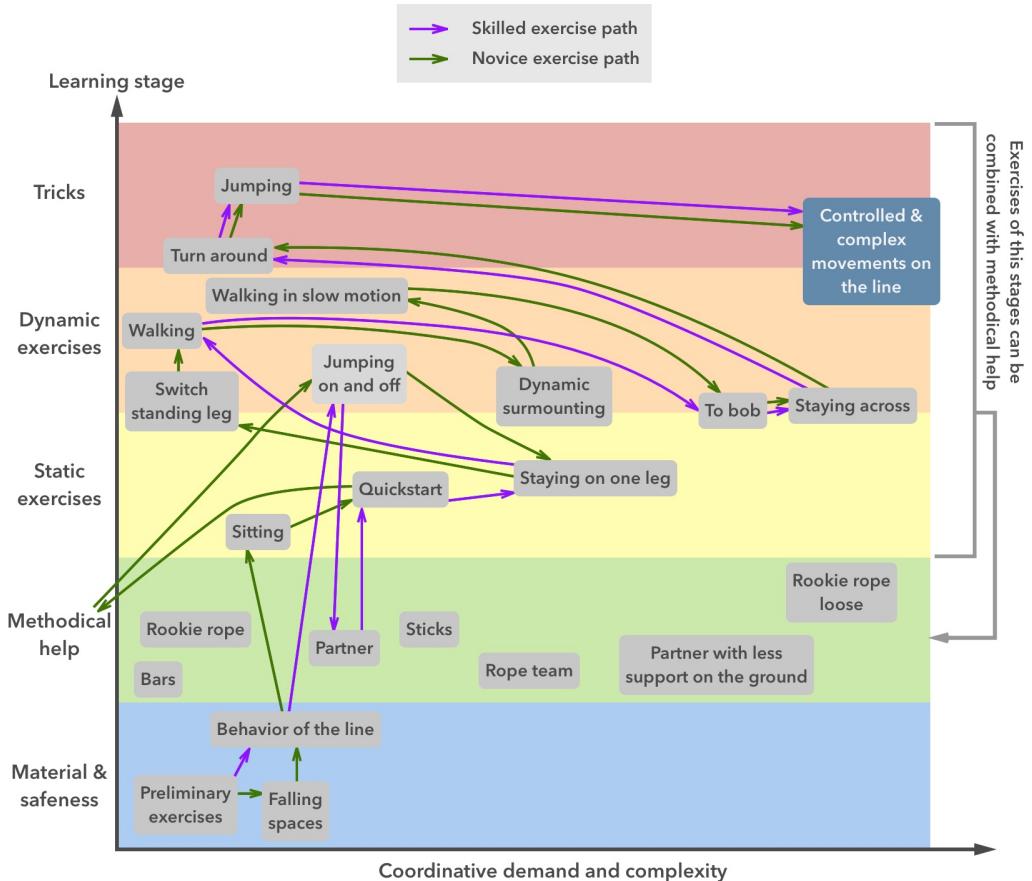


Figure 3.6: Dynamic methodic in slacklining, adapted from Thomann [63]

For proper training with the system the trainee should follow a clear workflow. Therefore the methodical routine is the better choice as a learning concept in this interactive learning system. She learns right from the beginning essential aspects of slacklining that are relevant and build up on each other. Because it follows a strict linear sequence, stages and exercises can be designed as levels and the implementation is more simple as a first approach of such a learning system. The next subsection *Levels and Exercises of Learning Slacklining* will cover a clear workflow integration of exercises for this learning system.

### 3.3.2 Levels and Exercises of Learning Slacklining

Repetitive trials are one approach of learning to walk on the line. However, this could result in dangerous situations and frustration for the slacker because of her missing skills. Therefore, a set of slacklining exercise can teach and guide the

trainee appropriately. It pursues the goal to balance in a controlled manner on the line, stand on it for a few seconds, and be able to walk a few steps.

In general, three core skills have to be acquired to achieve this goal [38]. At first, the slacker should be able to stay on one foot. This is essential because most of the time one foot serves as standing foot on the line and the other one as balance element. Second, balancing on a narrow surface is important since the slackline exists of a limited width. Lastly, she should manage the height due to the fact that a slackline is tensioned around the height of the knee and above.

Kroiß [38] defined a useful exercise set for slackline skill acquisition, which will be used as groundwork within the SLS. He elicited learning exercises for beginners on a slackline within a school class, which gives a structured basis on the exercise integration. Further, several other works [2, 13, 14, 24, 36, 37, 47, 63] integrated similar exercises for their slackline training approach. The exercises implemented in this thesis have been categorized into four levels, which represent the fundamental basis of the exercise routines. In the following, each level is introduced, its goal clarified, and the learning aspects described:

### **Level for Slacklining Skill Acquisition**

The first level serves as a preparation for the subsequent levels. Preliminary exercises will be executed on the ground and thus no slackline is needed. With this, the overall physical balance of the user will be strengthened. The trainee learns how to use her arms as a balance function, set a focus point to calm the visual sense, and to execute exercises slowly and controlled to prevent and handle unpredictable body behaviour.

Mastering the preliminary exercises leads the slacker to her first experience with the slackline. The goal is to get a feeling for the slackline, to be able to get up on the line, as well as to hold herself for a short amount of time on the line. This can be achieved by becoming familiar with the line, feeling the imbalance and how her body behaves, and getting a better feeling for counterbalancing unpredictable movements.

After finishing the second level the slacker is familiar with the line and able to get up the line. The goal of the third level is to make her more confident with standing and prepare her for walking on the line. All prior learned techniques prepared the trainee to this goal and have to be directly applied. Hereby she has to make more usage of the balancing leg, which servers as an additional balancing parameter beside the arms.

More dynamical exercises are part of the last level. The slacker should now be able to stand confidently on the line with one foot as well as with both feet. Its goal is to teach how to make first steps as a result for walking on the line. In general, several static exercises, like getting up, balancing with one foot, and standing with both feet on the line have to be applied together.

### 3.4 Conclusion

Slacklining can be compared with ropedancing but with a wider and flatter ribbon. It is a sport that needs a certain amount of balancing skills. Therefore, two learning techniques have been discussed for skill acquisition. The methodical routine and dynamic method. The SLS presented in this work will focus on the methodical routine. This technique follows a clear workflow and its structured routine can be easily implemented into the system as a prototype. Lastly a set of exercises have been selected that fit in this routine and train beginners appropriately.



---

---

# Chapter 4

## Concept

This chapter describes the conceptual elaboration of an interactive slackline learning system (SLS) with real-time feedback. The idea of the SLS is to provide helpful information, structured exercises, and appropriate feedback to the user for learning slacklining with the given application. The user should be able to interact independently of any physical input device, like a mouse, or external support like human help. Further, it responds appropriately to actions of the user and provides several real-time feedback indicators to support her during the execution of the exercise.

In the following, section *Basic Principles* describes basic design principles and system related requirements. This is followed by the more specific sections *Interaction*, *Levels*, and *Exercises* that describe how to interact with the system and how exercises are structured. Another main component is to provide adequate feedback to the user, which is part of the last section *Feedback System*.

### 4.1 Basic Principles

In general, the SLS should provide the following characteristics: easy to learn, understand, and a simple interaction technique. Usability heuristics can be applied to identify and prevent interaction design problems to ensure an appropriate user experience. Therefore, the SLS will acknowledge the interaction design principles by Nielsen [43] described in section *Ten Heuristic Principles for Interaction Design*. Beside that, certain tasks have to be considered that are more related to the system itself, like multiple user profiles or designing the exercise workflow. An overview about these can be found in section *System Specific Basics*.

### 4.1.1 Ten Heuristic Principles for Interaction Design

Nielsen designed his ten heuristics by comparing several sets of usability heuristics with existing usability problems from certain projects [43]. He was able to determine which heuristics identify usability problems the best and therefore created a set of them. They can also be used as a guideline for designing and developing a user friendly system to prevent usability problems. Examples of these can be found in the subsequent subsections. The SLS will respect these interaction design principles described in the following.

#### **Visibility of System Status**

The system should always keep the user informed about the current state through appropriate feedback in an adequate time.

*Example: Highlight if an exercise is executed correctly*

#### **Match between System and the Real World**

The system should provide the user with familiar terms and information. Using technical terms with which she is not familiar can lead to confusion. Therefore proper information should be natural and in a meaningful order.

*Example: Usage of familiar terms in the description for the exercises*

#### **User Control and Freedom**

If the user clicks accidentally on something she should be able to leave this state without any troubles.

*Example: Back button in each screen to return easily to the last screen*

#### **Consistency and Standards**

It should follow a clear design standard and provide consistency. The user should not be confused whether different terms or elements mean the same.

*Example: Visualization of buttons are always the same in their context*

#### **Error Prevention**

Conditions and actions that could easily result in errors should be prevented. Another option is to inform the user about the consequences that the action may have and which she has to actively confirm.

*Example: User should only start an exercise if she stands in the correct starting pose*

#### **Recognition rather than Recall**

The users memory load has to be minimized. She should not remember every action or information. Elements, actions, and options should be visible and instructions about the usage must be easy to retrieve.

*Example: Clear instruction of exercises and providing hints about actions during the*

*exercise execution*

### **Flexibility and Efficiency of Use**

Providing quick options and allowing to skip certain steps can speed up the interaction for more familiar users. Hence the system should take care of both novice and experienced users.

*Example: Skipping the tutorial of the system for experienced users*

### **Aesthetic and Minimalist Design**

Information should just contain aspects that are relevant to the user and that she really needs. Every irrelevant data decreases the intelligibility.

*Example: Providing relevant steps in the exercise description, time to hold the exercise, and the amount of repetitions*

### **Help Users Recognize, Diagnose, and Recover from Errors**

Error messages should accurately indicate the ongoing problem such that the user knows what is wrong. Providing a constructive solution helps the user to solve the problem.

*Example: Warn the user if she is not standing in the starting position to start the execution of the exercise*

### **Help and Documentation**

Optimally the system can be used without any further documentation. If it cannot be circumvented the provided help and documentation should be easy to find and clearly show the relevant steps.

*Example: Provide a tutorial when interacting with the system for the first time*

## **4.1.2 System Specific Basics**

One person at a time should be able to interact with the SLS. This is because mostly just one person can stay on the slackline especially for beginners. However, it should provide the ability to have multiple user profiles. Several people can thereby have their own profile in the same application. For proper user training the system should follow a clear workflow. Therefore two methods have been discussed in section *Methods for Slackline Skill Acquisition*. A methodical routine will be used with which levels and exercises can be designed. These should be locked at the beginning and the user can unlock them by successfully executing the prior exercises. Another important part is the user tracking. The SLS should be able to track the user in an adequate accuracy and precision such that it can match the users' movement with the actual exercise. This is in correlation with properly providing real-time feedback, which is further discussed in section *Feedback System*. All relevant recorded data should be immediately saved when it is needed, e.g. when successfully accomplishing an exercise.

## 4.2 Interaction

A bigger part of the system is the interaction since it is independent of any external controlling devices. The user should be able to navigate through the system by herself with her hands as interaction input. A cursor should always be visualized to navigate through the systems interface. If the user initially starts the system, there should be an engagement gesture to convey that the system initially recognises and responds to a user action. Furthermore, a small tutorial should be given in which the user will be trained on how to use the interaction possibilities with the system (*cf. Recognition rather than recall*). To make her familiar with these, she should directly apply these techniques in the tutorial. The current state of the interaction is clearly visualized, such that the user knows if she triggers an action regarding an element (*cf. Visibility of system status*). To be able to interact with elements and start the exercise execution the user should stay in a predefined initial position. The SLS then recognises if a user is ready to start. Interaction will also play a role in exercise execution. During the execution she interacts with the SLS by trying to match the predefined exercise. The user should then get appropriate feedback, which is further explained in section *Feedback System*.

## 4.3 Levels

The SLS covers predefined exercises, which are subdivided in levels that have been discussed in section *Levels and Exercises of Learning Slacklining*. They follow a structure of a level design in which the user has to unlock each level to make progress. With this an exergame approach is followed to motivate the user for unlocking the next level. Therefore a menu should exist for all available levels as well as for all subdivided exercises. The very first level and exercise should be unlocked and interactable to give the user a starting point. She can then unlock the next level by accomplishing all exercises in the current one. In this way it can be ensured that the user is able to encounter with more difficult exercises in the next level. An introduction into each level should inform the user about the purpose and goals of it, as well as general information about the exercise within that level. Lastly a summary gives an overview of her performance for the entire level.

## 4.4 Exercises

Each exercise is part of one level. An exercise consists of two body sides, which are further divided into several repetitions (see Figure 4.1). Every exercise is locked except the first one to provide a starting point, like seen in the last section Levels. The next exercise should be unlocked by accomplishing both sides of the current one. Similarly, a side will be completed if all repetitions have been finished. As for the level, each exercise should be instructed for the user such that she can

successfully perform it. The SLS will also recognise if the user is ready to start with the exercise. During the execution she gets real time feedback about her current performance. An exercise summary should then show the performance of the execution with several performance parameters regarding the given exercise.

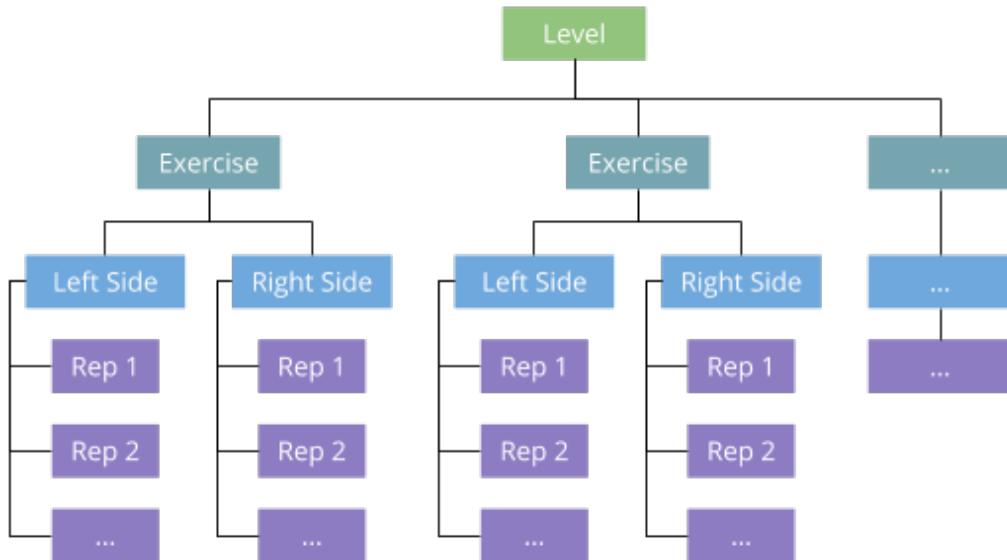


Figure 4.1: Exercise structure

## 4.5 Feedback System

Feedback is the main and most powerful component of the SLS. Since the user should interact on her own with it one has to assume that no other person interferes with her and the system. With this in mind the feedback of the system should be designed in a way, that the user knows at any time what she has to do or has done (cf. *Aesthetic and minimalistic design*). In general, audio and visual feedback will be provided to the user. Regarding the interaction with the system, e.g. clicking a button, the system should respond with an audio signal as well as changing the visual state of an element accordingly.

Real-time feedback supports the trainee during her performance and improves the learning effect when given in an appropriate manner [29, 39, 67]. The SLS should therefore respond to the user with immediate helpful information during the training to improve the exercise execution. This can be seen in several other sport applications like *EA SPORTS Active 2*<sup>2</sup> or *Nike +*<sup>3</sup>. The provided feedback should mainly indicate whether the current execution is performed correctly or not, visualize the the performance of the user regarding the predefined exercises,

<sup>2</sup><https://www.ea.com/de-de/news/ea-sports-active-2-bringt-fitnessfans-in-die-form-ihres-lebens>

<sup>3</sup><https://news.nike.com/news/introducing-nike-kinect-training>

and show the execution progress. The user should also see herself mirrored in an appropriate environment to see her current execution and if she is in detection range of the tracking device. With this, a baseline is built for appropriate real time feedback.

## 4.6 Summary

The interactive slackline learning system should be able to teach and support users how to slackline with predefined exercises. For proper realization the SLS has to consider several aspects. It should comprise an appropriate amount of user experience. By following and respecting Nielsens ten usability heuristics it provides an overall standard of usability. Further, some system specific groundwork should be integrated. This involves, for example, autonomous interaction, adequate user tracking, and supportive real-time feedback. More specifically, the levels and exercises should be able to unlock by successfully completing exercises. Each of these exercises should be introduced to the user to give her an understanding of the correct execution. Lastly, the feedback system is one of the biggest components. It involves audiovisual real-time feedback for the user interaction as well as exercise execution, and general feedback for rating her performance regarding an exercise or the entire level. The next chapter *System Implementation* relies on this concept and discusses the development process.

---

---

# Chapter 5

## System Implementation

The following chapter discusses the implementation of an interactive slackline learning system (SLS) with real-time feedback based on the prior conceptual elaboration. Like already discussed in section *Comparison of Tracking Technologies* the low-cost tracking camera Microsoft Kinect v2 will be used as tracking device. Before going into detail with the actual implementation, section *Hardware* discusses the general system architecture including a comparison of the Kinects' tracking performance to several slackline positionings. Further, section *Data Model* covers how the data is structured and stored. Currently each exercise has to be created by the developer such that the SLS can match and compare the movement performance of a trainee with the actual exercise. The workflow of constructing such exercises is described in section *Movement Recognition*. Lastly section *Frontend* explains the relationship between the Kinect SDK and Unity3D as game engine. Furthermore, each component of the application is visualized on a top-down workflow through the user interface.

### 5.1 Hardware

#### 5.1.1 Components

In the following several hardware components of the system architecture will be described. Each component is important for the functionality of the SLS and the study afterwards.

Since the focus of this thesis lies mainly on beginners, the mobile slackline device *alpidex POWER-WAVE 2.0*<sup>4</sup> is used (see figure 5.1).

<sup>4</sup><http://www.alpidex.com/fitness/slacklines/slackline-gestell-in-2-laengen-power-wave-2-0-inklusive-slackline/a-10288/>



Figure 5.1: Mobile slackline *alpidex POWER-WAVE 2.0* [1]

It provides the needed mobility and independency due to its comparatively short length of three meters. A major advantage is the possibility to set it up indoors as well as moving it in different positions with minimum effort. The included slackline is tensed around brackets at both ends of the device. It is placed in front of the *Microsoft Kinect v2*, which is used as tracking device, like discussed in section *Comparison of Tracking Technologies*. The Kinect itself is attached on a tripod with a height of about 90 cm. A *STEAM® MACHINE by ZOTAC*<sup>5</sup> served as development PC that fulfilled the recommended specs of the Kinect. As visual output device a projector with a resolution of 1920x1080 was attached on a traverse system. The interface was visualized on a projector screen with a size of 2.40 x 3.00 m to give the user a more immersive feeling. A general overview about the interplay of all hardware can be seen in Figure 5.2.

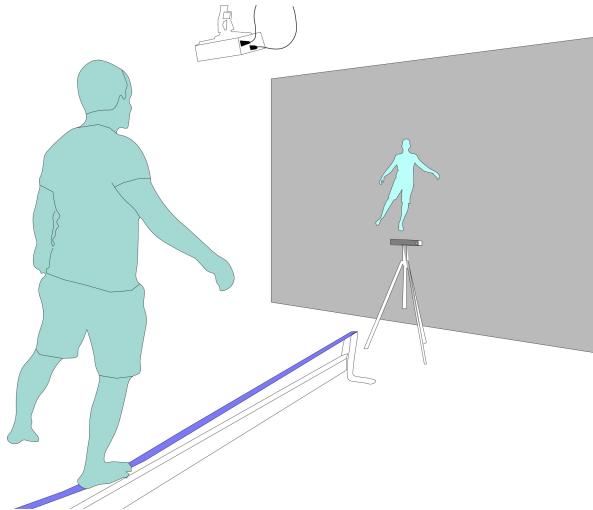


Figure 5.2: Setup of all components

---

<sup>5</sup>Technical details of the *STEAM® MACHINE*: Intel Core i5-6400T @ 2.2 GHz, NVIDIA GeForce® GTX 960, 8 GB RAM

### 5.1.2 Kinect and Slackline Positioning

Tracking a person on a slackline with the Kinect is very different from the common use case. The combination of the slackline range, vibration of the line, and unpredictable movements because of balancing actions of the user could lead to imprecise and inaccurate input data for tracking. The major approach is to compare different slackline positions (Vertical: 0 Degrees, Diagonal: 45 Degrees, Orthogonal: 90 Degrees) regarding multiple angles and heights of the Kinect (80 cm, 160 cm, 240 cm), which is attached on a tripod or traverse system. This scenario clarifies how good a person can be tracked on the entire slackline as well as at the beginning of the line for study purposes of this thesis.

#### Limitations of the Kinect

A considerable role plays the angle and tracking range of the Kinects' depth sensor in the positioning. Its angle of vision covers horizontally 70 degrees and vertically 60 degrees (see Figure 5.3a). Since the slackline is about 30 cm off the ground body parts of the user could be cropped depending on the Kinects' height and its angle. The total tracking range of the sensor covers a range between 0.5 and 4.5 meters, whereas the sweet spot area lies between 1 and up to 4 meters (see Figure 5.3b) [9]. The mobile slackline device used in this thesis has a length of three meters and fits theoretically entirely within the sweet spot.

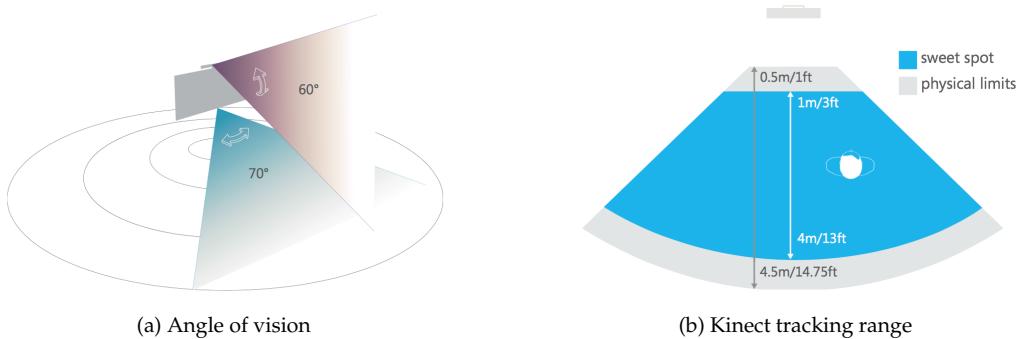


Figure 5.3: Limitations of the Kinect v2 sensor [9]

#### Best Positioning for Study Purposes

##### *Slackline Positioning*

With a slackline positioned orthogonal (90 Degrees) to the Kinect, no interference regarding the limit of the tracking range can happen because the whole body is in a constant line with the tracking area. However, permanent overlapping of body parts resulted in problems to detect body joints with an appropriate accuracy and precision (see Figure 5.4a). When placing the slackline diagonal (45 Degrees) the

body is more visible to the sensor and showed better results. Tracking failure still happen especially when regaining equilibrium on the line. Mainly the joints of the arms and legs interfere with other body joints (see Figure 5.4b). In addition, every time the user wants to interact with the Kinect she has to turn towards it, which leads to a more complicated user experience. Positioning the slackline vertical to the Kinect avoids this. Furthermore, the sensors' view can see the full body and track joints without any occlusion. Problems occurred at the starting position of the slackline since it uses the entire tracking range. The user stands here at the outermost limit of this range, where the detection of the Kinect begins to get worse (see Figure 5.4c). Because of this the slackline must be arranged, such that the starting position of the line lies within the sweet spot area.

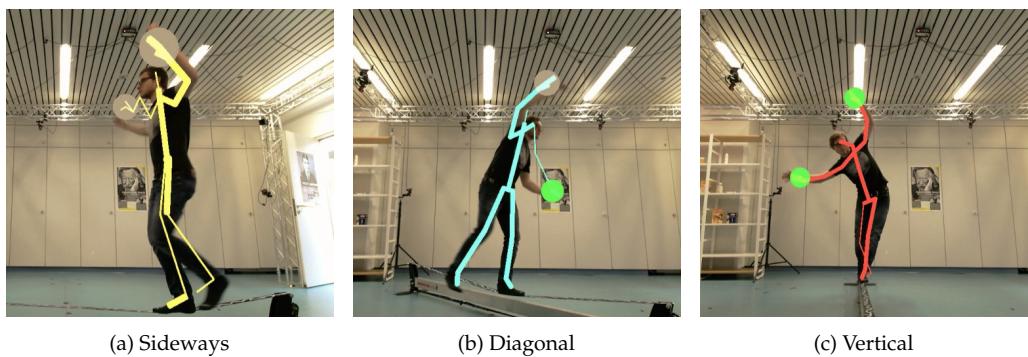


Figure 5.4: Different positions of the slackline. The coloured lines visualise the skeletal tracking of the Kinect. Thin lines represents inferred joints

### *Kinect Height*

Beginning with a height of 2.40 meters the Kinect has a very steep view angle. Hereby, the tracking range shifts more downwards and shrinks in its height (see Figure 5.5a). With users of a height above 1.85 m the starting position cannot be arranged for appropriate usage. The same problem applies for a Kinect height of 1.60 m. The view angle is more flat but the slackline must be positioned further away from the Kinect to prevent cropped body parts like the head or arms (see Figure 5.5b). A height of 1.20 up to 0.80 meters results in a flatter view angle and therefore in a more homogeneous view and tracking range (see Figure 5.5c). The body is fully visible in the entire tracking range and not limited in the height of the Kinect view. Additionally the Kinect is in a position that won't disturb the visual sense of the slacker during her training on the slackline, e.g. by setting a focus point in front of her.

The best combination resulted in placing the slackline vertically and having a Kinect height of 0.80 up to 1.20 meters. Hereby, the Kinect can track the entire body with nearly no joint overlap. Since the focus of the study in this thesis lies mainly on beginners, the starting position of the slackline is important and must not lie at the outermost tracking range. Hence, it makes more sense to move the

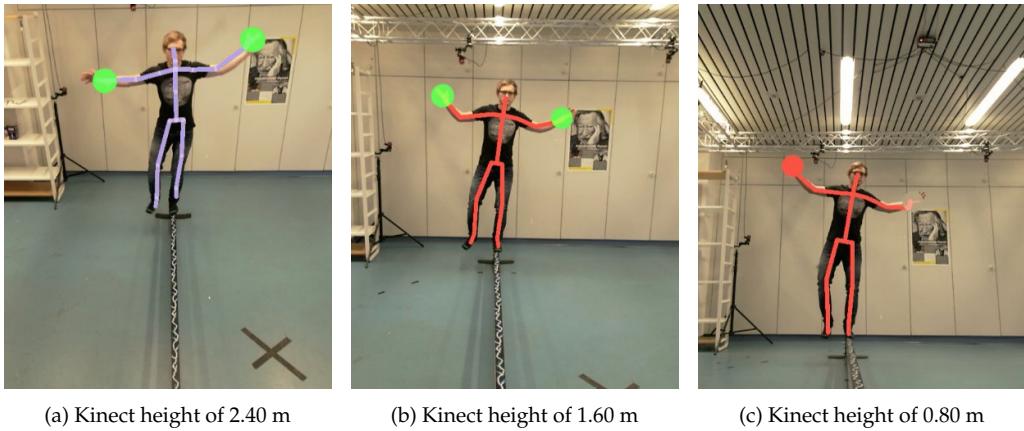


Figure 5.5: Kinect view on different heights. The coloured lines visualises skeletal tracking.

slackline very close to the Kinect. The starting position on the line fits then within the sweet spot area.

## 5.2 Data Model

All relevant data are stored in JSON files. It consists of human-readable data and makes accessing as well as updating data simple. The set of exercises are the same for all users. A default exercise JSON file serves as template for all registered users in the SLS. To make data management and adjustments more easy an internal editor was created. Figure 5.6 shows the overall data structure.

Each user has her own user data file that represents the profile of a slacker who wants to train with the system. It consists of her name and a default template of levels and exercises. Only one user profile at a time can be active. This ensures that no other profiles can be affected by the current user.

A level has a name, can be unlocked, and accomplished. Unlocking the next level means the current one has been successfully accomplished. This again means that each exercise of it has been finished. Furthermore, each level consists of a name, a list of goals, and a description that gives hints about the general execution of its exercises. Several exercises are part of a level.

Exercises consist of a name and a thumbnail picture that is shown in the menu. The introduction of an exercise provides a description and a looping video of the correct execution. For each body side the user has to challenge several repetitions with a minimum time to hold the specific position. If all repetitions have been successfully executed for both body sides, the current exercise is accomplished and the next one will unlock. A check list provides the user during her training with supportive real-time feedback, which guides her for a successful exercise execution. The performance of the user during her ongoing execution is given by a constant varying confidence value. If her movement exceeds a certain

confidence, a timer starts and she has to hold the exercise until a predefined minimum time has been reached. An exercise has a type that can be either discrete or continuous, which is important to know for the user tracking. The actual exercise is stored as a gesture in the database to match it against the current user movement. The next Section *Movement Recognition* describes the purpose of a type, gesture, and the database more specifically.

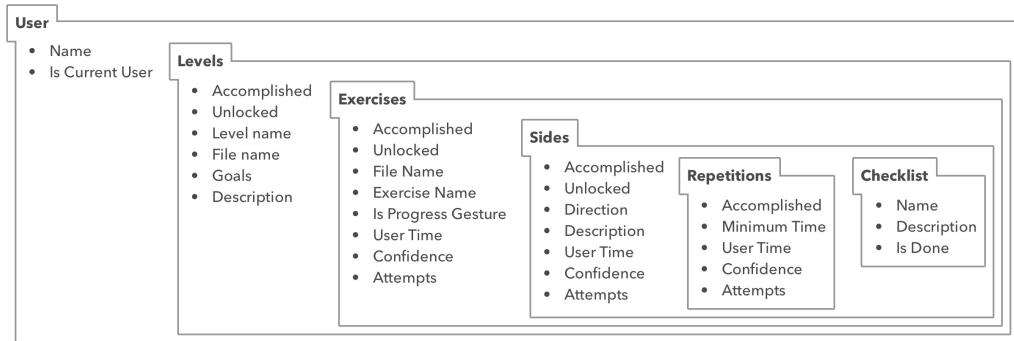


Figure 5.6: Data model overview

## 5.3 Movement Recognition

The SLS guides the trainee through predefined exercises for slacklining. In the case of this thesis it is important to know that exercises are defined as *gestures* within the context of the Kinect development. The *Kinect for Windows Human Interface Guidelines* describe the term gesture as follows: "[...] we use the term gesture broadly to mean any form of movement that can be used as an input or interaction to control or influence an application." [9].

### 5.3.1 Heuristics vs. Visual Gesture Builder

The Kinect SDK provides two approaches for tracking a gesture in an application [10]. The first one is called heuristic approach, which means to manually track each body joint position of the user in the code. Conditions can be defined according to the action that should happen e.g. if a joint exceeds a certain threshold or is in a defined range. Heuristics are mainly used for simple gestures like raising the hand over the head, which is implemented in the SLS as engagement gesture. For more complex gestures, the developer must have a good understanding about the movement and behaviour of the human body. Furthermore, environmental factors like an inappropriate mounting of the Kinect could exacerbate managing and maintaining the code.

Usually a common developer has not the appropriate expertise of the human body behaviour or it would take too much effort. Hence, it is recommended to use the *Visual Gesture Builder* (VGB) provided by Microsoft. More complex

gestures can be easily defined. For example doing one legged squats is a sequence of multiple actions with several factors (It is also implemented in the SLS as an exercise). The VGB uses machine learning to build a database out of pre-recorded clips. Afterwards it can be implemented in an application to track the desired gesture. A major advantage is that environmental factors are not as complex to handle as in comparison to heuristics. The user just records multiple clips with the Kinect and builds a new database. In the heuristic approach this has to be considered manually in the code. The cons of the VGB are the huge file size of the recorded clips that can take very much disk space. Also tagging the clips for the gestures, which should be detected by the application, is time consuming. On the other hand the tool is simple to use and constructing complex gestures can be easy like described in the next subsection.

### 5.3.2 Workflow for Building Gestures

The workflow for creating a gesture follows a general routine (see Figure 5.7). At first the gesture has to be recorded via *KinectStudio*. This is a tool provided by Microsoft for monitoring and recording raw clips of the Kinect streams. Before inserting the clip into the VGB a new project has to be created. Therefore, the developer first selects the body parts that are necessary for the gesture. After that an indicator has to be defined, which can be either discrete or continuous. Discrete gestures define a binary state and validate if a certain gesture is currently performed or not (e.g. standing on one leg). It provides a confidence value that compares the correctness of the users' execution regarding the gestures in the database. A continuous gesture means usually the combination of motions to a sequence of small gestures (e.g. switching standing leg). Instead of the confidence, a progress value gives feedback about the ongoing movement of the person matching the gesture sequence in the database.

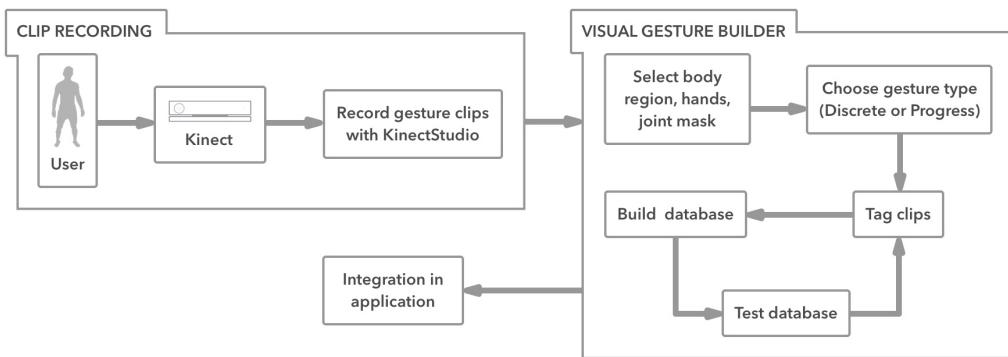


Figure 5.7: Workflow of creating a gesture database

After the project creation the recordings can be inserted as training data. The developer has to tag the clips to define a starting as well as an end point of the gesture. After finishing with tagging a database file can be built. It is recommended

to test it via a live preview or with other recorded clips in a separate analysis area. If the results are not satisfying, more clips can be recorded and added as training data or existing tags of the clips can be adjusted. After the testing phase the gesture database file is ready for the integration into the application to detect gestures in runtime.

## 5.4 Frontend

### 5.4.1 Unity3D and Kinect SDK

The software development process consists of the interplay of two major software components (see Figure 5.8). First the cross-platform game engine *Unity3D* by *Unity Technologies*. It is widely known for game development but also for development with several interaction devices (e.g. *HTC Vive*, *Leap Motion*). Applications can be deployed for various platforms like desktop, mobile, web, console, TV, or virtual/augmented/mixed reality devices. Unity is used in the SLS to create the virtual environment, interface design, manage actions by the user, and for data management.

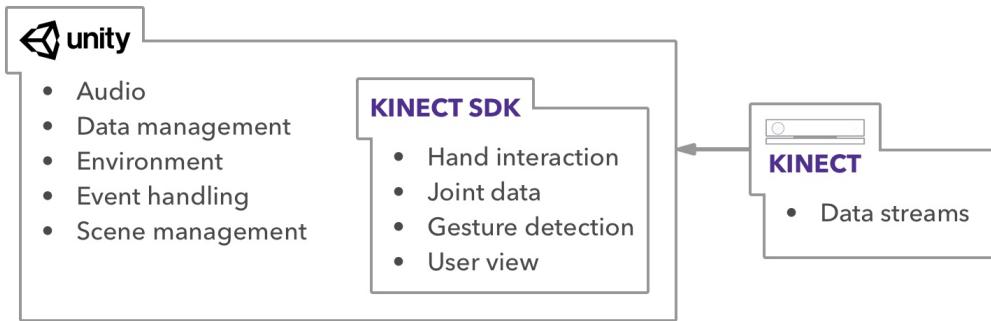


Figure 5.8: Unity and Kinect architecture

As second component the *Microsoft Kinect SDK v2.0*<sup>6</sup> has to be installed on the PC as well. It consists of several tools, application examples, and scripts to access the data stream of the Kinect. Microsoft offers also a *Kinect for Windows Unity package*<sup>6</sup> to create a Kinect based Unity application. The *Kinect v2 Examples with MS-SDK*<sup>7</sup> package by Rumen Filkov was used to get an idea on how to handle the data streams of the Kinect. In addition, it makes accessing input data of the user recognized by the Kinect, like e.g. joint position and interaction implementation, more simple and provides several code examples.

<sup>6</sup><https://developer.microsoft.com/de-de/windows/kinect/tools>

<sup>7</sup><https://www.assetstore.unity3d.com/en/#!/content/18708>

### 5.4.2 Implementation

The frontend implementation of the SLS will be explained on the basis of the workflow that a user would run through. It consists of four main parts. First a small tutorial to get familiar with the interaction, second the selection menus, third the description and introduction of a level as well as an exercise, and fourth the exercise execution with real-time feedback.

#### Interaction Tutorial

When a user starts with the SLS (see Figure 5.9a) an engagement gesture is the very first interaction. She has to raise any hand over the head. This conveys that the system recognises and reacts to specific movement actions.

Afterwards the user is introduced into the interaction techniques (see Figure 5.9b & 5.9c). Her hands serve hereby as input for navigating and interacting with interface elements in the SLS. Therefore she is in constant interaction with the system and becomes more familiar to it. The current position on the screen is visualised by a virtual hand cursor.



(a) Welcome screen with engagement gesture

(b) How to click part I

(c) How to click part II

Figure 5.9: Instruction on how to use the SLS

Four different approaches were tested as hand interaction gesture. First, hovering with the hand over elements for a few seconds (see Figure 5.10a). It caused problems because of accidental and unwanted misclicks due to relatively big and many interaction elements in the interface. As second interaction technique the hand should be closed to a fist or grab gesture (see Figure 5.10b). It also triggered unwanted misclicks if the hand of the user closes a bit during navigation. A better interaction was performed by the so called *V-sign*, where the user makes a pointing gesture with her index and middle finger. The click event triggers when the user releases her hand into the default state (see Figure 5.10c). Relating to the real word, a button is triggered by pushing it down with the hand or finger. This is used as an analogy in the last interaction gesture, where the user pushes the open hand towards the Kinect. It is the most intuitive, natural, and least error-prone technique (see Figure 5.10d). Therefore the push technique is used as main interaction. The *V-sign* is implemented as second interaction technique, since it resulted in better interaction experience than the fist and hover gesture.

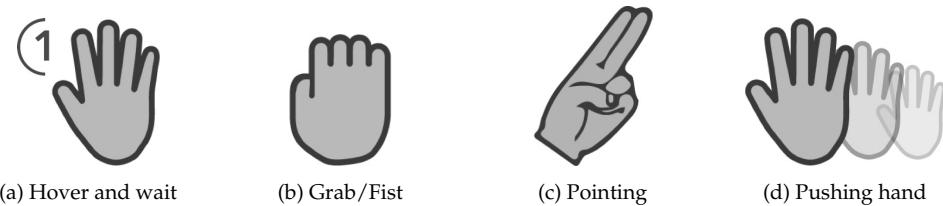


Figure 5.10: Several tested hand interaction techniques

When finished with the interaction techniques the user is introduced on how to stand in the right starting position (see Figure 5.11). She has to stand with both feet parallel and in front to the Kinect. This ensures the readiness of the user and is required before starting the exercise execution.



Figure 5.11: Instruction on how to stand in the correct position

## Selection Menus

The system consists of several selection menus. At first a user profile has to be selected (see Figure 5.12a). Hereby it provides the possibility that more than one user can train with the system separately. When selecting a profile, the appropriate JSON file will be loaded into the system for accessing and managing the user data. Levels and exercises are also structured as menus (see Figure 5.12b & 5.12c). At first they are all locked except the very first one to provide a starting point. A level can be unlocked by accomplishing each exercise of the previous level. This procedure applies similarly to the exercises. Hereby, the next exercise can be unlocked by accomplishing all body sides and repetitions of the current exercise.

## Level and Exercise Description

Selecting a level leads the user to the level introduction (see Figure 5.13a). She is informed about the goals of the current level and gets helpful information for the execution of the following exercises. After that she selects the first exercise in the menu and afterwards a body side, which she wants to train first (see Figure 5.13b). This leads her to the detailed exercise description (see Figure 5.13c).

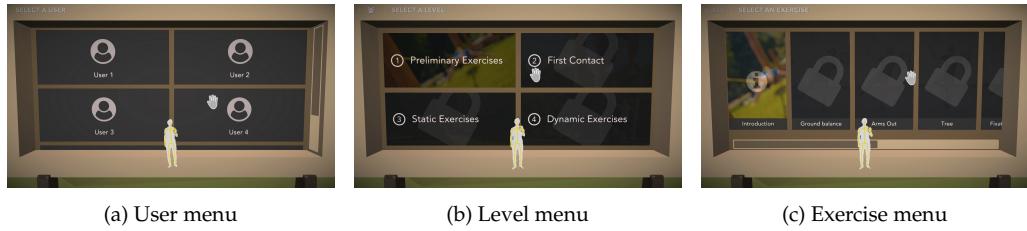


Figure 5.12: Visualisation of selection menus

It is introduced by a list of actions she has to follow to perform it correctly. Additionally, the amount of repetitions and the minimum time to hold the gesture are given. Furthermore, a looping video on the visualizes the correct execution to the user.

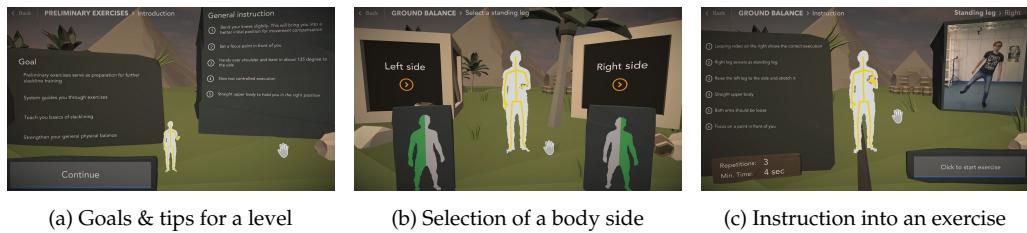


Figure 5.13: Instruction screens for a level and an exercises

## Exercise Execution

The exercise execution consists of the biggest functionality implementation (see Figure 5.14a). Feedback indicators provide the user with necessary information about the current exercise in real time. This should help to enhance the performance in her execution and for successfully accomplishing the exercise. In the SLS the following feedback indicators are integrated:

- Checklist about key elements of an exercise
- Amount of repetitions in general, finished, and left
- Correct performance of an exercise (Timer starts and confidence increases)
- Elapsed time the user is performing the exercise (Timer with a filling circle)
- How good the exercise is currently performed (Confidence/Progress bar)
- If a repetition was successful (Audio signal, timer color, success text, and incrementing repetitions counter)
- If a repetition attempt was not successful (Audio signal and timer reset)

After each successful exercise execution the user is forwarded to a summary screen (see Figure 5.14b). She gets an overview about performance parameters for the execution time, attempts, and the confidence for each repetition. Averaged values for the accomplished side summarize this. A similar summary screen for the entire level can be selected in the exercise menu. It provides an overview of the same performance parameters for each exercise in average (see Figure 5.14c).



Figure 5.14: Exercise execution and summary screens

## 5.5 Summary

The system setup consists of several components, which are the Kinect as tracking device, PC for running the application, as well as a projector and screen for projecting the interface. An important consideration is the positioning of the Kinect and slackline, mainly because of the tracking range and angle of the Kinect. The best combination resulted in a Kinect height of 0.80 m up to 1.20 m and placing the slackline vertically directly in front of the Kinect. Data of the current user and her progress with the system are stored in a separate folder as JSON file. They are human-readable and accessing as well as writing data is rather simple. Gestures can either be defined by the developer self, which is called heuristics or with the tool Visual Gesture Builder provided by Microsoft. Heuristics are good for checking small simple gestures and if the trainee accomplishes key elements of the current gesture. In contrast, the VGB is used to create complex gestures, like standing on the slackline or switching the standing leg. Unity3D serves as game

engine to develop the frontend of the application and Microsoft Kinect SDK v2.0 to access the Kinect data stream. A playful game environment design, in which the user can see herself mirrored, makes the interaction more enjoyable. The system teaches the user how to interact with itself from the beginning. Feedback is an important key feature. Several indicators, like the amount of repetitions or the elapsed time the user is performing an exercise, provide the user with appropriate feedback about her current performance during the exercise execution.



---

---

# **Chapter 6**

## **Study**

This chapter describes the conducted study in detail. At first, the goal and hypothesis of the study is introduced as well as the purpose clarified in section *Introduction and Research Questions*. After that, section *Participants* provides information about the trainees that have participated in the study. Further, section *Method* describes the conditions, apparatus, design, procedure, and the independent and dependent variables. Along with that, the outcome of the study is reported in section *Results and Analysis*. At last, these results are discussed in section *Discussion*.

### **6.1 Introduction and Research Questions**

The SLS familiarizes beginners with the slackline and provides an appropriate learning structure to teach them the basics of standing and walking on a slackline. The conducted study measures and evaluates the learning progress of beginners on a slackline with the SLS and shows whether it motivates a beginner who is interested in learning slacklining. Furthermore, it points out, if the participants are interested in using such a learning system and where it could be applied in the real world.

A personal human trainer is the common way of learning slacklining because she can provide immediate feedback and hints to the trainee. Therefore, the SLS is compared against this method to demonstrate if it can show similar results and compete with it. The participant shares also her thoughts, informs the study leader about the way she thinks when making an action, and where problems exist from her point of view.

Several research questions arise that are stated in the following and will be analysed and discussed in the study discussion:

- Is the system usable for learning new skills in the field of sport slacklining?
- Can it compete with a personal human trainer, as common training method for teaching beginners on a slackline?
- Has the SLS statistical relevant influence to the learning progress of beginners on a slackline?
- Does the SLS support the participant in learning slacklining and during the execution?
- Is the participant motivated in learning new skills and techniques for slacklining?
- Is the structure of the exercises provided by the system perceived challenging, ascending in its difficulty, and shows positive effects in the learning progress?
- Can the real difficulty of the exercises match the subjective difficulty perception of the participants?

## 6.2 Participants

A total amount of twelve participants were recruited from the campus of Saarland University. Among them eight were males and four females.

All demographic data is stated in Table 6.1. The age ranged from 21 years to 42 years ( $M=28$ ,  $SD=6$ ), the body height from 154 cm to 197 cm ( $M=177$  cm,  $SD=12$  cm), and the weight from 45 kg to 112.5 kg ( $M=75$  kg,  $SD=19.5$  kg). The lateral performance of the leg was determined with a *Lateral Preference Inventory Questionnaire* by Coren [8]. All participants had moderate to strong preference to the right leg. The physical activity level was determined with the *Physical Activity, Exercise and Sport Questionnaire (Bewegungs- und Sportaktivität Fragebogen - BSA-F)* by Fuchs et. al [21]. It is divided into physical activities in their job, in free time and sport activities. The participants were not familiar with intermediate slacklining or further balance training. They showed no history of musculoskeletal disorders that may have affected training or testing.

All participants were briefed and gave their consent for taking part on the study and agreed with audiovisual data recording. The present study was approved by the local ethic commission.

Table 6.1: Demographic data of the participants

	ISG (n=6)	HTG (n=6)	Total (n=12)
Gender [f/m]	2/4	2/4	4/8
Age [years]	26 (3)	29 (7)	28 (6)
Weight [kg]	74.2 (18.9)	75.8 (21.8)	75 (19.5)
Lateral Preference Feet [index]	3 (1.1)	2.3 (1.4)	2.7 (1.2)
BSA Job [index]	0.78 (0.34)	0.61 (0.74)	0.69 (0.56)
BSA Spare time [min/week]	223.3 (231.6)	181.7 (149.3)	202.5 (187.1)
BSA Sport [min/week]	148.1 (153)	141.1 (101.7)	144.6 (123.9)

ISG: Interactive System Group; HTG: Human Trainer Group; Data is indicated as means with standard deviations (SD); Lateral preference feet index ranges from strong left (-4) to strong right (+4); BSA: Physical activity; BSA Job index ranges from low active (0) to highly active (+3)

## 6.3 Method

### 6.3.1 Conditions of Slackline Training

Participants were randomly assigned to either an interactive system group (ISG) or human trainer group (HTG). Both groups were provided with the same levels, exercises, detailed description about the execution, and amount of training. The difference in each conditions lies in the training method itself, how instructions are provided to the participant, and how feedback about the execution is given. All participants agreed to train without shoes but with socks to provide a consistent training condition per participant. In the following each condition is described as well as its apparatus.

#### Interactive System Group (ISG)

Within the ISG condition two participant had no experience with interactive devices, four had intermediate experience or advanced experience.

The participant interacts on her own with the system, which teaches her how to interact with it and guides her through predefined exercises. It explains the user how to execute the exercises with a step by step description and a looping video of the correct execution. Furthermore, how many repetitions and in which time to accomplish each repetition. It provides real-time feedback about the current execution performance with several indicators. Since it is a think-aloud study, the participant is encouraged to tell on which actions she is troubling with and if there is any confusion or misunderstanding with the system implementation. No hints or answers concerning the exercise execution were given by the experiment leader to ensure the autonomy of the user with the system.

### **Human Trainer Group (HTG)**

In this condition the participant is instructed by a human trainer, which is the director of the study. All exercises, description, repetitions, and time to hold the exercises correspond to the ISG condition. At first the trainer provides an instruction about the ongoing level of exercises. Then the specific exercise is instructed on how to execute the exercise, how many repetitions, and the minimum time the trainee should hold the pose. After that the trainer demonstrates the execution of the exercise for the trainee. The trainer himself has an exercise description sheet to provide the trainee with the same information as the ISG.

#### **6.3.2 Procedure**

At first the participant was welcomed and briefed about the condition as well as what she can expect from the study. Further, an introduction about the training method in which she participates was given. After agreeing to participate on the study she had to confirm a form consent. Next she had to answer a questionnaire for collecting demographic data and her prior experience with slacklining. Participants of the ISG had to answer one more question about the prior experience with interactive devices (e.g. Kinect, Wii, PlayStation Move, etc.). The physical activity level as well as the lateral preference was determined as stated above.

The general balance ability of the participant was verified before the actual pre-measurement to exclude participants with a balance disorder. Thereby she had to execute a single leg stand for the right and the left foot at first on the ground and then on a towel for a maximum of 10 seconds with 3 trials. This ensures the participant had no problems with holding her own balance on a stable and uneven underground.

After successful accomplishment the actual pre-measurement test was conducted. It is divided in two parts. First, a single leg stance for the left and right foot on the slackline with a maximum of 10 seconds. Second, trying to walk with as few steps as possible on the entire slackline with the left as well as the right leg as starting point. For each measurement and leg the participant had to accomplish three trials, which results in an amount of 12 trials.

If the pre-measurement validated the qualification of the participant for the study a short introduction about the ongoing procedure was provided to her. For all exercises she had to stay on a marked position on the ground, which visualizes the starting point. Depending on the training method, the introduction, repetitions and time to hold each exercises is provided by the trainer or interactive system. During the execution either the trainer or the system hints the participant about the correct execution of the exercise. If an execution was not accurate, she had to repeat it until all repetitions of the exercises are accomplished successfully. The participant had the possibility to skip the exercise if it was too difficult to accomplish or not appropriately recognised by the system. During the training she could take breaks if she wanted to. When accomplishing an exercise set, the

participant was asked to rank the exercise she just completed on a scale of 1 (very easy) to 5 (very difficult).

When finished with the training part, a post-measurement was conducted with the same procedure as in the pre-measurement seen above.

Finally the participant had to answer questions in a semi-structured interview to obtain her opinion on the general training method and application scenarios for exactly this method with the slackline and other sport activities that could fit this method. The ISG were additionally asked about the user interface of the slackline learning system and their experience with the interaction. The specific questionnaires and interview questions can be seen in the appendices.

### Apparatus

Figure 6.1 shows the setup of the study. The Kinect was attached on a tripod with a height of 90 cm. It is placed in front of a wall, which is used as projector screen. The camera is faced in the direction of the slackline. A projector is mounted on the ceiling of the room to project the systems interface on a wall. The mobile slackline stands, like discussed in Section 5.1.1, directly in front of the Kinect. Marker attached on the slackline provide information for pre- and post-measurements as well as the starting point for the participant to get up the line. The set up for the human trainer group was the same, but without the projector and the Kinect. To record the execution a video camera was placed behind the participant to have her actions as well as the interface interaction recorded. The set up was not changed during the study to have the same condition for every participant.

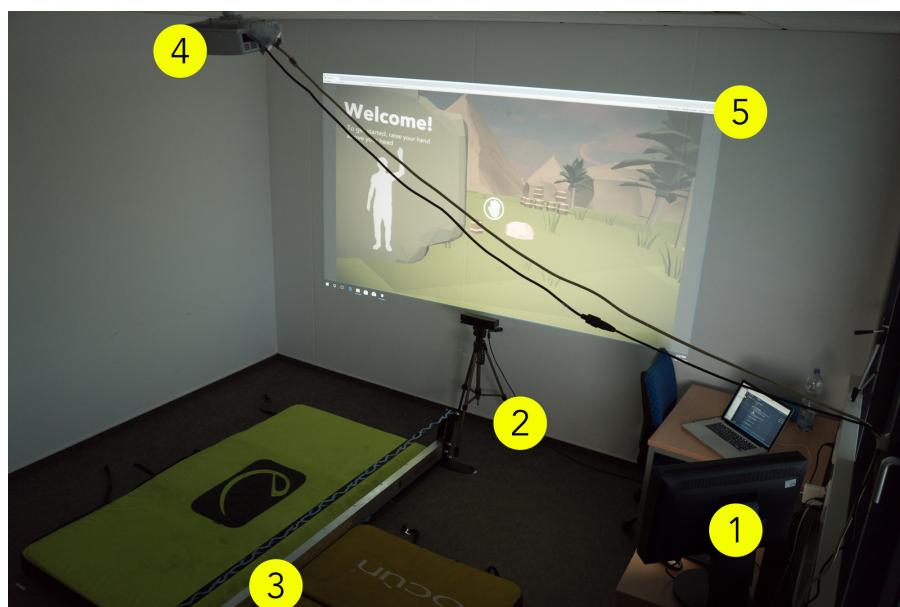


Figure 6.1: Apparatus of the user study (1 - PC, 2 - Kinect, 3 - Slackline with crashpads, 4 - Projector, 5 - Wall serves as screen)

### **6.3.3 Design and Independent & Dependent Variables**

The experiment of the study is a  $2 \times 2$  mixed factorial design, more specifically a 2 level of group (group: ISG, HTG)  $\times$  2 measurements (time: pre, post). Within subject a pre-measurement and post-measurement after the training was conducted. The measurements are divided into three parts. First, measuring the time of a single leg stance with the left as well as the right foot on the slackline with a stopwatch by the director of the study. Second and third, measuring the steps and distance the participant can walk on the slackline with the left and right foot as starting point. Therefore the slackline was divided into 12 parts with tape marks with a distance of 0.5 meters for each, to be able to measure the distance on the video recording with a certain amount of accuracy. Three consecutive attempts per side of the foot and method were executed and measured to compare the results. All pre- and post-measurement were recorded by video. With the help of these video recordings each trial of the participants were checked twice after the study.

#### **Independent Variables**

- Interactive Slackline Group
- Human Trainer Group

#### **Dependent Variables**

- Time stood on line with left and right foot
- Number of possible steps on the line
- Distance walked on the line

## **6.4 Results and Analysis**

Data are provided as means with standard deviations. Each calculated variable (for the left and right leg separately in single leg standing time, walked steps over the line, walked distance on the line) was averaged across the three consecutive recorded trials. Separate  $2 \times 2$  (group: ISG and HTG)  $\times$  2 (time: PRE and POST) mixed-design analysis of variance (mixed ANOVA) was performed. To match the requirements of the mixed ANOVA, all parameters were tested on normality with the Shapiro-Wilk test. Despite walking steps performance in the post measurement for the left and right foot, all data were normally distributed with  $p > 0.05$ . Further, the homogeneity of error variances was assessed by Levene's test with  $p > 0.05$  and the homogeneity of covariances were calculated by Box's test with  $p > 0.05$ . Given these requirements the mixed ANOVA was used for testing interaction effects with sphericity assumed since the group level is  $< 3$ , global differences in the dependent variables between PRE and POST, and possible

differences between ISG and HTG. Level of significance was set at  $p < 0.05$ . Effect size was shown by using partial eta squared ( $\eta_p^2$ ) and was defined as small for  $\eta_p^2 \geq 0.01$ , medium for  $\eta_p^2 \geq 0.06$ , and large for  $\eta_p^2 \geq 0.14$ .

As testing with removed and/or corrected outliers have not shown any essential difference in effects of significance, only the parametrical test results without any removed or corrected data will be shown, to present the results in a uniform manner. All analyses were performed using SPSS Statistics version 25.

The measurement results can be seen in Table 6.2 and the results of the analysis in Table 6.3. In the following, the requirements and results of the mixed ANOVA testing will be reported for each condition separately as well as for the left and right leg.

#### 6.4.1 Single Leg Stance Performance

The homogeneity of error variances was given for the single leg performance for the left and right leg, as assessed by Levene's test with  $p > 0.05$ . There was also homogeneity of covariances, as assessed by Box's test for the left ( $p = 0.699$ ) and right leg ( $p = 0.601$ ).

No statistically significant interaction effect between time and group has been found, for the left  $F(1.0, 10.0) = 0.069$ ,  $p = 0.798$ , partial  $\eta_p^2 = 0.007$  as well as for the right leg  $F(1.0, 10.0) = 0.004$ ,  $p = 0.950$ , partial  $\eta_p^2 = 0.000$  (see Figure 6.2). Since there was no significant interaction effect, the main effects will be reported.

There was no statistically significant main effect within-subjects for time (PRE to POST) for the left leg,  $F(1.0, 10.0) = 3.843$ ,  $p = 0.078$ , partial  $\eta_p^2 = 0.278$ . However, a large statistically significant main effect within-subjects for time (PRE to POST) was found for the right leg,  $F(1.0, 10.0) = 15.548$ ,  $p = 0.003$ , partial  $\eta_p^2 = 0.609$ .

No significant main effect between-subjects for group (ISG to HTG) has been found for the left  $F(1.0, 10.0) = 0.009$ ,  $p = 0.928$ , partial  $\eta_p^2 = 0.001$  and right leg,  $F(1.0, 10.0) = 0.008$ ,  $p = 0.931$ , partial  $\eta_p^2 = 0.001$ .

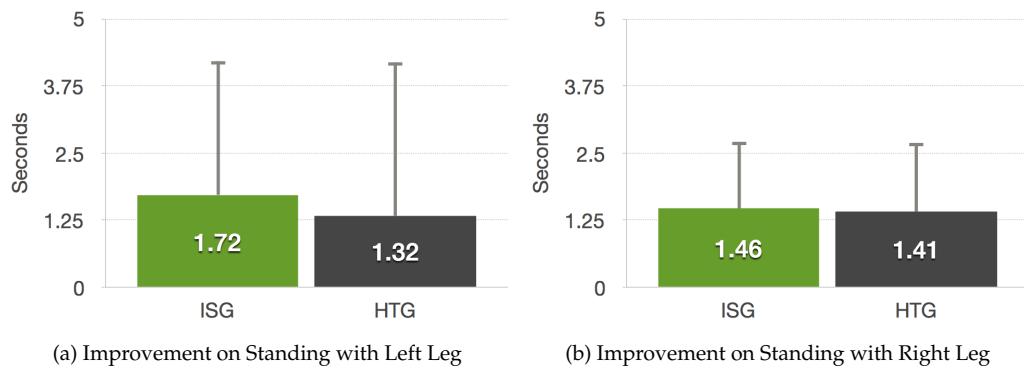


Figure 6.2: Single Leg Stance Improvement

#### 6.4.2 Walked Steps Performance

The homogeneity of error variances was given for the single leg performance for the left and right leg, as assessed by Levene's test with  $p > 0.05$ . There was also homogeneity of covariances, as assessed by Box's test for the left ( $p = 0.831$ ) and right leg ( $p = 0.420$ ).

There was no statistically significant interaction effect between time and group, for the left ( $F(1.0, 10.0) = 0.044$ ,  $p = 0.838$ , partial  $\eta_p^2 = 0.004$ ) as well as for the right leg ( $F(1.0, 10.0) = 1.039$ ,  $p = 0.332$ , partial  $\eta_p^2 = 0.094$ ) (see Figure 6.3). Since no statistical significant interaction effect has been found, the main effects within the tests of within-subject effects will be reported.

There was a large statistically significant main effect within-subjects for time (PRE to POST) for the left leg, ( $F(1.0, 10.0) = 15.868$ ,  $p = 0.003$ , partial  $\eta_p^2 = 0.613$ ) and also for the right leg ( $F(1.0, 10.0) = 12.519$ ,  $p = 0.037$ , partial  $\eta_p^2 = 0.367$ ).

No significant main effect between-subjects for group (ISG to HTG) was found for the left ( $F(1.0, 10.0) = 0.753$ ,  $p = 0.406$ , partial  $\eta_p^2 = 0.070$ ) and right leg ( $F(1.0, 10.0) = 0.351$ ,  $p = 0.567$ , partial  $\eta_p^2 = 0.034$ ).

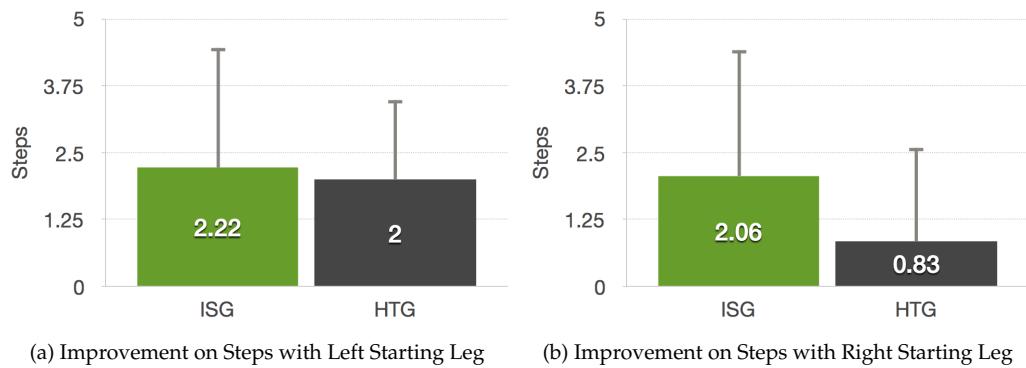


Figure 6.3: Walked Steps Improvement

#### 6.4.3 Walked Distance Performance

The homogeneity of error variances was given for the single leg performance for the left and right leg, as assessed by Levene's test with  $p > 0.05$ . There was also homogeneity of covariances, as assessed by Box's test for the left ( $p = 0.712$ ) and right leg ( $p = 0.193$ ).

There was no statistically significant interaction effect between time and group, for the left ( $F(1.0, 10.0) = 0.006$ ,  $p = 0.942$ , partial  $\eta_p^2 = 0.001$ ) as well as for the right leg ( $F(1.0, 10.0) = 1.235$ ,  $p = 0.292$ , partial  $\eta_p^2 = 0.110$ ) (see Figure 6.4). Since no statistical significant interaction effect has been found, the main effects within the tests of within-subject effects will be reported.

In terms of within-subject time (PRE to POST) a large statistically significant main effect has been found for the left leg ( $F(1.0, 10.0) = 18.563$ ,  $p = 0.002$ , partial  $\eta_p^2 = 0.650$ ) and also for the right leg ( $F(1.0, 10.0) = 7.082$ ,  $p = 0.024$ , partial  $\eta_p^2 = 0.415$ ).

No significant main effect between-subjects for group (ISG to HTG) was found for the left ( $F(1.0, 10.0) = 0.399$ ,  $p = 0.542$ , partial  $\eta_p^2 = 0.038$ ) and right leg ( $F(1.0, 10.0) = 0.145$ ,  $p = 0.711$ , partial  $\eta_p^2 = 0.014$ ).

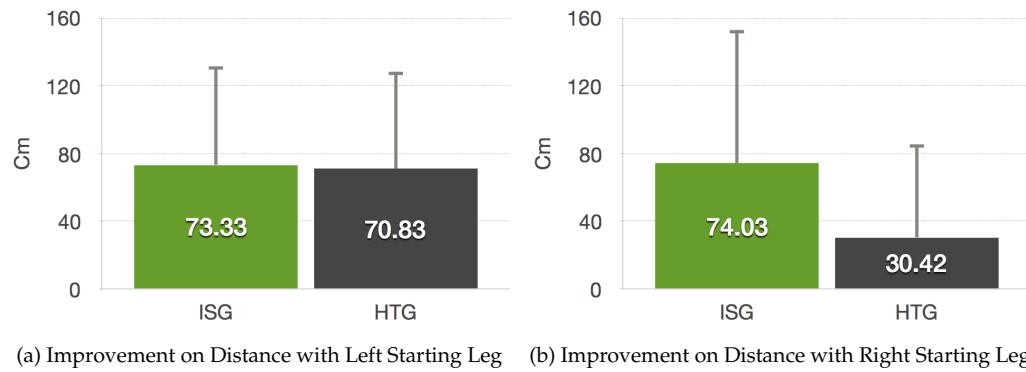


Figure 6.4: Walked Distance Improvement

Table 6.2: Means and standard deviation results for single leg stance, walked steps, and walked distance in the interactive system group (ISG) and human trainer group (HTG)

	ISG		HTG	
	PRE	POST	PRE	POST
Stand Left (sec)	4.92 (1.80)	6.64 (2.60)	5.21 (2.25)	6.53 (1.65)
Stand Right (sec)	6.44 (2.02)	7.90 (2.33)	6.35 (2.92)	7.76 (2.16)
Steps Left	2.44 (1.26)	4.66 (1.53)	2.06 (1.00)	4.06 (1.56)
Steps Right	2.33 (1.05)	4.39 (2.00)	2.61 (1.48)	3.44 (0.89)
Distance Left (cm)	112.92 (35.90)	186.25 (43.25)	101.67 (28.46)	172.50 (63.94)
Distance Right (cm)	105.14 (25.30)	179.17 (66.65)	119.17 (56.86)	149.58 (36.13)

Table 6.3: Interaction, time, and group effects on single leg stance, walking steps, and walked distance

	Main Effect					
	Group x Time	$\eta_p^2$	Time	$\eta_p^2$	Group	$\eta_p^2$
Stand Left (sec)	p = 0.798	0.007	p = 0.078	0.278	p = 0.928	0.001
Stand Right (sec)	p = 0.950	0.000	<b>p = 0.003</b>	<b>0.609</b>	p = 0.931	0.001
Steps Left	p = 0.838	0.004	<b>p = 0.003</b>	<b>0.613</b>	p = 0.406	0.070
Steps Right	p = 0.332	0.037	<b>p = 0.037</b>	<b>0.367</b>	p = 0.567	0.034
Distance Left (cm)	p = 0.942	0.001	<b>p = 0.002</b>	<b>0.650</b>	p = 0.542	0.038
Distance Right (cm)	p = 0.292	0.110	<b>p = 0.024</b>	<b>0.415</b>	p = 0.711	0.014

#### 6.4.4 Observations of the User Study

In the pre measurement all participants had no real control of their body during standing and walking over the slackline. Furthermore, they tried to walk fast over the slackline. The post measurement, after the training, showed that each participant improved to stand and walk slowly and with a certain sense of body control on the line.

All participant had fun during the training and enjoyed to play with the system. They were positively surprised by the tracking ability of the Kinect.

The checklist seen in Figure 6.5 at the left side above the repetitions and the coloured timer on the mid right side, were mentioned as very useful feedback indicator.

Participants were also motivated to accomplish the current exercises for unlocking the next excises.

Beside these, there were also a number of problems that occurred. In the case of general tracking performance with the Kinect there existed problems with the clothing color of a participant. She showed up with black clothes, with which the Kinect had problems to detect her. This is because black clothing absorb the infrared light of the Kinect that makes the tracking ability more difficult [69].

Concerning the exercises during the training problems occurred with the gesture detection while sitting on the slackline for five out of six participants. Like seen in the user view of Figure 6.5, the leg of the participant was wrongly tracked. With other participants their leg was often mistaken with the slackline by the Kinect. All participants of both groups noted also that the sitting exercises are very uncomfortable.

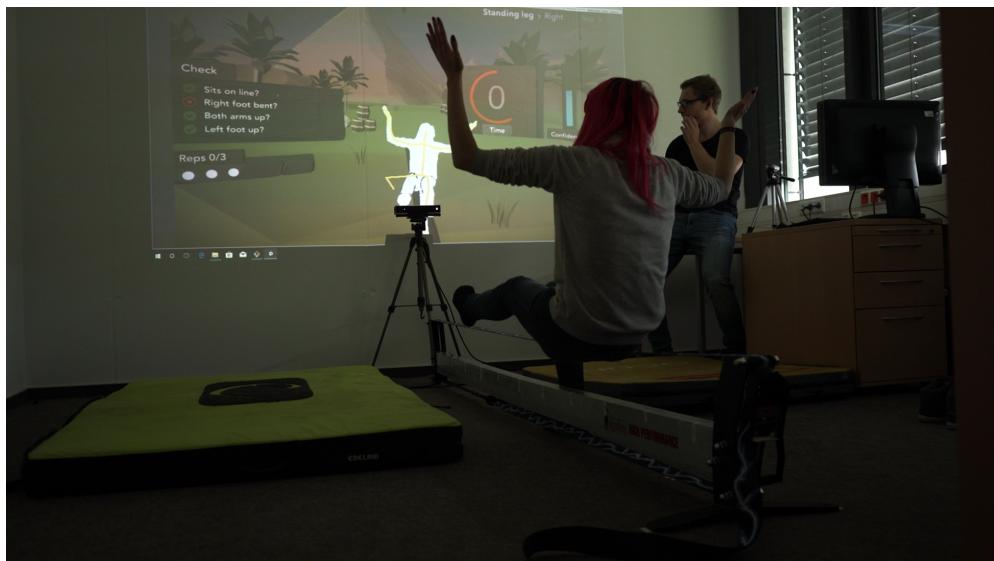


Figure 6.5: The leg of the participant is wrongly tracked by the Kinect, which caused problems for the participant to finish the exercise

The very last exercise resulted also in tracking problems with four out of six participants. Here, the participants had to walk two steps forward on the slackline and hold the end pose for a half second.

A general problem was going up on the slackline. When the participant put her outer leg too close to the line while going up, the Kinect did not track it appropriately. The exercise execution was therefore sometimes not successfully counted.

Three participants in the ISG had small problems with the interaction of the system. Especially with scrolling the exercise list at the beginning, because they didn't know how to interact with it.

#### 6.4.5 Rating of Exercise Difficulty

Participants were asked to rate each exercises after finishing a set of exercises with both legs. They could choose a difficulty on a scale from 1 (very easy) to 5 (very difficult). The ratings of all participants were averaged. Figure 6.6 shows the ratings of each exercise (blue line) as well as a trendline, which is a linear interpolation of the values (green line), and the standard deviation of each rating (grey bars).

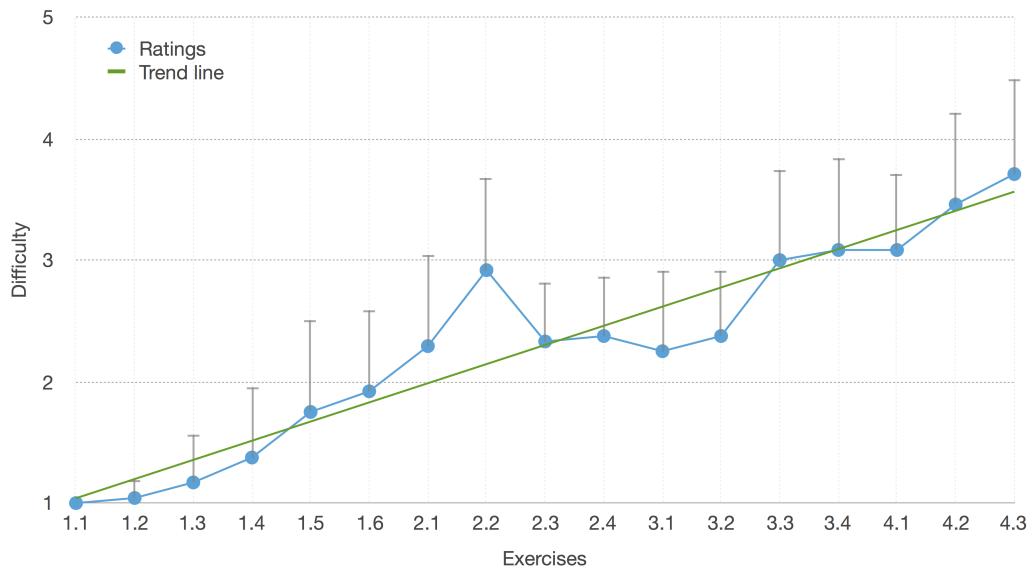


Figure 6.6: Averaged exercise difficulty rating of the participants. Blue points: Rating, Green line: Trend line, Grey bars: Standard deviation

The exercises of the first level follow a smooth increase in difficulty. For the second level there is a massive increase in difficulty for the first two exercises. The ratings for the exercises 2.3, 2.4, 3.1, and 3.2 show comparable difficulty results, since they were the same but exercise 3.1 and 3.2 were different in the

time the user has to hold the exercise. Furthermore, the ratings follow a linear ongoing trend.

#### 6.4.6 Semi-Structured Interview

The general experience with the training method showed similar outcomes for both groups. They mentioned a positive learning progress during the training and had a sense of achievement through challenging but practicable exercises.

All participants in the ISG liked the environment design, clear description, and especially the looping videos of the exercises as well as the appropriate feedback during the execution. Participant 6 said further "*I liked the user view because you can see how you act by yourself. It is also positive that I can use the system without any further help.*"

Participant 3 (ISG) mentioned "[...] *There is no need to watch YouTube tutorials with such a system. It displays all relevant information and provides appropriate feedback*". Participant 4 and 6 (ISG) said a personal trainer could be more helpful due to the fact for giving more specific advises, which the Kinect could not detect.

The most annoying experience for the ISG was the partially bad gesture recognition of the Kinect and the interaction with it. Participant 10 of the HTG mentioned missing exercises for how to get up on the slackline and participant 12 noted especially the uncomfortableness of the sitting on the slackline exercises.

Lastly, a various amount of application scenarios for the interactive training system were mentioned. Among others the most stated were physiotherapy, rehabilitation, in general as training for sport activities, gym, and home trainer.

### 6.5 Discussion

#### Interaction Effects

No interaction effect for group x time can be shown for any measurement variable for the ISG or the HTG. Therefore, the hypothesis that the interactive system shows better results than a human trainer cannot be proven with a statistically significance. Looking at Figures 6.2, 6.3, and 6.4 of the improvements for the group in each measurement, no real difference can be seen between the groups. The ISG group is most of the time slightly better in all conditions, which is not sufficient to prove a statistically significance. A bigger difference can be shown in terms of the right leg side for the walked steps (see Figure 6.3b) and walked distance measurements (see Figure 6.4b). It shows that the ISG is approximately 2.5 times better for the right leg. However, the standard deviation of each group is very high, so that it is also not sufficient to have a certain significance.

Since all significance values are larger than the defined alpha value of 0.05, the null hypothesis cannot be rejected. This means that no interaction effect can be

found over time from pre to post measurements comparing the groups ISG and HTG and therefore no group is better or worse than the other one. This can be caused by multiple reasons.

The duration of the training could have been too short to show a statistically significant difference between the groups. All participants learned just basic techniques of slacklining but no further slackline skill has been trained. For learning more complex exercises and techniques especially the introduction and feedback given during the execution is very important, since these are key elements of understanding how the exercise works and how to perform it correctly. Therefore, further exercises and training over a longer time period could lead to a more specific result.

Second, the participants could have been too exhausted for showing a relevant effect. Participants trained at least 45 minutes on the slackline. After this the post measurement has been executed. Taking the time of the training into account, the measurement results after the training could have been affected by the exhaustion of the participants. As a result of that no real improvement can be showing.

Lastly, there was no distinction in general balance skill of the participants. Subjects were chosen if they had no intermediate slackline experience or no further balance skill through special sport activities. The results show a large standard deviation for all variables in the difference of pre to post. This is because participants improved differently after the training respectively to their pre measurement. Differences in the general balance characteristics for the participants have been found. Therefore, for further studies it is recommended to test on the general balancing skill and characteristic of the participants, to minimize the chance of randomized data because of not qualified participants.

However, a trend can be observed, that the ISG improved slightly better in numerical average than the HTG. This could be the case, because the system's gesture recognition is less tolerant about the exercise execution than a human trainer. Whereas a trainer provides more tolerance concerning the users exercise execution, the system has a predefined gesture database to which the user has to adapt her execution. It leads to more trial executions, because of the strict recognition of the system.

### Time Effects

The time effect seen in Table 6.3 in the column *Time* shows that it differs significantly from pre to post measurement, without considering any group (see Figure 6.7). This means the time effect is observed for all participants as one entity, like no groups would exist. The results state for all measurement conditions a significant improvement, except for standing left leg. Hereby, it is proven that the used training exercises in both groups are useful and have an effect on the learning progress of the participant.

The time standing on the left leg showed no statistically significant result ( $p = 0.078$ ). It is more difficult to hold the balance on a weaker leg, because it is less familiar with handling these situations than the primary leg. Since slacklining is a more complex balance activity, the general balance of the trainee has to be trained with her weaker leg to show an improvement of the slackline specific training. It can be assumed that non-dominant leg won't show an improvement as good as the dominant leg that has a certain general sense of balance. Furthermore, the physical strain could have exhausted the functionality of the leg, since post results has been measured directly after the training.

In contrast, the right leg shows significant results. For all participants the right leg was determined as their primary leg. The general balance skill for this leg is given through everyday physical effort and therefore it shows more stable data for balance improvements.



Figure 6.7: Improvements of each measurement condition for the time effect

## Group Effects

The main effect for the group is analogue to the previous main effect of the time. With this, the group differences can be calculated without considering the time. The pre and post measurements results are combined and averaged together, so the group effect over the entire time range can be obtained. Looking at Table 6.3 in column *Group*, no significant effect can be seen. This means no group differs from each other. The diagrams in Figure 6.8 show that all results are relatively similar. Although, the ISG is numerically slightly better than the HTG it is not sufficient to have a statistically significance difference.

The same arguments of the prior subsection *Interaction Effects* apply here as well. Both groups were provided with the same exercise structure, description, repetitions, and time to hold the exercise. Just the method how the information is provided to the user and the feedback during the execution of the exercise differed. It could be the case that both training methods provide a similar amount of information and feedback such that no group has had an advantage. This again results in similar group effects. However, it proves that both training methods show similar results and can be therefore compared with each other.

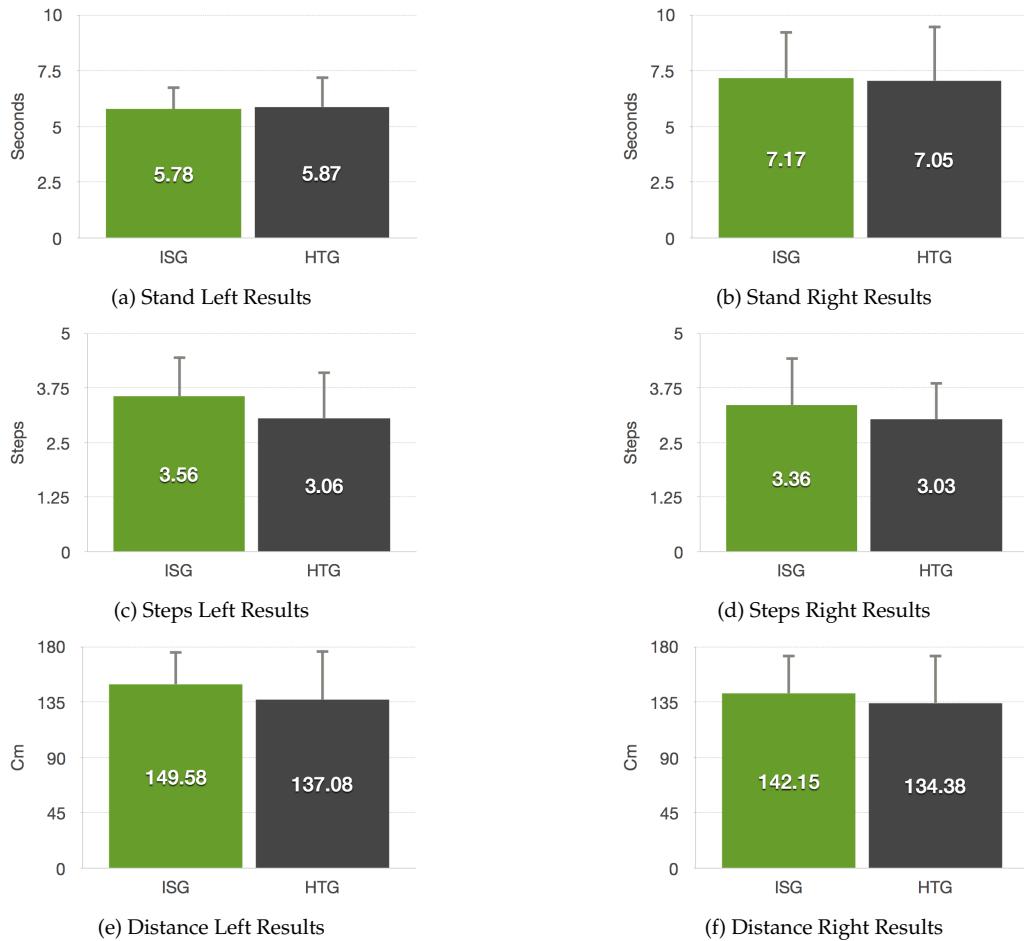


Figure 6.8: Scores for comparing the main effects of the group

### Observations of the User Study

The observations during the study help to improve the system since each participant differs in their interaction with the system. It is useful to consider these observations for further practice with the interactive slackline system and to improve it.

Since all participants had no real control of their body balance, it proves they were all beginners and had no further experience with the slackline. Within the training participants were strengthened in their balance, learned to feel how their body behaves on the slackline, and how to counterbalance the body movement. The post measurement proves the positive effect of this training since all participant improved in standing and walking more controlled on the line.

The virtual environment design gave a sense of a more playful training system with which participants enjoyed to interact with and motivated them. Although

there existed problems with the recognition of the Kinect, each participant had fun during the training and was motivated to accomplish each exercise.

The check list and timer in the exercise execution screen were mentioned as very helpful feedback indicators. They provide support by notifying participants about the current status of their execution with clear audiovisual feedback. It helped them to ensure their body was in the correct position for the exercise and when they are executing the exercise correctly. This motivated participants because they were provided with immediate feedback about which part of the exercise is executed wrong and whether an exercise repetition was counted as correct.

On the other side there existed several tracking problems. The black clothes of one participants absorbed the infrared light of the Kinect, therefore making the tracking ability more difficult. It would be helpful to inform participants not to wear any black clothes when using the Kinect.

Beside this, there was a problem with tracking participants while sitting on the slackline. The leg was not properly tracked or mistaken with the slackline itself by the Kinect. Furthermore, it was a very uncomfortable exercise for all participants. Because of the way of how the problem exist, this exercise should be omitted from the exercise list or replaced with exercises to train the first contact with the slackline in a more practicable way.

Going up and walking on the line also resulted in tracking problem. The Kinect did not properly track the second step of the participants, which resulted in failures of the correct exercise execution. This problem could be fixed by tracking the gestures with more people that execute different variations of a correct exercise execution.

Concerning the interaction problems with scrolling in the exercise menu, it would be helpful to add an instruction on how to scroll a list in the system.

### **Rating of Exercise Difficulty**

The ratings of the first level of the exercises matches the idea of slowly strengthen the general balance skill of the participants and preparing them for standing on a slackline.

However, the first two exercises of the second level were rated as very difficult. This corresponds with the observations in the prior subsection *Observations of the User Study*, since in exercise 2.1 and 2.2 participant had to sit on the line. They claimed these exercise were very uncomfortable or too difficult for them.

Exercise 3.1 is the same as 2.3 and exercise 3.2 is the same as 2.4, in which the participant learned to go up on the line. Exercise 3.1 and 3.2 increased just in the time to hold the exercise. Some participants noted they felt more secure to stand longer on the slackline after doing the short-time exercises. Therefore they rated them similar to the prior exercise.

Further, the ratings follow a linear ongoing trend and match the intended exercise difficulty. Overall this verifies the appropriate integration of the implemented exercises as a training model for beginners on a slackline.

### **Semi-Structured Interview**

In general, the participants noted the exercises were well structured such that they felt a learning progress. The enjoyable environment gives a playful character for the training situation and the challenging exercises motivate them to reach their goal of accomplishing the exercise. All participants had fun playing with the interactive slackline learning system and noted they would try it again. They also recommend it for people who want to try slacklining. Especially, because it is more structured as a gamified training system.

The application scenarios stated by the participants, like the usage in rehabilitation or as home trainer, verifies the system can be used to help and support people, who have problems with their balance or want to improve it.



---

---

# **Chapter 7**

## **Conclusion and Future Work**

This last chapter provides a conclusion of the research questions. In the second part, it states issues with the system that should be improved. Furthermore, possible ideas to extend and improve the system itself as well as recommendations for further research work will be provided.

### **7.1 Conclusion**

At first the research questions stated in section *Research Questions* will be discussed and how they have been realized within the scope of this thesis.

**Has slacklining a positive training effect and what has to be considered to build an appealing interactive learning system?**

Slacklining shows positive effects on muscle strength improvements and muscle activation. It also can be used as an alternative way to general balance training, because it shows improvements in postural control. The Microsoft Kinect resulted in the best tracking device for the case of this thesis. Appropriate and simple feedback help the user during the exercise execution, as well as motivating her for further exercises. This is achieved by an enjoyable virtual training environment, a challenging exercise structure, and a user friendly interface.

**How can a conceptual design of a prototypical interactive slackline learning system be elaborated?**

The conceptual design has been elaborated by defining basic and system specific requirements based on the related work and comparable applications, Nielsens

ten usability heuristics, and human interface guidelines provided by Microsoft. Splitting exercises into levels allows to separate them into different difficulty ranks. Unlocking levels and exercise through accomplishing them, gives a sense of motivation and enjoyable gameplay. Providing the user with a well structured interface and a clear workflow helps to enhance the user experience

**Which technical architecture and hardware are necessary for developing such a system?**

The system has been built with the help of Unity3D and Microsoft Kinect SDK as connection between Unity and Kinect hardware. For displaying the UI on a big screen a projector has been used. The best combination of positioning the Kinect and the slackline resulted in a Kinect height of 0.80 up to 1.20 meters and positioning the slackline directly in front of the Kinect. Exercises for the movement recognition were created with the tools *KinectStudio* and *Visual Gesture Builder* by Microsoft. Furthermore, checking on small and simple gestures has been achieved with heuristics, which means programmatically checking on certain joint positions and angles in the x-, y- and z-axis.

**Can the slackline learning system compete with a common learning method and show a learning progress on users that trained with the system?**

A conducted study compared the slackline learning system with a personal human trainer. A 2 (group: ISG, HTG) x 2 (time: PRE, POST) mixed factorial study design has been used with the measurement parameters single leg stance, steps walked over the line, and distance walked over the line. The results showed no interaction effect between the groups for the time and no main effect between subjects. However, a significant main effect between pre and post measurement has been found for all participants. This means that both groups do not differ after the training regarding their performance, but all participants improved their own balance skill in almost all measurement categories. Considering the numeric data results of the learning progress, the performance of both groups (HTG and ISG) can be seen as very similar. Therefore the learning progress on the slackline learning system can be compared with a personal human trainer.

## 7.2 Limitations and Future Work

The following section will suggest improvements, ideas, and approaches for further development with the system from multiple perspectives and application fields.

For further development of the system in the area of slacklining the tracking should be improved. Like seen in section *Observations of the User Study* there exist problems with tracking exercises while going up and walking steps on the line.

More variations of the exercises should be tracked with several people to enhance the gesture database.

The SLS itself can be improved to make it more attractive for different user groups. Especially for people that have a sense of competition or want to improve themselves for this kind of sport. To achieve this, the system could at first assess the skill level of the user with predefined exercises. Based on the outcome, a pool of exercises would be created by the system. Like seen in section *Methods for Slackline Skill Acquisition*, a differential method could also serve as an alternative training method to the methodical routine used in this study. An integration of a differential method provides the user with more freedom in choosing exercises over the entire range of the difficulty levels. The experience of the user could also be calculated in points based on her performance, which could be the amount of attempts for the exercise, how confident she was, and how much time she needed to accomplish the exercise. Furthermore, an achievement system could be tested to motivate the user and reward her. An animated character would be an alternative to the looping videos in the exercise instruction. It could be used to support the trainee during the exercises, like seen in the *Nike +* application of section *Motivation*.

In terms of application scenarios, further work could investigate the usage of the slackline learning system as a home workout system. This can show if the system would be an appropriate alternative for private people to become more fit and motivate them for balance sport activities. A similar scenario would be to integrate the SLS in a company in which office job is the main activity. It would be interesting, if employees are motivated to use the system for having a certain amount of variety in their job. Additional research could observe if employees will become more fit, prevent problems with their posture, or improve their posture, which is strained due to sitting activities.

Another interesting part would be the investigation of the SLS in fields of sport medicine, e.g. for physiotherapy or in a rehabilitation center. Patients could be more motivated through the gamified environment and for unlocking exercises. A further question would be, if it has positive effects to support the patients in respect of the cure of their balance disorder. Because of its autonomous usage a workload reduction of the medical personal can be assumed. They could focus on other work than supervising patients during their training period.

Noted by participants in the study of this thesis, the system could find its application as balance training system for several other sport activities. Especially where self control and controlling the own body balance is essential, like in martial arts, dancing, or rowing. Furthermore, gyms rely more and more on a virtual trainers. Such a learning system could therefore find its application in a gym environment or in a climbing hall as alternative training method.

It would also be interesting to adapt other sport activities than slacklining for such a learning system. Participants of the study named for example boxing,

basketball, yoga, dancing, or skiing. In general, all balance activities or activities in which a choreography are part of them could be integrated.

Another open question would be, if slacklining could be combined with virtual reality technology. This would be an application for more advanced slacker, because the risk of accidents is probably be too high for beginners on a slackline. In special, elaborating the impact of a pleasing virtual environment on the slacker and if the application could provide a more immersive feeling because of the virtual environment. Further, the learning approach could also be integrated in virtual reality, in which a virtual trainer provides the exercises and demonstrates them to the trainee.

# **Appendices**



---

---

## **Appendix A**

### **Questionnaires of the User Study**

This chapter presents the questionnaires provided for each participant in the study. Not all questions were shown for the human trainer group in *Demographic Data* and *Guided Interview* because these were specifically related to the interactive system group. Each questionnaire is accommodated in separate sections. Participants fulfilled the questionnaires as structured in the following order.

## Demographic data

### 1. Participant number

### 2. Gender

Male

Female

### 3. Height

cm

### 4. Age

years old

### 5. Weight

kg

### 6. How often have you tried slacklining?

- None
- Sometimes ( e.g. 1-2 times)
- Intermediate (e.g. 3-10 times)
- Advanced (e.g. over 10 times)

### 7. Last contact with slacklining

- Never
- 1 month ago
- 2 - 6 month ago
- 6-12 months ago
- Over a year ago

### 8. Experience with interactive devices (Kinect, Wii, PlayStation Move, etc.)

- None
- Beginner ( e.g. tried 1-2 times)
- Intermediate (e.g. played by a friend)
- Advanced (e.g. owning such a device)

Figure A.1: Demographic data for participants in the study. Question 8 was just shown for the interactive system group

## BSA-Questionnaire

Participant  1/2

**Q1 Are you employed, studying, or in an apprenticeship (also homemaker)?**

- Yes (continue with Q2)       No (continue with Q3)

**Q2 Your job involves...**

	None	Sometimes	Mostly	Always
sitting activities	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
some activities	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
intensive activities	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

**Q3 On how many days and how long have you practiced the following activities in the last 4 weeks?**

	on ... days	ca. ... min/day	None
Walking to work	<input type="text"/>	<input type="text"/>	<input type="checkbox"/>
Walking to the supermarket	<input type="text"/>	<input type="text"/>	<input type="checkbox"/>
Riding by bike to work	<input type="text"/>	<input type="text"/>	<input type="checkbox"/>
Riding bike for other purposes	<input type="text"/>	<input type="text"/>	<input type="checkbox"/>
Go for a walk	<input type="text"/>	<input type="text"/>	<input type="checkbox"/>
Physically demanding homework (cleaning, tyding up, etc.)	<input type="text"/>	<input type="text"/>	<input type="checkbox"/>
Physically demanding care work (maintaining kids or care recipient)	<input type="text"/>	<input type="text"/>	<input type="checkbox"/>

**Q4 On how many days and how long have you climbed stairs in the last 4 weeks?**

on  days      ca  floors/day      None

Figure A.2: First page of the physical activity questionnaire, adapted from Fuchs et. al [21]

2/2

Participant **Q5 Have you practiced sport activities in the last 4 weeks?** Yes (continue with Q6) No (finished)**Q6 Which sport activities have you practiced?**

A	B	C
<input type="text"/>	<input type="text"/>	<input type="text"/>
I have practiced activity <b>A</b> in the <u>last 4 weeks</u> for <input type="text"/> times and each time for <input type="text"/> minutes	I have practiced activity <b>B</b> in the <u>last 4 weeks</u> for <input type="text"/> times and each time for <input type="text"/> minutes	I have practiced activity <b>C</b> in the <u>last 4 weeks</u> for <input type="text"/> times and each time for <input type="text"/> minutes

Figure A.3: Second page of the physical activity questionnaire, adapted from Fuchs et. al [21]

## The Lateral Preference Inventory

Participant

Simply read each of the questions below. Decide which hand, foot, etc. you use for each activity and then put a check mark next to the answer that describes you the best. If you are unsure of any answer, try to act out the action.

	Left	Right	Either
1. With which hand do you draw?	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
2. Which hand would you use to throw a ball to hit a target?	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
3. In which hand would you use an eraser on paper?	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
4. Which hand removes the top card when you are dealing from a deck?	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
	Left	Right	Either
5. With which foot would you kick a ball to hit a target?	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
6. If you wanted to pick up a pebble with your toes, which foot would you use?	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
7. Which foot would you use to step on a bug?	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
8. If you had to step up onto a chair, which foot would you place on the chair first?	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
	Left	Right	Either
9. Which eye would you use to look through a telescope?	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
10. If you had to look into a dark bottle to see how full it is, which eye would you use?	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
11. Which eye would you use to peep through a keyhole?	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
12. Which eye would you use to sight down a rifle?	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
	Left	Right	Either
13. If you wanted to listen on a conversation going on behind closed doors, which ear would you place against the door?	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
14. On which ear would you pickup your phone if it's calling?	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
15. If you wanted to hear someone's heartbeat, which ear would you place against their chest?	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
16. Which ear would you press against a box on a table with a small clock within, to find out if the clock is ticking?	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>

Figure A.4: Lateral preference inventory to determine the preference of the body side, adapted from Coren [8]

## Guided Interview Questionnaire

### Block 1: General questions about the learning method

- Q1: How is your general experience about this training method?  
Q2: What do you like the least?  
Q3: What do you like the most?  
Q4: Would you use this method and why?

### Block 2: Application scenarios

- Q1: Could you think of any other application scenario for exactly this training method with the slacklining approach? (no hints but e.g. rehabilitation, sport medicine, etc.)  
Q2: Could you think of any other sport activities, than slacklining, that could fit in this method?

### Block 3: User Interface / System Feedback Evaluation <sup>8</sup>

- Q1: What do you like the most about the system?  
Q2: What was most frustrating / disturbed you?  
Q3: What would you change?  
Q4: How would you describe the system in one sentence?

---

<sup>8</sup>These questions were just asked for the interactive system group

---

---

# Appendix B

## Statement of the Ethical Review Board



Saarbrücken, 14.11.2017

**Statement of the Ethical Review Board (ERB)  
in response to your application (No. 17-11-1)**

Dear Mr. Murlowski,

The ERB has reviewed your research project "Elaboration of an interactive slackline learning system with beginners". According to its regulations, approved by the Department of Computer Science of Saarland University on October 26, 2016, the ERB has come to the following conclusion:

"There are no ethical concerns against the implementation of the research project".

If you have any questions, please let me know. We wish you all the best in your future research endeavours.

Best regards, on behalf of the ERB

*Jürgen Steinle*

Prof. Dr. Jürgen Steinle  
Member of the Ethical Review Board  
of the Department of Computer Sciences at Saarland University

Figure B.1: Approvement of the Ethical Review Board in response to the research project



---

## List of Abbreviations

**3D**  
Three-Dimensional

**CM**  
Centimetre

**F**  
F-Ratio

**HTG**  
Human Trainer Group

**ISG**  
Interactive System Group

**M**  
Meters

**P**  
Asymptotic Significance

**PC**  
Personal Computer

**SEC**  
Seconds

**SDK**  
Software Development Kit

**SLS**  
Slackline Learning System

**UI**  
User Interface

**VGB**  
Visual Gesture Builder



---

# List of Figures

1.1	Ingame screenshot of the <i>Nike+ Kinect Training<sup>9</sup></i> Application. A virtual avatar demonstrates the exercise on the left side. The user can see herself mirrored on the right side of the screen. . . . .	1
1.2	Person standing on a slackline and balancing out his sway . . . . .	2
2.1	Supportive exercises [38] . . . . .	6
2.2	Basic exercises [38] . . . . .	7
2.3	Advanced techniques [38] . . . . .	7
2.4	Anatomical terms of location . . . . .	11
2.5	Definition of accuracy and precision [68] . . . . .	12
2.6	Guideline for enhancing the cognitive load [66] . . . . .	14
2.7	Interface of a rehabilitation training application [22] . . . . .	18
2.8	3D Model as avatar [16] . . . . .	19
2.9	Rail-time user representation [30] . . . . .	19
2.10	User interface of a rehabilitational application [7] . . . . .	19
2.11	Feedback methods [9] . . . . .	20
2.12	Feedback indicator and movement visualization as an avatar [9] .	21
2.13	User Viewer on top [9] . . . . .	21
2.14	Direct manipulation of a slider with intuitive interaction [9] . . .	22
2.15	Teaching new gestures [9] . . . . .	22
2.16	Physical interaction zone [9] . . . . .	23
3.1	Main categories of slacklines . . . . .	26
3.2	Slackline variations . . . . .	27
3.3	Categorization of slacklining . . . . .	28
3.4	Methodical routine, adapted from Thomann [63] . . . . .	29
3.5	Comparison methodical routine vs. differential method, adapted from Thomann [63] . . . . .	30
3.6	Dynamic methodic in slacklining, adapted from Thomann [63] . .	31
4.1	Exercise structure . . . . .	39
5.1	Mobile slackline <i>alpidex POWER-WAVE 2.0</i> [1] . . . . .	42

---

5.2	Setup of all components . . . . .	42
5.3	Limitations of the Kinect v2 sensor [9] . . . . .	43
5.4	Different positions of the slackline. The coloured lines visualise the skeletal tracking of the Kinect. Thin lines represents inferred joints . . . . .	44
5.5	Kinect view on different heights. The coloured lines visualises skeletal tracking. . . . .	45
5.6	Data model overview . . . . .	46
5.7	Workflow of creating a gesture database . . . . .	47
5.8	Unity and Kinect architecture . . . . .	48
5.9	Instruction on how to use the SLS . . . . .	49
5.10	Several tested hand interaction techniques . . . . .	50
5.11	Instruction on how to use stand in the correct position . . . . .	50
5.12	Visualisation of selection menus . . . . .	51
5.13	Instruction screens for a level and an exercises . . . . .	51
5.14	Exercise execution and summary screens . . . . .	52
6.1	Apparatus of the user study (1 - PC, 2 - Kinect, 3 - Slackline with crashpads, 4 - Projector, 5 - Wall serves as screen) . . . . .	59
6.2	Single Leg Stance Improvement . . . . .	61
6.3	Walked Steps Improvement . . . . .	62
6.4	Walked Distance Improvement . . . . .	63
6.5	The leg of the participant is wrongly tracked by the Kinect, which caused problems for the participant to finish the exercise . . . . .	64
6.6	Averaged exercise difficulty rating of the participants. Blue points: Rating, Green line: Trend line, Grey bars: Standard deviation . . . . .	65
6.7	Improvements of each measurement condition for the time effect . . . . .	68
6.8	Scores for comparing the main effects of the group . . . . .	69
A.1	Demographic data for participants in the study. Question 8 was just shown for the interactive system group . . . . .	80
A.2	First page of the physical activity questionnaire, adapted from Fuchs et. al [21] . . . . .	81
A.3	Second page of the physical activity questionnaire, adapted from Fuchs et. al [21] . . . . .	82
A.4	Lateral preference inventory to determine the preference of the body side, adapted from Coren [8] . . . . .	83

B.1 Approvement of the Ethical Review Board in response to the re-search project . . . . .	85
--	----



---

## List of Tables

6.1	Demographic data of the participants . . . . .	57
6.2	Means and standard deviation results for single leg stance, walked steps, and walked distance in the interactive system group (ISG) and human trainer group (HTG) . . . . .	63
6.3	Interaction, time, and group effects on single leg stance, walking steps, and walked distance . . . . .	63



---

## Bibliography

- [1] ALPIDEX. Slackline Gestell in 2 Längen Power Wave 2.0 inklusive Slackline, 2014. [Online; accessed 13-March-2017].
- [2] BALCOM, S. *Walk the Line: The Art of Balance and the Craft of Slackline*. Slack Daddy Press, 2005.
- [3] BECK, F. Sportmotorik und Gehirn : Differenzielles Lernen aus der Perspektive interner Informationsverarbeitungsvorgänge. *German Journal of Exercise and Sport Research* 38, 4 (2008), pp. 423–450.
- [4] BLAUSEN MEDICAL COMMUNICATIONS, INC. Medical gallery of Blausen Medical 2014. *WikiJournal of Medicine* 1, 2 (2014).
- [5] BOGDANOVYCH, A. AND STANTON, C. A Novel Approach to Sports Oriented Video Games with Real-time Motion Streaming. In *Proceedings of the 7th ACM SIGCHI Symposium on Engineering Interactive Computing Systems* (2015), EICS '15, ACM, pp. 64–73.
- [6] BUDDHARAJU, P. AND LOKANATHAN, Y. Mobile Exergaming: Exergames on the Go. In *Proceedings of the International Conference on Mobile Software Engineering and Systems* (2016), ACM, pp. 25–26.
- [7] CHANG, C.; LANGE, B.; ZHANG, M.; KOENIG, S.; REQUEJO, P.; SOMBOON, N.; SAWCHUK, A. A. AND RIZZO, A. A. Towards pervasive physical rehabilitation using Microsoft Kinect. In *6th International Conference on Pervasive Computing Technologies for Healthcare (PervasiveHealth) and Workshops* (2012), pp. 159–162.
- [8] COREN, S. The lateral preference inventory for measurement of handedness, footedness, eyedness, and earedness: Norms for young adults. *Bulletin of the Psychonomic Society* 31, 1 (Jan 1993), pp. 1–3.
- [9] CORPORATION, MICROSOFT. Kinect for Windows | Human Interface Guidelines v2.0, 2014. [Online; accessed 13-March-2017].
- [10] CORPORATION, MICROSOFT. *Visual Gesture Builder: A Data-Driven Solution to Gesture Detection*, 2014.
- [11] DAVIS, L. Photography of a man highlining at Taft Point, Yosemite National Park, with El Capitan in the background., 2013.

- [12] DE M., PÂMELLA; C., RENATA; Z., MARCELY ALMEIDA; DA S., SIOMARA APARECIDA; B., THAIS SILVA AND C., FERNANDO LUIZ. Exergames as a Tool for the Acquisition and Development of Motor Skills and Abilities: A Systematic Review. *Revista Paulista de Pediatria* 35 (2017), pp. 464–471.
- [13] DONATH, L.; ROTH, R.; RUEEGGE, A.; GROPPA, M.; ZAHNER, L. AND FAUDE, O. Effects of Slackline Training on Balance, Jump Performance & Muscle Activity in Young Children. *International Journal of Sports Medicine* 34, 12 (2013), pp. 1093–1098.
- [14] DONATH, L.; ROTH, R.; ZAHNER, L. AND FAUDE, O. Slackline training and neuromuscular performance in seniors: A randomized controlled trial. *Scandinavian Journal of Medicine & Science in Sports* 26, 3 (2016), pp. 275–283.
- [15] DONATH, L.; ROTH, R.; ZAHNER, L. AND FAUDE, O. Slackline Training (Balancing Over Narrow Nylon Ribbons) and Balance Performance: A Meta-Analytical Review. *Sports Medicine* (2016), pp. 1–12.
- [16] ESTEPA, A.; PIRIZ, S. SPONTON; ALBORNOZ, E. AND MARTÍNEZ, C. Development of a Kinect-based exergaming system for motor rehabilitation in neurological disorders. *Journal of Physics: Conference Series* 705, 1 (2016), p. 012060.
- [17] FETZ, F. *Allgemeine Methodik der Leibesübungen*. ÖBV Pädagogischer Verl., 1996.
- [18] FREITAS, D. Q.; DA GAMA, A. E. F.; FIGUEIREDO, L.; CHAVES, T. M.; MARQUES-OLIVEIRA, D.; TEICHRIEB, V. AND ARAÚJO, C. Development and Evaluation of a Kinect Based Motor Rehabilitation Game. In *Proceedings of SBGames 2012* (2012), pp. 144–153.
- [19] FRIEDRICH, B. Photograph of a person walking on a rodeoline in Graz, 2006.
- [20] FRIEDRICH, F. Photograph of a person waterlining over the Sulm in Austria, 2007.
- [21] FUCHS, R.; KLAPERSKI, S.; GERBER, M. AND SEELIG, H. Messung der Bewegungs- und Sportaktivität mit dem BSA-Fragebogen. *Zeitschrift für Gesundheitspsychologie* 23, 2 (2015), pp. 60–76.
- [22] GARRIDO, J. E.; MARSET, I.; PENICHET, V. M. R. AND LOZANO, M. D. Balance Disorder Rehabilitation Through Movement Interaction. In *7th International Conference on Pervasive Computing Technologies for Healthcare and Workshops* (2013), PervasiveHealth '13, ICST (Institute for Computer Sciences, Social-Informatics and Telecommunications Engineering), pp. 319–322.
- [23] GRAF, DIANA L.; PRATT, LAUREN V.; HESTER, CASEY N. AND SHORT, KEVIN R. Playing Active Video Games Increases Energy Expenditure in Children. *Pediatrics* 124, 2 (2009), pp. 534–540.

- [24] GRANACHER, U.; ITEN, N.; ROTH, R. AND GOLLHOFER, A. Slackline training for balance and strength promotion. *International Journal of Sports Medicine* 31 (2010), pp. 717–723.
- [25] GRIŽON, S. Photograph of a person doing a handstand on a trickline, 2013.
- [26] GRÖSSING, S. *Einführung in die Sportdidaktik*. Limpert, 1997.
- [27] HÄMÄLÄINEN, P. Interactive Video Mirrors for Sports Training. In *Proceedings of the 3rd Nordic Conference on Human-computer Interaction* (2004), NordiCHI '04, ACM, pp. 199–202.
- [28] HICKS, L. AND HIGGINS, J. Exergaming: Syncing Physical Activity and Learning. *Strategies* 24, 1 (2010), pp. 18–21.
- [29] HODGES, NICOLA J. AND FRANKS, IAN M. Modelling coaching practice: the role of instruction and demonstration. *Journal of Sports Sciences* 20, 10 (2002), pp. 793–811.
- [30] HOLSTI, L.; TAKALA, T.; MARTIKAINEN, A.; KAJASTILA, R. AND HÄMÄLÄINEN, P. Body-controlled Trampoline Training Games Based on Computer Vision. In *CHI '13 Extended Abstracts on Human Factors in Computing Systems* (2013), CHI EA '13, ACM, pp. 1143–1148.
- [31] INSTITUTE, NATIONAL CANCER. Picture of the planes of human anatomy., 2006.
- [32] JENSEN, M. M.; RASMUSSEN, M. K. AND GRØNBÆK, K. Design Sensitivities for Interactive Sport-training Games. In *Proceedings of the 2014 Conference on Designing Interactive Systems* (2014), ACM, pp. 685–694.
- [33] JOHNSON, D.A.; ROSE, F.D.; RUSHTON, S.; PENTLAND, B. AND ATTREE, E.A. Virtual Reality: A New Prosthesis for Brain Injury Rehabilitation. *Scottish Medical Journal* 43, 3 (1998), pp. 81–83.
- [34] KAJASTILA, R. AND HÄMÄLÄINEN, P. Augmented Climbing: Interacting with Projected Graphics on a Climbing Wall. In *Proceedings of the Extended Abstracts of the 32Nd Annual ACM Conference on Human Factors in Computing Systems* (2014), CHI EA '14, ACM, pp. 1279–1284.
- [35] KAJASTILA, R.; HOLSTI, L. AND HÄMÄLÄINEN, P. The Augmented Climbing Wall: High-Exertion Proximity Interaction on a Wall-Sized Interactive Surface. In *Proceedings of the 2016 CHI Conference on Human Factors in Computing Systems* (2016), CHI '16, ACM, pp. 758–769.
- [36] KELLER, M.; PFUSTERSCHMIED, J.; BUCHECKER, M.; MÜLLER, E. AND TAUBE, W. Improved postural control after slackline training is accompanied by reduced H-reflexes. *Scandinavian Journal of Medicine & Science in Sports* 22, 4 (2012), pp. 471–477.

- [37] KLEINDL, R. *Slackline: Die Kunst des modernen Seiltanzens*. Meyer & Meyer, 2011.
- [38] KROISS, A. Der Trendsport Slackline und seine Anwendungsmöglichkeiten im Schulsport. Master's thesis, TU München, 2007.
- [39] LIEBERMANN, DARIO G.; KATZ, LARRY; HUGHES, MIKE D.; BARTLETT, ROGER M.; MCCLEMENTS, JIM AND FRANKS, IAN M. Advances in the application of information technology to sport performance. *Journal of Sports Sciences* 20, 10 (2002), pp. 755–769.
- [40] LIM, D.; KIM, C.; JUNG, H.; JUNG, D. AND CHUN, K. J. Use of the Microsoft Kinect system to characterize balance ability during balance training. *Clinical Interventions in Aging* 10 (2015), pp. 1077–1083.
- [41] MILLER, F.; MAUSER, D. *Slackline - Tipps Tricks Technik*. Panico Alpinverlag, 2012.
- [42] MVN, XSENS. Motion capture suit. [Online; accessed 07-October-2017].
- [43] NIELSEN, J. Enhancing the Explanatory Power of Usability Heuristics. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (1994), CHI '94, ACM, pp. 152–158.
- [44] NUSMAN, D. Real-time full-body motion capture in virtual worlds. Master's thesis, June 2006.
- [45] OPTITRACK. Optical motion capture system. [Online; accessed 07-October-2017].
- [46] PAAS, F.; RENKL, A. AND SWELLER, J. Cognitive Load Theory and Instructional Design: Recent Developments. *Educational Psychologist* 38 (2003), pp. 1–4.
- [47] PFUSTERSCHMIED, J.; BUCHECKER, M.; KELLER, M.; WAGNER, H.; TAUBE, W. AND MÜLLER, E. Supervised slackline training improves postural stability. *European Journal of Sport Science* 13, 1 (2013), pp. 49–57.
- [48] PFUSTERSCHMIED, J.; STÖGGL, T.; BUCHECKER, M.; LINDINGER, S.; WAGNER, H. AND MÜLLER, E. Effects of 4-week slackline training on lower limb joint motion and muscle activation. *Journal of Science and Medicine in Sport* 16, 6 (2013), pp. 562–566.
- [49] PISAN, Y.; MARIN, J. G. AND NAVARRO, K. F. Improving Lives: Using Microsoft Kinect to Predict the Loss of Balance for Elderly Users Under Cognitive Load. In *Proceedings of the 9th Australasian Conference on Interactive Entertainment: Matters of Life and Death* (2013), IE '13, ACM, pp. 29:1–29:4.

- [50] POMPEU, J.E.; ARDUINI, L.A.; BOTELHO, A.R.; FONSECA, M.B.F.; POMPEU, S.M.A.A.; TORRIANI-PASIN, C. AND DEUTSCH, J.E. Feasibility, safety and outcomes of playing Kinect Adventures!™ for people with Parkinson's disease: a pilot study. *Physiotherapy* 100, 2 (2014), pp. 162–168.
- [51] POMPEU, J. E.; TORRIANI-PASIN, C.; DONÁ, F.; GANANÇA, F. F.; DA SILVA, K. G. AND FERRAZ, H. B. Effect of Kinect Games on Postural Control of Patients with Parkinson's Disease. In *Proceedings of the 3rd 2015 Workshop on ICTs for Improving Patients Rehabilitation Research Techniques* (2015), REHAB '15, ACM, pp. 54–57.
- [52] RILLIEUX-LA PAPE, M. Photograph of a person slacklining in an urban area in Rillieux-la-Pape, 2016.
- [53] RUDELLA, J. L. AND BUTZ, J. V. Exergames: Increasing Physical Activity through Effective Instruction. *Journal of Physical Education, Recreation & Dance* 86, 6 (2015), pp. 8–15.
- [54] RYAN, R. AND DECI, E. Self-determination theory and the facilitation of intrinsic motivation, social development, and well-being. *American Psychologist* 55, 1 (2000), pp. 68–78.
- [55] RYAN, RICHARD M. AND DECI, EDWARD L. Intrinsic and Extrinsic Motivations: Classic Definitions and New Directions. *Contemporary Educational Psychology* 25, 1 (2000), pp. 54–67.
- [56] SCHLÖMER, T.; POPPINGA, B.; HENZE, N. AND BOLL, S. Gesture Recognition with a Wii Controller. In *Proceedings of the 2nd International Conference on Tangible and Embedded Interaction* (2008), TEI '08, ACM, pp. 11–14.
- [57] SCHÖLLHORN, W. Individualität - ein vernachlässigter Parameter? *Leistungssport* 29, 2 (1999), pp. 5–12.
- [58] SINCLAIR, J.; HINGSTON, P. AND MASEK, M. Considerations for the Design of Exergames. In *Proceedings of the 5th International Conference on Computer Graphics and Interactive Techniques in Australia and Southeast Asia* (2007), ACM, pp. 289–295.
- [59] TAICHI, T. Photography of Alexander Schulz walking on a 340m longline for a world record in Mitterbruch, 2012.
- [60] TANAKA, K.; PARKER, J.; BARADOY, G.; SHEEHAN, D.; HOLASH, JOHN R. AND KATZ, L. A comparison of exergaming interfaces for use in rehabilitation programs and research. *Loading* 6, 9 (2012), pp. 69–81.
- [61] TANG, R.; YANG, X.; BATEMAN, S.; JORGE, J. AND TANG, A. Physio@Home: Exploring Visual Guidance and Feedback Techniques for Physiotherapy Exercises. In *Proceedings of the 33rd Annual ACM Conference on Human Factors in Computing Systems* (2015), CHI '15, ACM, pp. 4123–4132.

- [62] THIN, ALASDAIR G. AND POOLE, N. *Dance-Based ExerGaming: User Experience Design Implications for Maximizing Health Benefits Based on Exercise Intensity and Perceived Enjoyment*. Springer Berlin Heidelberg, 2010, pp. 189–199.
- [63] THOMANN, A. Slacklineunterricht im formellen Sport der Schulen und Vereine. *Aktuelle Studien zu Entwicklung und Praxis der Trendsportart Slackline* 28 (2012), pp. 91–100. Deutsche Sporthochschule Köln, Institut für Natursport und Ökologie (INOEK).
- [64] THOMANN, A. *Die Entwicklung der Trendsportart Slackline im urbanen Raum*. PhD thesis, 2017.
- [65] USTINOVA, K. I.; PERKINS, J.; LEONARD, W. A. AND HAUSBECK, C. J. Virtual reality game-based therapy for treatment of postural and co-ordination abnormalities secondary to TBI: A pilot study. *Brain Injury* 28, 4 (2014), pp. 486–495.
- [66] VAN DER SPEK, E. D. COgnition-based DEsign Rules Enhancing Decision-making TRaining In A Game Environment (Code Red Triage): Doctoral Consortium Paper. In *Proceedings of the 28th Annual European Conference on Cognitive Ergonomics* (2010), ECCE '10, ACM, pp. 319–322.
- [67] WINSTEIN, CAROLEE J. AND SCHMIDT, RICHARD A. Reduced frequency of knowledge of results enhances motor skill learning. *Journal of Experimental Psychology: Learning, Memory, and Cognition* 16, 4 (1990), pp. 677–691.
- [68] WOOLFORD, K. Defining Accuracy in the Use of Kinect V2 for Exercise Monitoring. In *Proceedings of the 2nd International Workshop on Movement and Computing* (2015), MOCO '15, ACM, pp. 112–119.
- [69] XBOX, MICROSOFT. Troubleshoot body tracking. [Online; accessed 03-March-2018].
- [70] ZAK, H. *Slackline: Das Praxisbuch*. BLV, 2011.