SAARLAND UNIVERSITY

Faculty of Natural Sciences and Technology I
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Related Work Summary

DRAFT - Interactive technology in slackline training

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Abstract

Combining sport activities with interactive technology is an ongoing and growing trend. With the help of interactive devices, like the Kinect for Windows, applications can be made to 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 -> (sollte man human weg lassen?) trainer. However, this comes with several constraints. The beginner needs to know someone that has fundamental knowledge about slacklining. Further, she is dependent on him and his knowledge. A trainer cannot give constant real time feedback about the all necessary performance parameters of the slacker. An intelligent interactive slackline training system provides independency of any other help and constant real time feedback. Further it can be used to store the progress of specific exercises and train several persons with the same system. A user study was conducted to compare the interactive slackline training system with a personal trainer, as common training method, to show if a learning progress can be measured and whether it can compete against the common training method. The beginner had no prior experience with slacklining or general balance activities.

- results

- conclusion

Contents

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.

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 application with exercises in which the user needs both hands or should not be disturbed by any other device benefited from this (Figure 1.1).

Figure 1.1: Ingame screenshot of the *Nike+ Kinect Training*[1]application. A virtual avatar demonstrates the exercise on the left side. The user can see herself mirorred on the right side of the screen.

[1] `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* [4, 50]. The uprising modern sedentary way of life nowadays, due to working on a compute or watching television, leads to insufficient movement throughout the day. Exergames can bring more contrast into their daily routine when implemented effectively [45]. Several studies showed that such applications can improve the physical activity level, increase the engagement of the user, promote exercises, and provide an enjoyable experience [18, 22, 53]. Further works have shown, that interactive system applications with an exergame approach can improve and train more sport specific skill acquisition, e.g. in trampoline or climbing [3, 9, 24, 25, 28].

Slacklining is a specific sport that relies on the balance of the user. She has to walk over a narrow ribbon that is in general tensed between two static end points and about the height of a the knee. 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 with an expert, that has some knowledge and can support her in this way. However, the trainee must know such an person and is dependent on her.

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

These problems can be conquered by an interactive slackline learning system. At the current stage of this thesis no technology or application is known that 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 her how to stand and walk on 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 due to several indicators. Lastly showing several performance parameters summarize her learning progress of the exercise execution.

1.2 Research Goals

The research goals of this thesis are divided into four parts. First, the exploration of slackline training and the design of interactive tracking technologies. Second, the conceptual design of the actual interactive slackline learning system, further called SLS. Third, implementation details of the system from the view point of an developer. Lastly the investigation of the SLS with slackline beginners in a user study to show if a positive learning effect can be achieved and if it can compete against a common learning method. These parts are further described in the following.

Exploration of slackline training and designing appealing interactive systems

At first the usage of slacklining and its training effects 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 providing an adequate user experience. Several learning methods exist to train beginners on a slackline. Mainly the investigations of Thomann [54] and Kroiß [31] are used to provide an appropriate training method and exercises.

Conceptual design of a prototypical interactive slackline learning system

The conceptual design will be described on the basis of the related work and the slackline exercises. The used tracking technology was not taken into account for the concept. Hence, it provides the possibility to adapt it for other tracking systems. It contains basic interaction design principles, specific basics for the system regarding slacklining, structuring of the exercises, and the feedback system.

Implementation for the usage in a user study

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 payed to the positioning of the slackline related to the Kinect as tracking device and the coherence of the Kinect with the development platform Unity are part of this.

Investigation of the slackline learning 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 confronted with personal trainer. Therefore, the study is divided in two groups in which one group trains with the SLS and the other one 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. Therefore, 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 outlined in the following. As a groundwork the *Related Work* chapter involves 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 *User Interface Design*. Chapter *Introduction into Slacklining and Slacklining Learning Techniques* gives an overview about the sport and how to learn slacklining appropriate with 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 development 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 Outlook* 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. It provides exercises and feedback for beginners on a slackline with the Microsoft Kinect v2 as a tracking device. Hence it is necessary to provide instructive teaching methods for beginners. Therefore, existing approaches and studies have been elaborated 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 regarding slacklining show how to build learning techniques for beginners, the efficacy in balance training, and areas of application. Next, the current tracking technologies have to be compared for tracking the human body on the slackline and 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 what exercises and tips are useful for very 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 can then be implemented in the assistance system. 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. [12] found in his meta-analysis significant improvements in the postural control after slackline training, which indicates the efficacy of this training method. 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 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 [54] differentiate two basic methods for the learning process on a slackline. Teaching a slackline beginner, further called slacker, without any help or with systematic external assistance. The investigation of Kroiß [31] resulted in no significant difference between both methods. But 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 (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, stretching out the arm, raising the hands over the shoulder level, turning the palms to the top, going slightly in the knees, have the feet straight with the line, and so on [30, 31].

(a) Stick support (b) Between bars (c) Human support

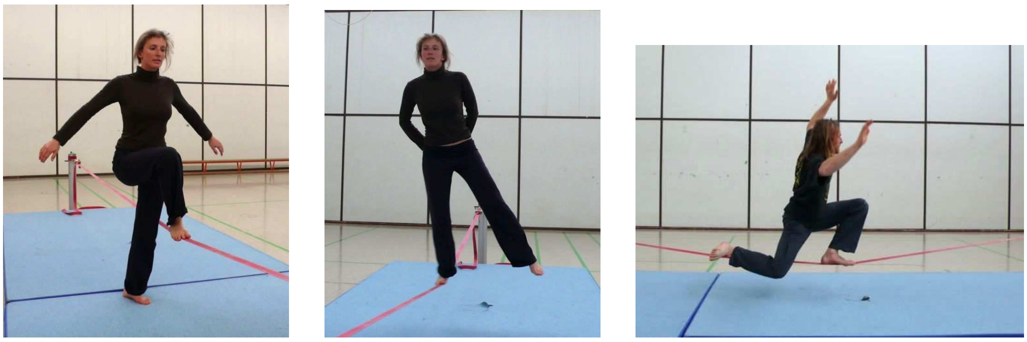
Figure 2.1: Supportive exercises [31]

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 (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.

(a) Basic start (b) One feet (c) Both feet

Figure 2.2: Basic exercises [31]

Advanced training should be practiced in a more dynamical way [54]. Like seen in several research works [10, 11, 19, 29, 40] this can be from crossover start (Figure 2.3a), turning on the line, hands on hips or behind the back (Figure 2.3b), walk sidewards or backwards up to catch and pass a pall, kicking a football, bouncing a basketball, or a kneel down on the slackline (Figure 2.3c).



(a) Crossover start (b) Hands behind back (c) Dropknee

Figure 2.3: Advanced techniques [31]

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 [29, 40, 41]. 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 [31].

The slacklining assistance system should mainly train and support slacker 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 an inspiration for supporting them with effective and efficient methods. Now is the question, what effect has slackline on the human body and where can it be applied? This is part of the next subsection.

2.1.2 Slackline Specific Training Effects and Application Scenarios

Donath et al. [10] 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. But 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 an effective training method.

A further study of Donath et al. [11] 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. [29] 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. [40] 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. [41] 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. [19] 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 [40]. 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 won't interrupt her. The Microsoft Kinect v2 seems like a suitable tracking system in this context, because the user don't need any further devices to be tracked. But it should be compared with other tracking technologies like the Nintendo Wii, Playstation Move, and motion capture systems, to justify its usage. In the following advantages and drawbacks of these systems will be discussed. Further several studies show how accurate and precise the Microsoft Kinect v2 is, if it can be applied for balancing purposes, give the user appropriate feedback, or useful analysis data for specialist like therapist.

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 [3, 51]. Gesture recognition is an essential aspect of the slacklining assistance system for giving appropriate feedback regarding the executed exercise. Schlömer et al. [48] 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 sonsists of an RGB camera called Move Eye that is used for tracking the 3D position of a lighting 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 [3, 51].

Both systems are good devices if the controller itself can be replicated as a virtual device like for example in golf or tennis. But 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* [35] or *OptiTrack* [38], markers have to be attached on the user's body for tracking her body motion and rotational data. This makes it the best device 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 [3, 5, 37]. This makes it an inappropriate device for user tracking on a slackline.

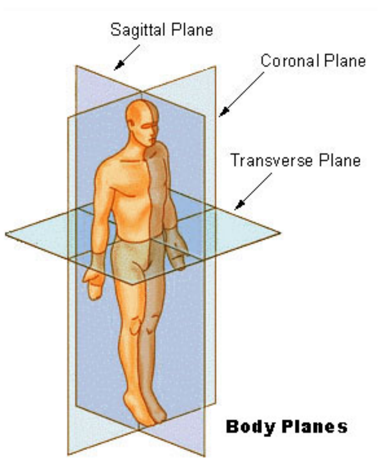
The Microsoft Kinect is a static device that includes a RGB camera and depth sensor. Because the body joints and player position are recognised by these, the user is free in her movement without any further controller. Another advantage is the low price in comparison to the motion control suite, and 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 [27, 52]. To the user they can be hidden, e.g. by only showing the output of the depth cam [24]. This problem can also occur in the slacklining case because of overlaying feet. Therefore a technical feasibility has to be 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 makes it the best system out of the stated devices.

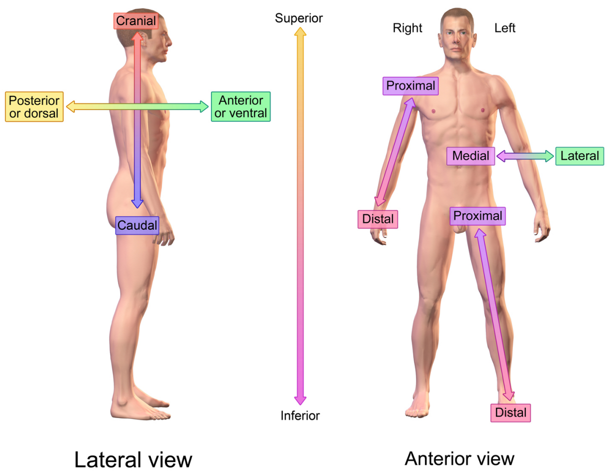
2.2.2 Accuracy of the Microsoft Kinect

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. [33] 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 (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) (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 (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) Body Planes



(b) Directional References (modified)

Figure 2.4: Anatomical terms of location [58]

Chang et al. [5] 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 performance comparison shows that the OptiTrack system is negligible faster than the Kinect.

Woolford [66] 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 (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.

(a) Inaccurate and imprecise system generates random-like measurements

(b) Inaccurate but precise system, where measurements are close to each other but have systematic error

(c) Accurate and precise system generates measurements that are close to the real world

(d) Accurate and suffice precise system generates measurements that are close to each other and are not systematically biased

Figure 2.5: Definition of accuracy and precision [66]

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. [5] 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 [66] 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. [33] 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. [56] 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. [42] 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. [43, 44]. The results affirm that the patients improve in balance purposes and motoric movements with this help.

Furthermore Estapa et al. [13] and Freitas et al. [15] 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. [17] 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. [39] describes that the acquisition of new skills is in conjunction with cognitive load. By adjusting this the learning effect can be easened 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 the him 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 [57] evaluated how to deal with the right complexity in serious games. He describes in his mental model construction (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 him. Since a serious game like approach should be developed this is an important reference for building an effective learning process to the user.

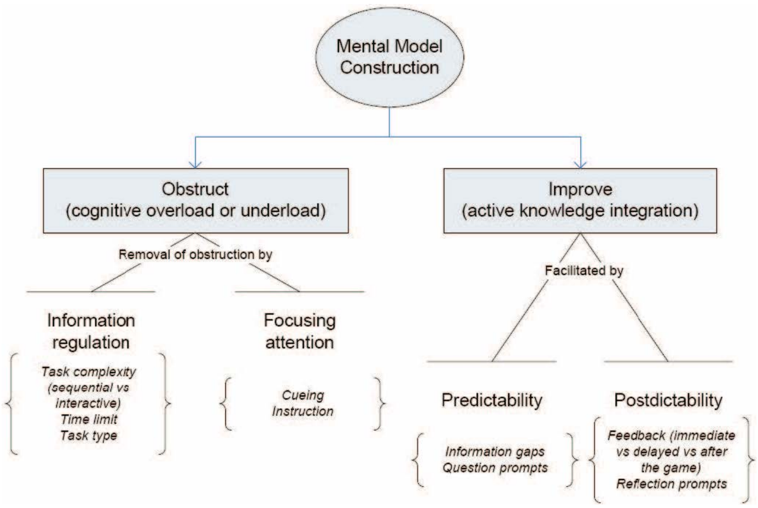


Figure 2.6: Guideline for enhancing the cognitive load [57]

Pisan et al. [42] 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 extend himself the user must have the willingness and commitment for practicing, which can be described as motivation. The self-determination theory by Ryan et al. [46, 47] 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. [26] stated regarding rehabilitation training that if exercises and the user himself 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. [42] 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. [56] 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. [15] 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. [13] 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 [27] 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. [32] 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 [7]. For example in balance training a warning signal can indicate that the current pose is not the desired one. If the user corrects his 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 [23, 65]. Therefore it should be easy to understand for enhancing the learning process.

Hämäläinen [21] 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. [24] 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 [27] 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. [28] 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.

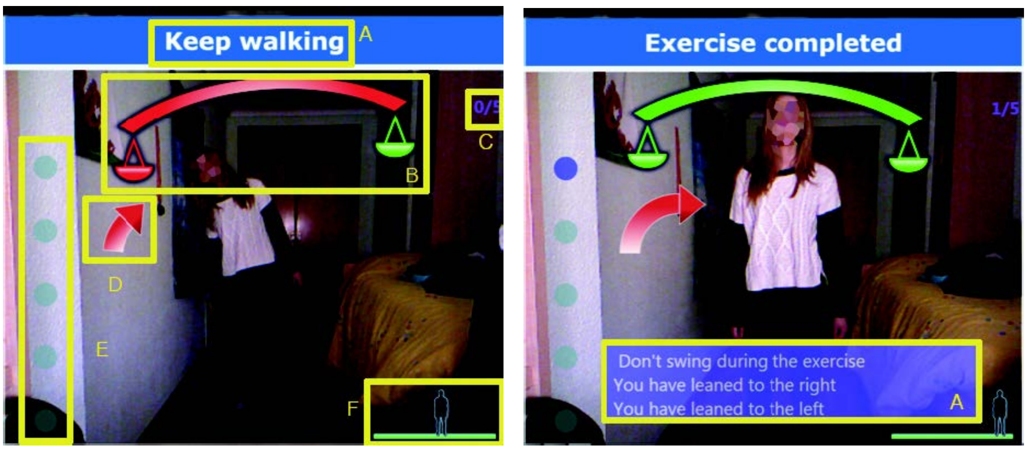
Like seen a delayed video feedback is a good approach to learn new skills. Combining this with a gaming approach can simultaneously lead to a joyful experience with training aspects. Also adding audio signals can further improve this experience for the user as well as for spectators. A well suited interaction 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 with 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 sorrounds her focus point. Directing her for 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. [17] 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 (Figure 2.7b).



(a) Surrounding elements in the interface (b) Completed exercise feedback summary

Figure 2.7: Interface of a rehabilitation training application [17]

Another method is to show the user itself or an avatar that demonstrates the correct performance of the current exercises like in Figure 2.8 and 2.9. Holsti et al. [24] implemented such a user integration and in user testing they endorse to see themself performing in real time.

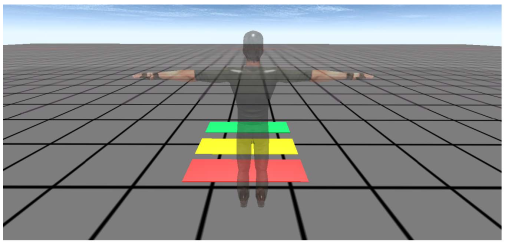


Figure 2.8: 3D Model as avatar [13]

Figure 2.9: Rail-time user representation [24]

The task about the execution has to be clarified. Chang et al. [5] provides real time feedback on the performance quality due to a visualised path. If the performance is correct the path will turn green. But if she moves outside the range the path turns red and an arrows guides him into the correct position. Instructions and highlighting objects can help to complete an exercise successfully (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 [5]

2.4.2 Kinect for Windows - Human Interface Guidelines

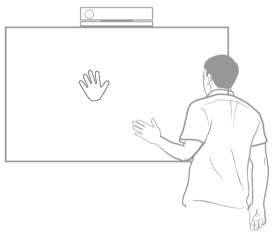
Microsoft itself offers Human-Interface-Guidelines (HIG) for developer and designer that describes several techniques of certain areas for developing a kinect application [7]. It provides a quick introduction into the Kinect itself, design principles for interactions regarding gesture and voice, techniques 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

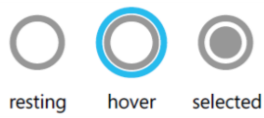
Context-awareness delivers the best user experience, e.g. controls should be placed where user would expect them to be and interactions should be appropriate for the environment. It is important that the user feel confident. This can be achieved by designing interactions simple and easy to learn. User 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

Giving the user constant feedback helps her to know what is happening. In general appropriate feedback should show if the sensor is ready, she is visible and engaging with the Kinect, and so on (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 (Figure 2.11b).



(a) Hand cursor visualizes the engagement and readiness of the system



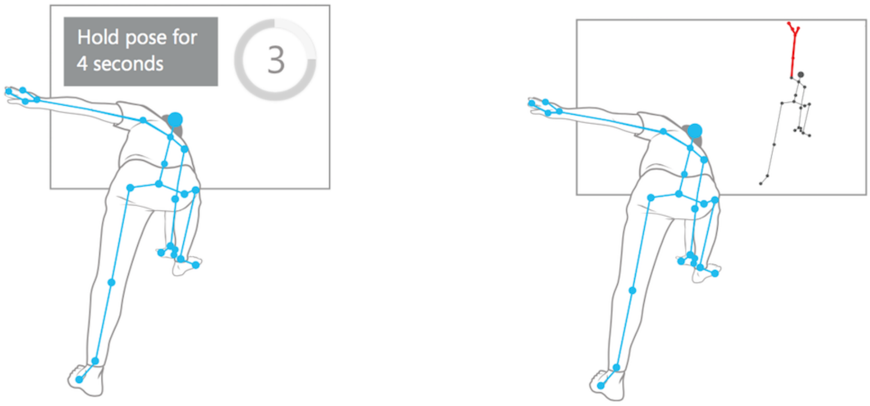
(b) Different states of UI controls

Figure 2.11: Feedback methods [7]

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 (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 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



(a) Repetition and time length indicators

(b) Avatar that shows correct movement and wrong body parts are highlighted

Figure 2.12: Feedback indicator and movement visualization as an avatar [7]

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.

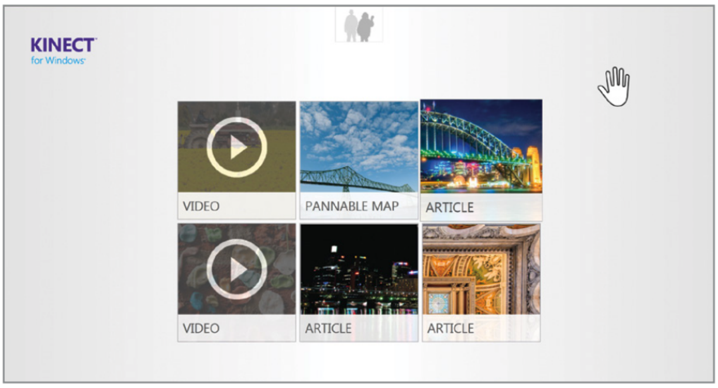


Figure 2.13: User Viewer on top [7]

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 (Figure 2.14). Also biliteral interaction support should be applied to cover both possibilities for left- and right-handed people.

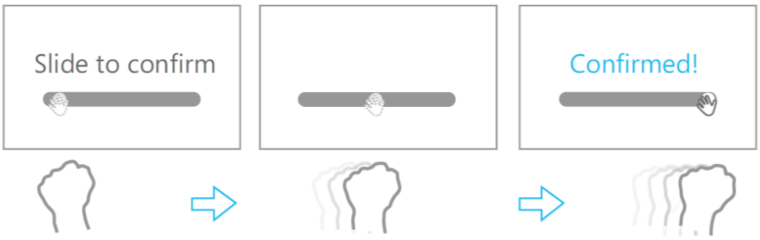


Figure 2.14: Direct manipulation of a slider with intuitive interaction [7]

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. (Figure 2.15).

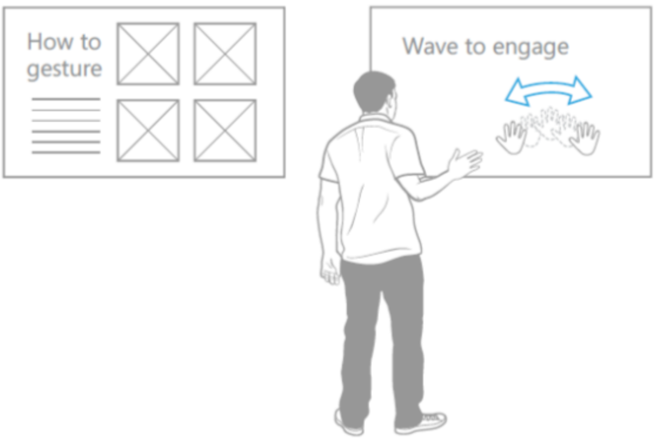


Figure 2.15: Teaching new gestures [7]

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 like seen in figure 2.16 to have a better understanding.

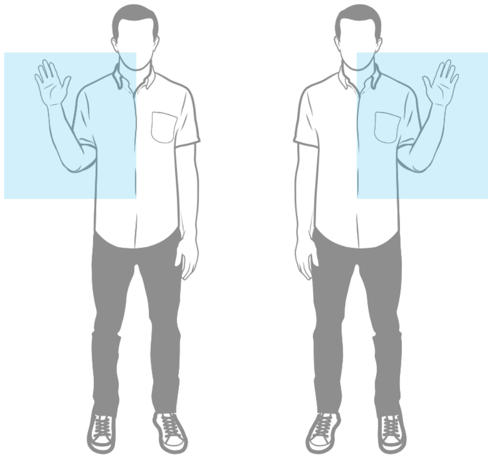


Figure 2.16: Physical interaction zone [7]

Summarizing the user interface should not distract the slacker but support him. 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 [68, 1, 34].

Hence slacklining comes from the climbing sport and can be compared with ropedancing in a broader sense [30]. 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 [30]. 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 [31]. 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 [30, 34, 55]. Regarding the height of the slackline fixation one can differentiate between a *lowline* (Figure 3.1a) and a *highline* (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 seperate rope above or under the regular line in which the person can hook herself into [30]. Hence, the majority of the lines are categorised as a lowline.

(a) Common lowline

(b) Highline between mountains [60]

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* (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* (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* (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 [62]

(b) Backflip on a jumpline [30]

(c) Rodeoline [61]

(d) Longline [59]

Figure 3.2: Slackline variations

(a) Waterlining over a river [64]

(b) Urbanlining in the city [63]

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 felt 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 [54] 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 [14]. Größing [20] 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 [54] 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 (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.

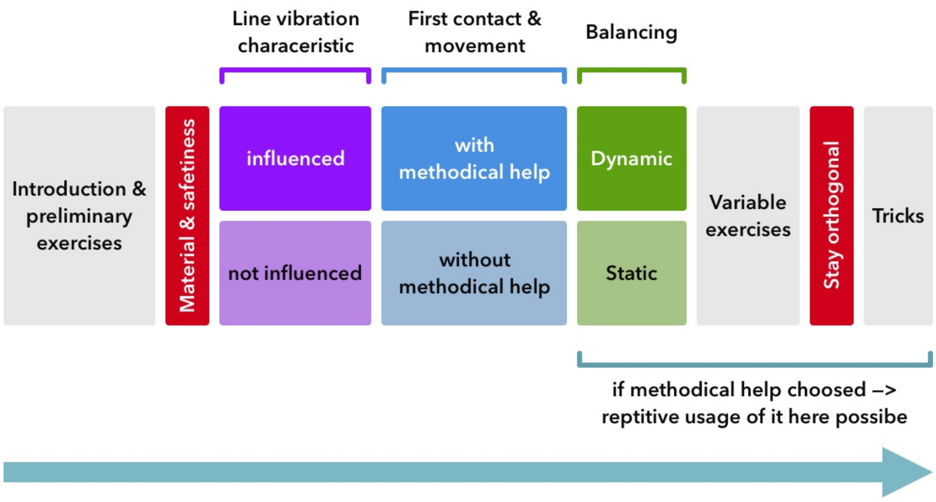


Figure 3.4: Methodical routine [54]

Differential method

The differential or dynamic method follows another approach. It is in coherence with an open learning situation [54]. 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 [2, 49]. 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.

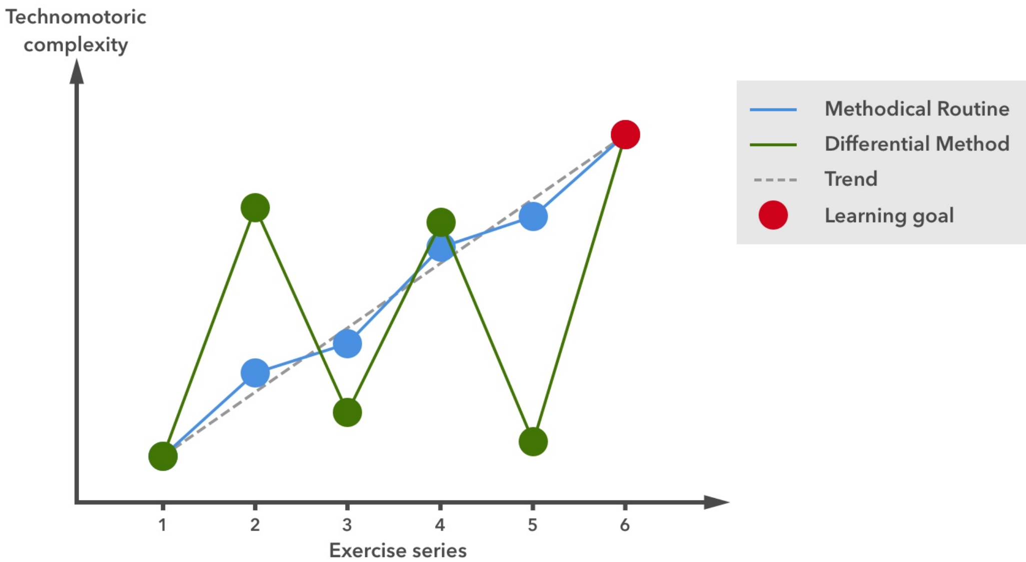


Figure 3.5: Comparison methodical routine vs. differential method [54]

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 [54] (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 venturesome, 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.

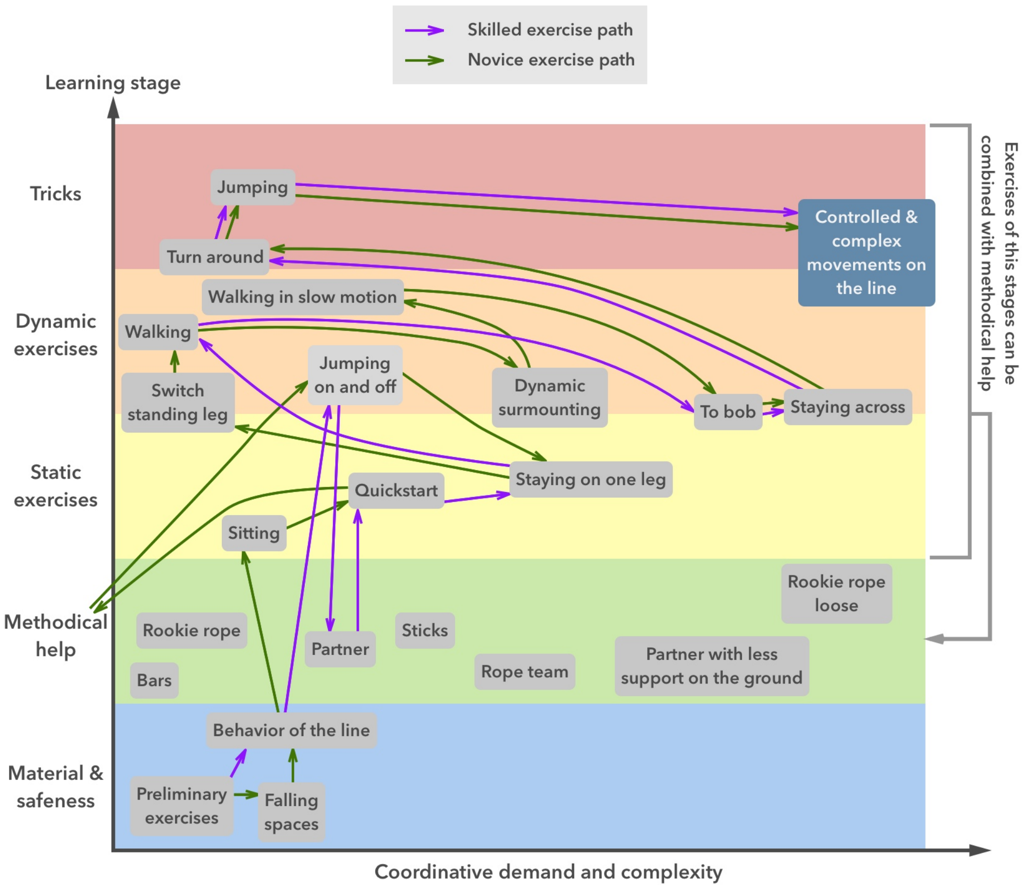


Figure 3.6: Dynamic methodic in slacklining [54]

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 [31]. 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 [31] defined a useful execise 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 [1, 10, 11, 19, 29, 30, 40, 54] 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 flater ribbon. It is a sport that claims a certain amount of balancing skills. Therefore, two learning techniques have been discussed for skill acquisition, which are 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 designed that fit in this routine and train beginners appropriately.

Chapter 4
Concept

This chapter describes the conceptual analysis 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 controlling device or external support like human help. Therefore, the SLS can only be controlled by the currently interacting user. Further, it responds appropriately to the actions of the user and provides several real-time feedback indicators to support her during the exercise execution.

In the following conceptual analysis will be elaborated. 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 be easy to learn, understand, and interact with. Appropriate user experience helps to achieve these characteristics. Usability heuristics are useful to identify or prevent problems in a system. Therefore the SLS will acknowledge the interaction design principles by Nielsen [36] described in section *Ten Heuristic Principles for Interaction Design*. Beside this, certain tasks have to be considered that are more related to this system. 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 [36]. 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. 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.

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.

User Control and Freedom
If the user clicks accidently on something she should be able to leave this state without any troubles.

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.

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.

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.

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.

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

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.

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.

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 her 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

The interaction can be seen as a bigger part of the system 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 input for the interaction. 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 (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.

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

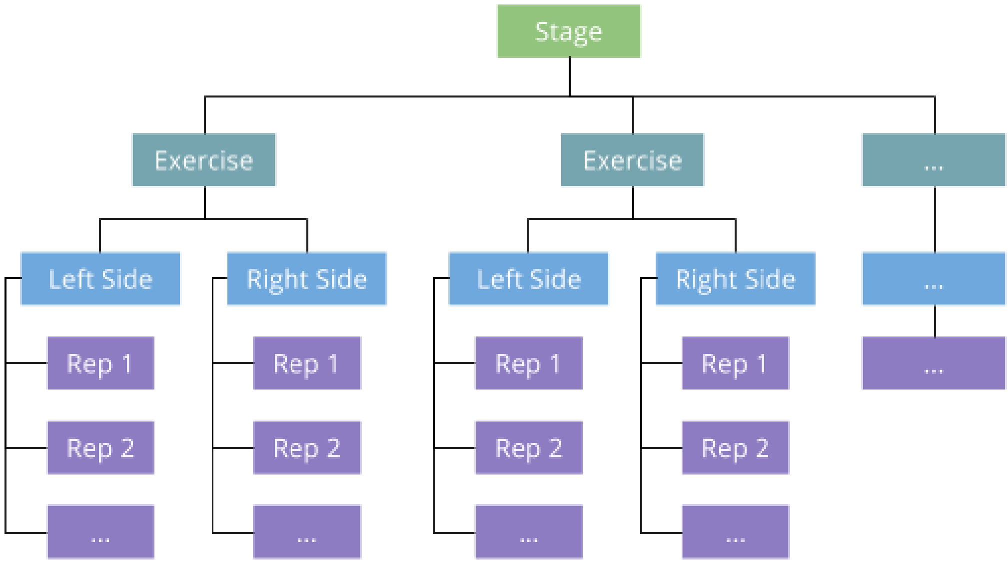


Figure 4.1: Exercise structure

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 [23, 32, 65]. 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*[2] or *Nike +*[3]. 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, 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 Conclusion

The interactive slackline learning system should be able to teach and support users how to slackline with predefined exercises. For proper realization the SLS

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

[3] https://news.nike.com/news/introducing-nike-kinect-training

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 for persons on a slackline. 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, as well as each application component based 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. An overview can be seen in Figure 5.1.

Since the focus of this thesis lies mainly on beginners the mobile slackline device *alpidex POWER-WAVE 2.0*[4] is used. It provides the needed mobility and indepen-

[4] `http://www.alpidex.com/fitness/slacklines/slackline-gestell-in-2-laengen-power-wave-2-0-inklusive-slackline/a-10288/`

dency 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* [5] served as development PC that fulfilled the recommended specs of the Kinect: *Windows 8, 4 GB Memory, Physical dual-core processor with 3.1 GHz or faster, USB 3.0 Gen-2 controller, DirectX 11 Graphics card*. 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.

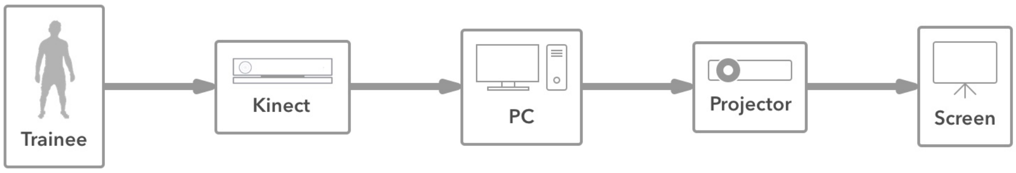


Figure 5.1: System overview

5.1.2 Kinect and Slackline positioning

Tracking a person on a slackline with the Kinect is very different from a common situation. 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 in horizontal 70 degrees and in vertical 60 degrees (Figure 5.2a). 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 up to 4 meters (Figure 5.2b) [7]. The mobile slackline device used in this thesis has a length of three meters and fits theoretically entirely within the sweet spot.

[5] Technical details of the STEAM® MACHINE: Intel Core i5-6400T @ 2.2 GHz, NVIDIA GeForce® GTX 960, 8 GB RAM

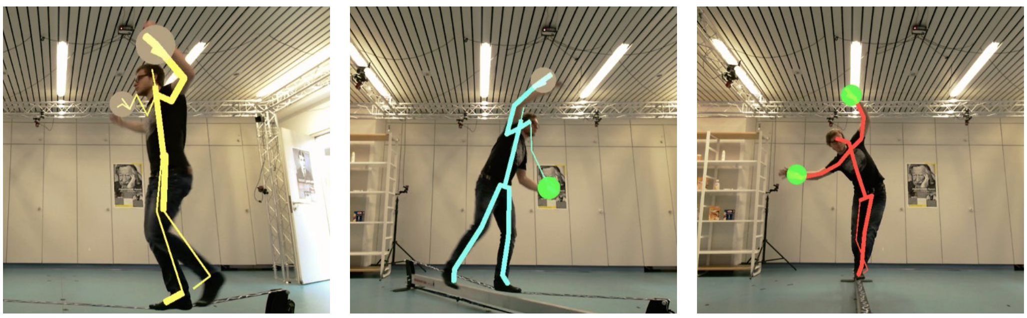
(a) Angle of vision (b) Kinect tracking range

Figure 5.2: Limitations of the Kinect v2 sensor [7]

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 (Figure 5.3a). 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 (Figure 5.3b). 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 (Figure 5.3c). Because of this the slackline must be arranged, such that the starting position of the line lies within the sweet spot area.

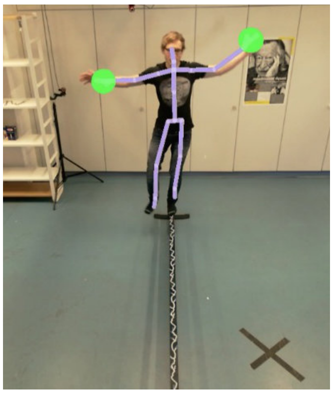


(a) Sideways (b) Diagonal (c) Vertical

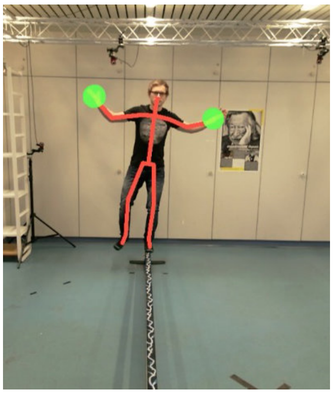
Figure 5.3: Different positions of the slackline. The coloured lines visualise the skeletal tracking of the Kinect. Thin lines represents inferred joints

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 (Figure 5.4a). 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 (Figure 5.4b). 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 (Figure 5.4c). 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 slacker during her training on the slackline, e.g. by setting a focus point in front of her.



(a) Kinect height of 2.40 m



(b) Kinect height of 1.60 m

(c) Kinect height of 0.80 m

Figure 5.4: Kinect view on different heights. The coloured lines visualises skeletal tracking.

The best combination resulted in placing the slackline vertical 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 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 is more human-readable and makes accessing as well as updating data simple. Each user should have the same basis of exercises. A default exercise JSON file serves as template for all registered users in the SLS. An internal editor was created to make data management and adjustments more easy. Figure 5.5 shows the overall data structure.

A user data file 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 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 consists of a name and a thumbnail picture that is shown in the menu. A description and a looping video of the correct execution are provided in the introduction. 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.

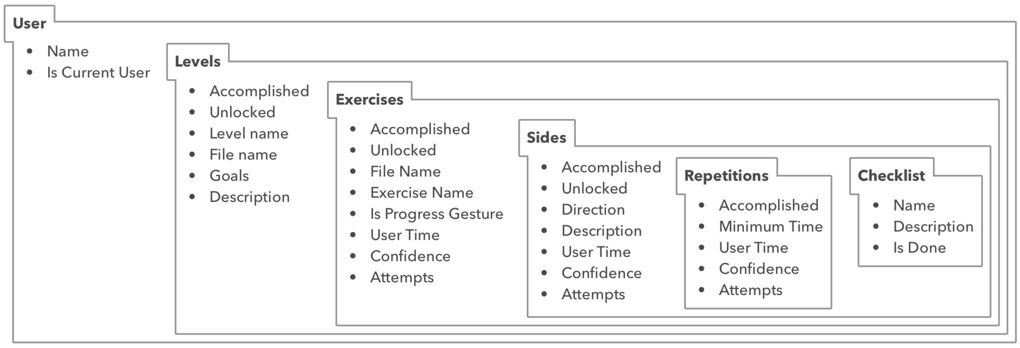


Figure 5.5: Data model overview

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.*" [7].

5.3.1 Heuristics vs. Visual Gesture Builder

The Kinect SDK provides two approaches for tracking a gesture in an application [8]. 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 (Figure 5.6). 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 validates 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 persons 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.

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 in the application to detect gestures in runtime.

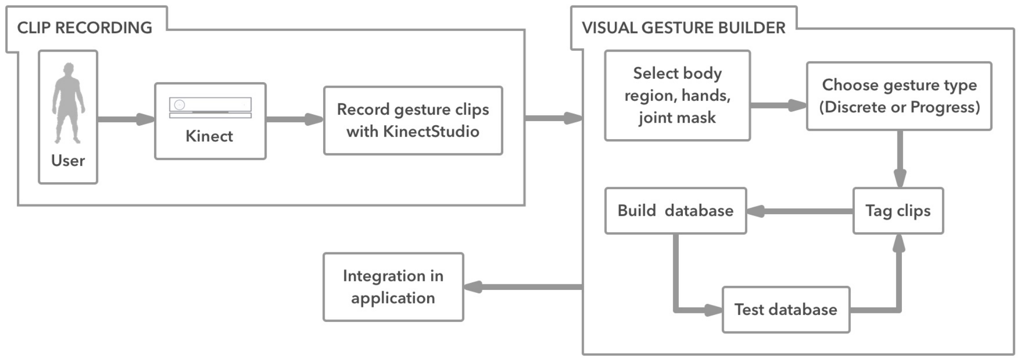


Figure 5.6: Workflow of creating a gesture database

5.4 Frontend

5.4.1 Unity3D and Kinect SDK

The software development process consists of the interplay of two major software components (Figure 5.7). 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.

As second component the *Microsoft Kinect SDK v2.0* [6] 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*[6] to create a Kinect based Unity application. The *Kinect v2 Examples with MS-SDK* [7] package by Rumen Filkov was used to get an idea on how to handle the data

[6]https://developer.microsoft.com/de-de/windows/kinect/tools
[7]https://www.assetstore.unity3d.com/en/#!/content/18708

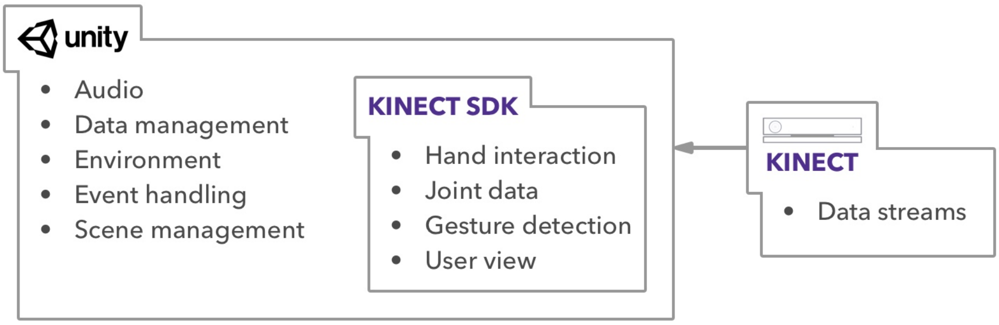


Figure 5.7: Unity and Kinect architecture

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.

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

If a user starts with the SLS (Figure 5.8a) 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 (Figure 5.8b & 5.8c). 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 5.8: 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 (Figure 5.9a). 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 (Figure 5.9b). 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 the middle finger. The click event triggers when the user releases her hand into the default state (Figure 5.9c). 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 (Figure 5.9d). 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.

(a) Hover and wait (b) Grab/Fist (c) Pointing (d) Pushing hand

Figure 5.9: Several tested hand interaction techniques

When finished with the interaction techniques the user is introduced on how to stand in the right starting position (Figure 5.10). 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.

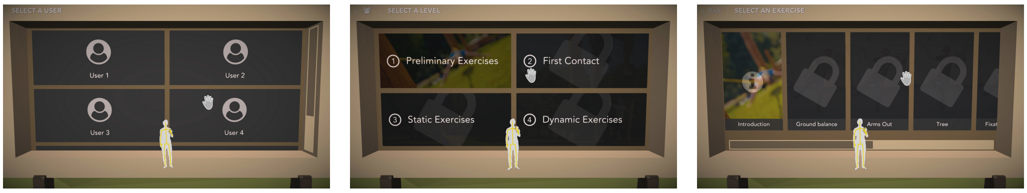
Figure 5.10: Instruction on how to use stand in the correct position

Selection Menus

The system consists of several selection menus. At first a user profile has to be selected (Figure 5.11a). 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 menu (Figure 5.11b & 5.11c). 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 for the exercise. Hereby, the next exercise can be unlocked by accomplishing all body sides and repetitions of the current exercise.



(a) User menu (b) Level menu (c) Exercise menu

Figure 5.11: Visualisation of selection menus

Level and Exercise Description

Selecting a level leads the user to the level introduction (Figure 5.12a). 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 (Figure 5.12b). This leads her to the detailed exercise description (Figure 5.12c). 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.

(a) Goals & tips for a level (b) Selection of a body side (c) Instruction into an exercise

Figure 5.12: Instruction screens for a level and an exercises

Exercise Execution

The exercise execution consists of the biggest functionality implementation (Figure 5.13a). 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 (Figure 5.13b). 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 (Figure 5.13c).

(a) Exercise execution

(b) Exercise summary

(c) Level summary

Figure 5.13: Exercise execution and summary screens

Chapter 6
Study

This chapter describes the conducted study in detail. At first, the idea of the study is introduced and its hypothesis as well as the purpose clarified in section *Introduction and Goals*. 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 elaborated reported in section *Results and Analysis*. At last, these results are discussed in section *Discussion*. The conducted study has its main purpose to test whether the SLS can This chapter describes the idea and procedure of the conducted study in detail.

6.1 Introduction and Goals

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

Like stated in Section section a personal human trainer is the common way of learning slacklining. Therefore, the SLS is compared against this method to show if it can show similar results and compete with it. It is a *think aloud* study, which means the participant shares her thoughts, informs the study leader about the way she thinks when making an action, and where she has problems.

Several research goals arise that are analysed and discussed, which are the following:

- The SLS supports the participant in learning slacklining and during the execution
- The SLS has some statistically relevant influence to the learning progress of beginners on a slackline
- It motivates the user in learning new skills and techniques for slacklining
- The system is usable for learning new skills in the field of sport slacklining
- The SLS can compete with a personal human trainer, as common training method for teaching beginners on a slackline
- The SLS shows similar effects of learning progress of beginner so a slackline as a human trainer
- The structure of the exercises provided by the system are challenging, ascending in its difficulty, and show positive effects in the learning progress
- 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 the saarland university and randomly assigned to either an interactive system group (ISG) or a human trainer group (HTG). Among them eight were males and four females.

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 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 [6]. All participants had moderate to strong preference to the right leg (Figure X). The physical activity level was determined with the *Physical Activity, Exercise and Sport Questionnaire (Bewegungs- und Sportaktivität Fragebogen - BSA-F)* by Fuchs et. al [16]. 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 muskuloskeletal 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 are 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

Each participant is 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 the user 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 further tells on which actions she is troubling with and when there is any confusion or misunderstanding with the system implementation. The experiment leader had no influence about questions regarding the exercise execution to ensure the autonomy of the user with the system.

Human Trainer Group (HTG)

The participant is instructed by a human trainer, which is the director of the study. 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.

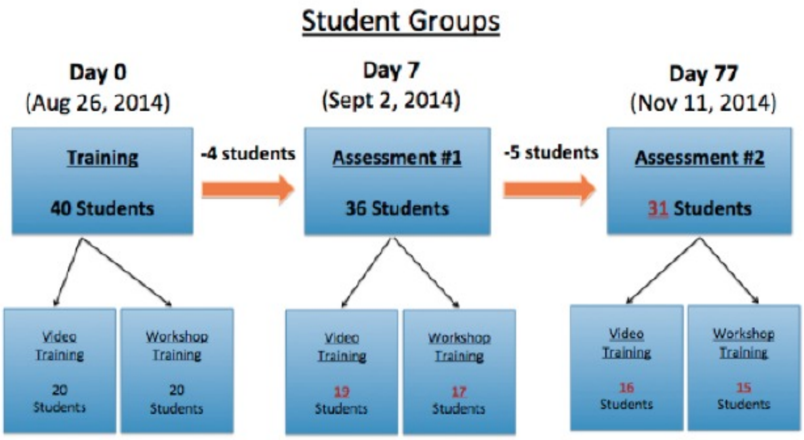


Figure 6.1: Study groups example

6.3.2 Procedure

At first the participant was welcomed and briefed about the idea 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. 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 like stated above.

At first the general balance ability of the participant was obtained before 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 has no problems with holding her own balance on a stable as well as on a uneven underground.

as few steps as possible to have a comparison 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 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.

After finishing the pre-measurements the participant was again shortly introduced about the ongoing procedure. For all exercises she had to stay on a marked position at 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).

After finishing 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 Appendix.

Apparatus

Figure [figure] 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]

6.3.3 Design and independent & dependent variables

The experiment of the study is a 2 x 2 mixed factorial design, more specifically a 2 levels of group (group: ISG, HTG) x 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
- As many steps as possible on the line
- Walking as far as possible 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 (group: ISG and HTG) x 2 (time: PRE and POST) mixed-design repeated measures analysis of variance (rANOVAs) was performed. To match the requirements of the rANOVA 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 rANOVA 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 (η_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,1 to present the results in a uniform manner. All analyses were performed using SPSS Statistics version 25.

In the following the the requirements and the test results of the mixed rANOVA testing will be reported for each condition separately as well as for the left and right leg.

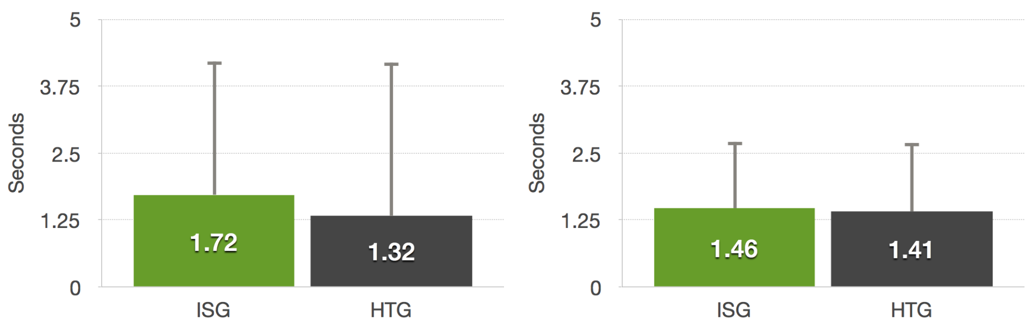
6.4.1 Single Leg Stance Performance

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 $\eta_p^2 = 0.000$. 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 $\eta_p^2 = 0.001$.



(a) Improvement on Standing with Left Leg (b) Improvement on Standing with Right Leg

Figure 6.2: Single Leg Stance Improvement

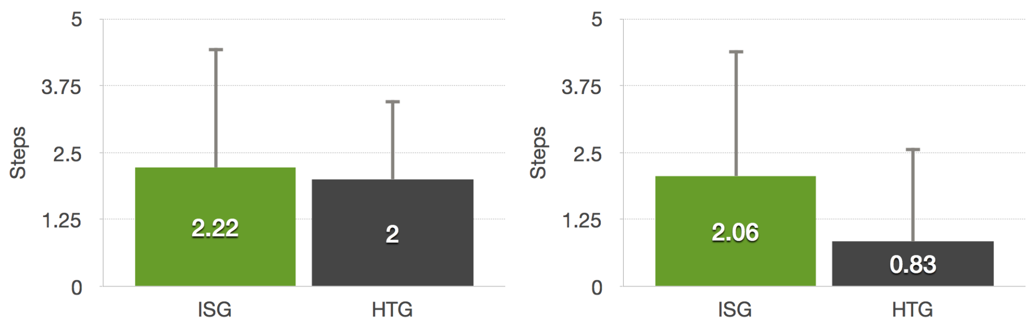
6.4.2 Walked Steps Performance

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 $\eta_p^2 = 0.094$). 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 $\eta_p^2 = 0.034$).



(a) Improvement on Steps with Left Starting Leg (b) Improvement on Steps with Right Starting Leg

Figure 6.3: Walked Steps Improvement

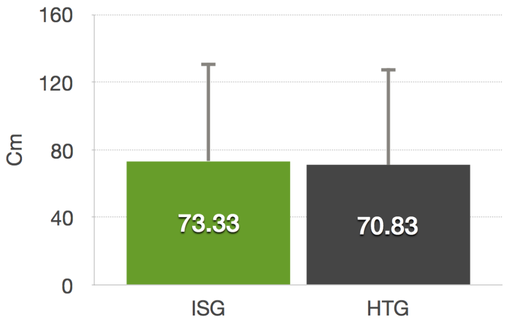
6.4.3 Walked Distance Performance

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 ($p = 0.193$).

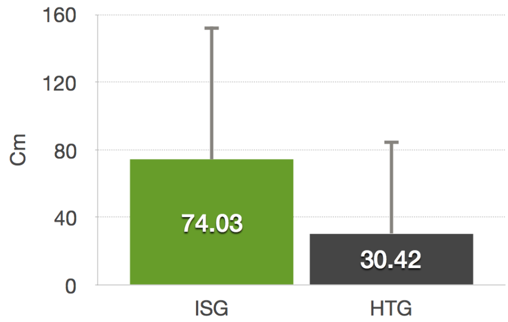
There was no statistically significant interaction effect between time and group, for the left ($F(1.0, 10.0) = 0.006$, p = 0.942, partial $\eta_p^2 = 0.001$) as well as for the right leg ($F(1.0, 10.0) = 1.235$, p = 0.292, partial $\eta_p^2 = 0.110$). Since no statistical significant interaction effect 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 η_p^2 = 0.650) and also for the right leg (F(1.0, 10.0) = 7.082, p = 0.024, partial η_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 η_p^2 = 0.038) and right leg (F(1.0, 10.0) = 0.145, p = 0.711, partial η_p^2 = 0.014).



(a) Improvement on Distance with Left Starting Leg



(b) Improvement on Distance with Right Starting Leg

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	η_p^2	Time	η_p^2	Group	η_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	**p = 0.003**	**0.609**	p = 0.931	0.001
Steps Left	p = 0.838	0.004	**p = 0.003**	**0.613**	p = 0.406	0.070
Steps Right	p = 0.332	0.037	**p = 0.037**	**0.367**	p = 0.567	0.034
Distance Left (cm)	p = 0.942	0.001	**p = 0.002**	**0.650**	p = 0.542	0.038
Distance Right (cm)	p = 0.292	0.110	**p = 0.024**	**0.415**	p = 0.711	0.014

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. This means that no group is better or worse than the other in any measurements. Therefore the hypothesis that the interactive system shows better results than a human trainer cannot be proven with a statistically significant. Looking at the figures of the improvements for the group in each measurement 6.2, 6.3, and 6.5, no real difference can be seen between the groups. The ISG group is at the most 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 (figure 6.3b) and walked distance measurements (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 large, so that it is also not sufficient to have a certain significance.

Since all significance values are larger 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 further training over a longer time range 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. Since the training lasted minimum one hour, the measurement results after the training could have been affected by the exhaustion of the participants and therefore not showing there real improvement.

Lastly, there was no distinction in general balance skill of the participants. Subjects were chosen if they had no intermediate slackline experience (i.d. tried slacklining at most two times) 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, because participants improved differently after the training respectively to their pre measurement. This means that subjects show different general balance characteristics. 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.

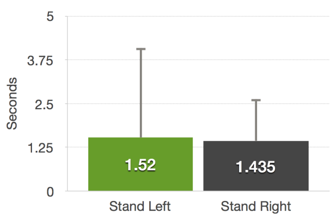
However a trend can be observed, that the ISG improved slightly better in numerical average than the HTG. This could be the case, because the system's gesture recognition is less tolerant about the exercise execution than a human trainer Whereas a trainer is more tolerant about the users exercise execution,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

Time effects

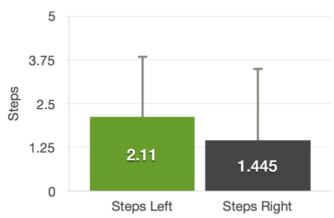
The time effect seen in table 6.3 in the column *Time* shows whether it differs significantly from pre to post measurement, without considering any group. This means the time effect is observed for all participants as one entity, like no group would exist. The results state for all measurement conditions a significant improvement, unless for stand left. With this it is proven that the used training exercises by both groups are useful and have an effect on the improvement of the participant.

The standing 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 less trained legs or participants won't show an improvement as good as participants or legs that have 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.

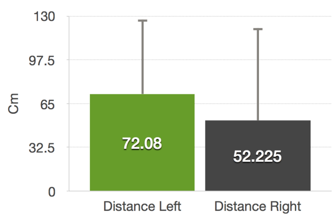
In reverse the right leg shows significant results. For all participants their right leg was the primary leg. The general balance skill for this leg is given through everyday physical effort and therefore it shows more stable data for balance improvements.



(a) Improvement on Distance with Left Starting Leg



(b) Improvement on Distance with Right Starting Leg

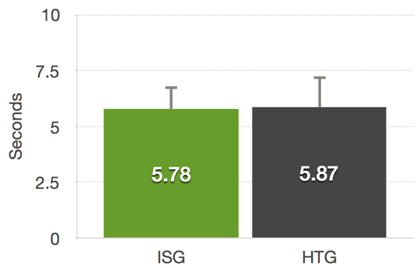


(c) Improvement on Distance with Right Starting Leg

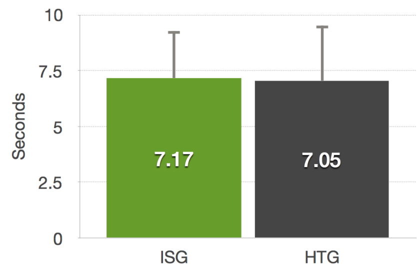
Figure 6.5: Walked Distance Improvement

Group effect

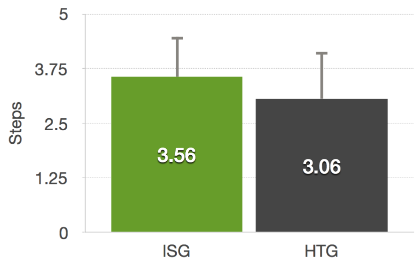
The main effect for the group is analogue to the previous main effect of the time. With this, the differences between groups can be calculated, without considering the time. Looking at table 6.3 in column *Group*, no significant effect can be seen. This means no group differs from each other. The diagrams in figure 6.6 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.



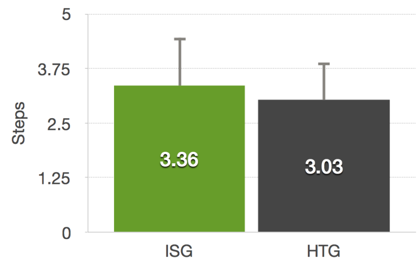
(a) Stand Left Results



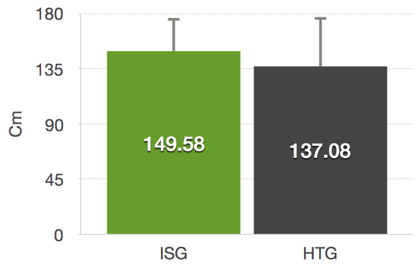
(b) Stand Right Results



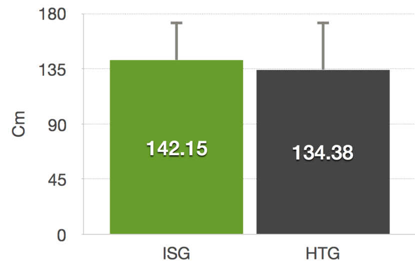
(c) Steps Left Results



(d) Steps Right Results



(e) Distance Left Results



(f) Distance Right Results

Figure 6.6: Scores for comparing the main effects of the group

Slackline Training Observations

During the training some observations have been made that would be useful to consider for further practice with the interactive slackline system.

A participant showed up with black pants, which resulted into problems with the Kinect tracking recognition. This is because some black clothing absorb the infrared light of the Kinect, which makes the trackability more difficult [67]. It would be helpful to indicate participants to not wear any black clothes.

Concerning the exercises there were problems with tracking the participants while sitting on the slackline (Figure Figure exercise). Five out of six participants had problems with this exercise. Almost all participants out of both groups noted that the sitting exercises are very uncomfortable. Because of the way the problem exist, this exercise should be eliminated from the exercise list or replaced with exercises to train going up on the slackline. Like seen in figure Figure exercise the leg of the participant was mistaken with the slackline by the Kinect.

The very last exercise resulted also in tracking problems with four out of six participants (Figure figure). Here they had to walk two steps forward on the slackline. A general problem was the up going on the slackline. If the leg was too close to the line while going up, the Kinect did not tracked it appropriately. Both problems could be fixed by tracking the gestures with more persons that execute different variations of a correct exercise execution.

Three participants in the ISG had especially problems with scrolling the exercise list at the beginning because they didn't know how to interact with it. Adding an introduction on how to scroll a list in the system could be helpful.

Subjects Rating of exercise difficulty

Participants were asked to rate 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 6.7 shows the ratings of each exercise (blue line) as well as a trendline, which is a linear interpolation of the values (green line).

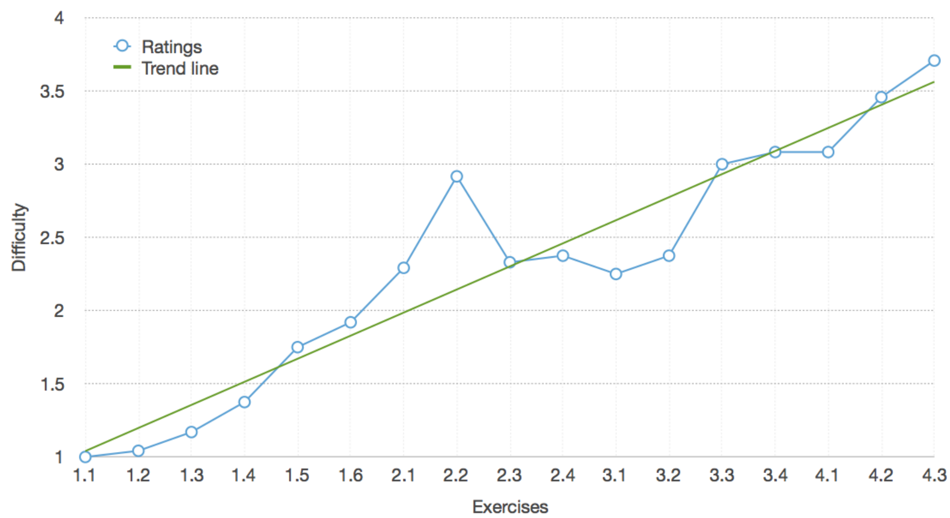


Figure 6.7: Study groups example

The exercises of the first level follow a smooth increase in difficulty, which matches also the idea of strengthen the general balance skill of the participants and preparing them for standing on a slackline. For the second level there is a massive increase in difficulty for the first two exercises. This corresponds also with the observations in section *Slackline Training Observations*, where participants claimed that the exercise is very uncomfortable or too difficult for them. Exercises 2.3, 2.4, 3.1, and 3.2 show similar ratings. This is because they are all very similar exercises, in which the participant learned to go up on the line. However the time was increased for exercise 3.1 and 3.2. Some participants noted that they felt more secure to stand longer on the slackline after doing the short-time exercises.

The ratings follow a linear ongoing trend and therefore verify the appropriate integration of exercises as an entire training model for beginners on a slackline.

Semi-structured Interview

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

Participant 3 (ISG) mentioned further *"[...] 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 for giving more specific advises that 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, whereas in the HTG participant 10 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.

On the other hand they 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 mentioend further *"I liked the user view because you can see how you act by yourself. Also I can use the system without any further help"*

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

Chapter 7
Conclusion and Outlook

Bibliography

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