Slackliner – An Interactive Slackline Training Assistant

Felix Kosmalla
DFKI, Saarland Informatics Campus
Saarbrücken, Germany
felix.kosmalla@dfki.de

Christian Murlowski
Saarland Informatics Campus
Saarbrücken, Germany
christianmurlowski@gmail.com

Florian Daiber
DFKI, Saarland Informatics Campus
Saarbrücken, Germany
florian.daiber@dfki.de

Antonio Krüger
DFKI, Saarland Informatics Campus
Saarbrücken, Germany
krueger@dfki.de

ABSTRACT

In this paper we present Slackliner, an interactive slackline training assistant which features a life-size projection, skeleton tracking and real-time feedback. As in other sports, proper training leads to a faster buildup of skill and lessens the risk for injuries. We chose a set of exercises from slackline literature and implemented an interactive trainer which guides the user through the exercises and gives feedback if the exercise was executed correctly. A post analysis gives the user feedback about her performance. We conducted a user study to compare the interactive slackline training system with a classic approach using a personal trainer. No significant difference was found between groups regarding balancing time, number of steps and the walking distance on the line for the left and right foot. Significant main effects for the balancing time on line, without considering the group, have been found. User feedback acquired by questionnaires and semi-structured interviews was very positive. Overall, the results indicate that the interactive slackline training system can be used as an enjoyable and effective alternative to classic training methods.

CCS CONCEPTS

• **Applied computing** → **Interactive learning environments**;
• **Human-centered computing** → *Empirical studies in HCI*;

KEYWORDS

Slackline; sports technologies; projection; real-time feedback.

ACM Reference Format:
Felix Kosmalla, Christian Murlowski, Florian Daiber, and Antonio Krüger. 2018. Slackliner – An Interactive Slackline Training Assistant. In *2018 ACM Multimedia Conference (MM '18), October 22–26, 2018, Seoul, Republic of Korea.* ACM, New York, NY, USA, 9 pages. https://doi.org/10.1145/3240508.3240537

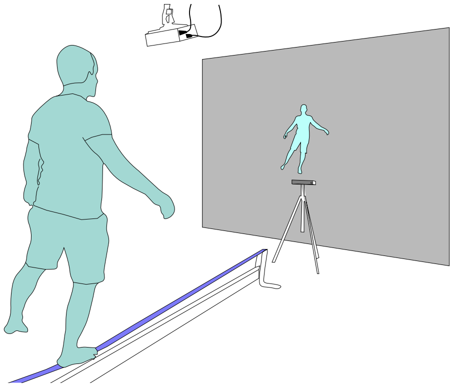

Figure 1: Setup of *Slackliner*. The slackline is placed in front of a projected display. A Kinect facing the user tracks her movements. Real-time feedback instructs the trainee during her exercises.

1 INTRODUCTION

Slacklining is a form of tightrope walking, the difference being is that much less tension is involved. This allows the material to stretch and bounce, resembling a very narrow trampoline, which enables experienced athletes to jump and flip. For the hobbyist, the usual way to exercise in this sport is to go to a park, set up the slackline between two trees, and try to walk from one side to the other. This requires a substantial amount of balance, core body strength, and focus [7].

However, as in many other sports, proper training leads to a faster buildup of skill and lessens the risk of injuries. For beginners, it is difficult to walk or even stand on a slackline. The seemingly uncontrollable swaying of the narrow rope results in unfamiliar movements that cannot be handled at the very beginning and may be very frustrating at first. Therefore, beginners should learn to concentrate, build up motor basics, and trust themselves, as well as manage their body behavior. For this, there are several exercises which focus on the individual aspects of successful slacklining [24, 28, 32]. In the best case, these exercises are explained and supervised by an expert or trainer. However, such a trainer is not available to everyone.

To overcome this issue, we present *Slackliner*, an interactive slackline training assistant. It guides the trainee through various exercises, monitors her performance in realtime, and gives instant feedback on how to improve her movements. Additionally, a post-analysis provides the trainee with more detailed feedback about her performance. We evaluated the system by asking 12 slackline novices to either train with an expert or the proposed interactive slackline training assistant. The study shows that both groups improved their slackline capabilities significantly, on the other hand, we could not show a significant difference between the performance

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MM '18, October 22–26, 2018, Seoul, Republic of Korea

ACM ISBN 978-1-4503-5665-7/18/10…$15.00
https://doi.org/10.1145/3240508.3240537

of the system versus a human trainer. In addition, user feedback indicates that the interactive slackline training assistant can be used as an enjoyable and effective alternative to classic training methods.

The contribution of the present paper is a user study comparing the training effects between our interactive slackline training system and the classic approach with a human trainer. Furthermore, the design and implementation of the system represents a contribution in itself, since it could be deployed in a variety of ways ranging from rehabilitation to fitness gyms and home use. In addition to that, we provide lessons learned, as interactive slackline training systems had not been studied to this extent.

2 RELATED WORK

2.1 Interpretation of Movements

The use of technology in sports has given athletes and trainers new possibilities in training. Simple measures such as video recording and manual analysis are now widely used for every professional athlete whether for running, swimming, or even rockclimbing. However, these practices, which were reserved for professional athletes, are to some extent now possible for the hobbyist by using off-the-shelf hardware like smartphones and consumer 3D cameras like the Kinect. [29].

Our work is related to other research projects that have used the Kinect for rehabilitation [3, 9, 12] and balance training purposes [27]. Furthermore, Estapa et al. [9] and Freitas et al. [10] collected Kinect 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, allowing subsequent analysis by the therapist. This approach of data analysis was also integrated by Garrido Navarro et al. [12] but in addition, they elaborated on whether the Kinect can serve as a rehabilitation home assistant. Many patients are taken out of their daily life environment for the purpose of accessing traditional rehabilitation training in a medical center. Here the patients incorporate the system into their daily life and avoid those trips.

2.2 Providing Feedback in Different Sport Scenarios

Several technological advances like video feedback, virtual environments and auditive information can be applied for providing feedback in sport activities. Liebermann et al. [26] evaluated those feedback methods regarding their field of application. Hämäläinen [15] developed applications for a camera output in front of an athlete. An automated motion controlled approach starts and stops the recording if the motion exceeds a certain threshold. Kajastilla et al. [18] studied how playing a simple body-controlled game while jumping on a trampoline affects the exercise experience. Kosmalla et al. [22, 23] investigated different feedback modalities in rock climbing, including wearables and in-place visualization of climbing movements using both projection and head-worn augmented reality. Kajastila and Hämäläinen [17, 19] projected interactive climbing games 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.

2.3 Technology Aided Motor Skill Learning

The work presented in this paper is also related to topics of technology-aided motor skill learning. There has been a substantial amount of previous research in the domain of feedback methods in motor learning. See [31] for a thorough review. In general, concurrent feedback can enhance performance in the acquisition phase, but one should also be aware of the guidance hypothesis which basically states that concurrent feedback can lead to a dependency [30]. Techniques for motor learning have also been developed within the domain of Virtual Reality [8, 33] and Augmented Reality [1, 34]. In YouMove, Anderson et al. [1] present an augmented mirror that allows movements of a user to be augmented with training content. Similar to this, *Slackliner* uses a mirrored view of the trainee during the exercises, which is augmented with visual performance indicators to guide the trainee through the exercises.

3 CONCEPT

When designing the slackline training system, we aimed to combine the benefits of a human trainer with those of an interactive system. The system should, like a human trainer, react to the movements of a trainee and should guide the user through a structured set of exercises, but it should also be able to be used autonomously like a computer program.

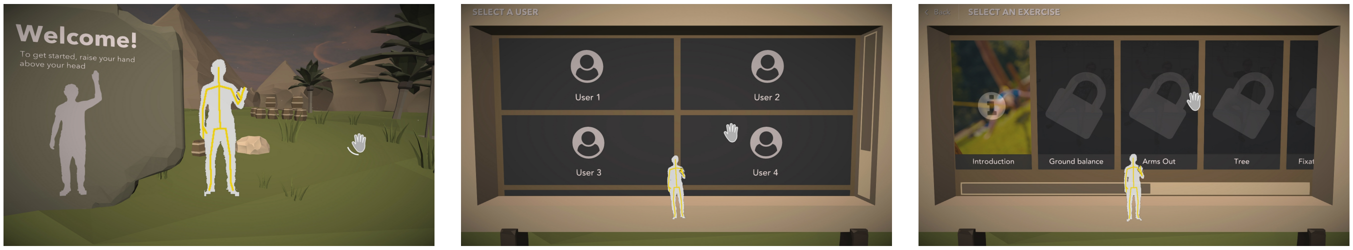
3.1 Training Methodology

Thomann [32] designed two learning procedures for slackline skill acquisition. One approach is the *differential method*, which follows a dynamical model where big stimulus differences are given to the trainee. A different approach is the *methodical routine*, which follows a more strict procedure and guides the trainee through more and more difficult exercises. Größing [14] describes the general procedure of the *methodical routine* as follows: at the beginning the trainee will perform warm-up exercises. After that, more advanced exercises will be provided. In doing so, she will learn the general motor basics, and train in movements that are needed to perform the activity. Furthermore, it ensures a smooth transition to the main exercises.

We decided to implement the *methodical routine*, since it follows a clear work flow by starting with essential aspects of slacklining that are relevant and build upon each other. This also allows for designing the stages and exercises as levels within the application. Finally, a more strict order of exercises is essential to compare the slackline training system with a human trainer in a user study.

The goal of the slackline training system is to teach beginners how to balance on the slackline in a controlled manner, stand on it for a few seconds, and be able to walk a couple of steps. In general, three core skills have to be acquired to achieve this goal [25]. At first, a beginner should be able to stand on one foot. This is essential because most of the time, one foot serves as a standing foot on the line and the other as a balance element. Second, balancing on a narrow surface is important, due to the fact that the slackline is not very wide. Lastly, she should be able to deal with heights because the slackline is often set up at knee height or above.

Kroiß [25] defined an exercise set for slackline skill acquisition which will be used as groundwork within the training system. He elicited learning exercises for beginners on a slackline within a



Welcome!

To get started, raise your hand above your head

(a) The welcome screen is used to make the user acquainted with the gesture controls.

(b) Multiple user accounts allow for an individual recording of the training progress.

(c) Exercises are organized in different levels which build up on each other.

Figure 2: The system is controlled via hand gestures. This allows the user to select her account and chose from a set of exercises.

classroom, which gives a structured basis to the exercise that will be pursued in the system. In addition, several other works [2, 5, 6, 13, 20, 21, 28, 32] included similar exercises to their slackline training approach.

The exercises implemented in the system presented in this work have been categorized into four levels which represent the fundamental basis of the exercise routines: (1) preliminary exercises on the ground; (2) stepping onto the slackline; (3) standing on the slackline; (4) walking on the slackline.

3.2 Feedback & User Interaction

Another key concept of the system is real-time feedback. The system should guide the trainee through the training and give individual feedback during the execution of the exercise. Real-time feedback supports the trainee during her performance and improves the learning effect when given in an appropriate manner [16, 26, 35]. The slackline training system should therefore respond to the user with in-situ information during the training to improve the exercise execution. The provided feedback should indicate whether the current execution is performed correctly and if not give hints on how to improve, and show the execution progress.

To allow free movement by the trainee, mid-air gestures are preferable to control the system, for example, to navigate through the menu and choose exercises.

4 THE SLACKLINER SYSTEM

The system consists of several components: a mobile slackline (*alpidex POWER-WAVE 2.0*[1]) which stands in front of a projected screen and a Kinect v2 facing the trainee (see Figure 1). Unity 3D is used to handle the program logic and visualize a graphical user interface on the projected screen.

4.1 User Tracking

We decided to use a Kinect v2 to track the trainee for several reasons: our goal was to develop a system that could be used in a variety of non-professional settings like home use, setup in a fitness gym, or at a physical therapy studio. While a more professional optical or inertial tracking system like *OptiTrack*, *Vicon*, or *Xsens* would significantly improve the tracking quality, such a system would require a much higher amount of setup time and would also multiply the costs dramatically.

① Looping video on the right shows the correct execution
② Right leg servers as standing leg
③ Raise the left leg to the side and stretch it
④ Straight upper body
⑤ Both arms should be loose
⑥ Focus on a point in front of you

Repetitions: 3
Min. Time: 4 sec

Figure 3: Before the execution of each exercise, the user is presented a set of specific instructions and a short video clip presenting the movements.

When placing the Kinect, we tried out multiple locations ranging from the side of the slackline to an angle from the ceiling. Placing the camera on a tripod at waist height in front of the user resulted in the best tracking, although the legs of the trainee might occlude each other during the exercises.

The actual recognition of the movements during the training employs a *rule-based* and a *gesture-based* approach. Gestures could be as simple as standing on one leg while raising the trainee's arms above her head, or more complex ones that involve movement sequences like walking to step on the slackline and then stretching one leg to the side. For these gestures, we used the Visual Gesture Builder from Microsoft[2]. The tool uses machine learning techniques that are trained with recordings of movements and produce databases which can then be used within Unity 3D to detect the gestures. However, the gesture recognition system only returns a confidence value for each recognized gesture, and not what has to be changed in order to reach a higher confidence value. This is why we also implemented a simple rule-based recognition which covers most of the cases. Rules like *left arm above head*, *on slackline*, *leg pointing outwards* could be added to each exercise, and is later used to give the trainee feedback on how to improve during the exercise. These rules are displayed as a checklist during the exercise execution (see Figure 4).

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[1] http://www.alpidex.com

[2] http://kinect.github.io/tutorial/lab12/index.html

4.2 User Interface

Unity is used in *Slackliner* for the creation of the virtual environment, interface design, managing actions by users, and data storage. The interface consists of several screens. A small silhouette of the trainee is always shown in the center of the screen to give her feedback on the status of the tracking system. Based on the Microsoft Human Interface Guidelines for the Kinect[3], we implemented a gesture based navigation system which allowed users to interact with the system naturally: The hand controls a virtual cursor on the projection, and with the movement of the palm of the hand directed toward the screen, buttons could be activated.

Welcome Screen. The welcome screen gives the trainee an opportunity to get accustomed to the projected interface and the gestures to control the system (see Figure 2a).

User Selection. Using hand gestures, the trainee can select her user profile. This is especially useful for setups where more than one user is going to use the system (see Figure 2b).

Exercise Menu. After choosing a level, the trainee can pick an exercise from a list (see Figure 2c). Successfully executing an exercise unlocks the next game.

Exercise Instructions. After picking an exercise, the trainee is instructed via text and a video clip showing the execution of the exercise (see Figure 3).

Exercise Execution. The exercise execution screen (see Figure 4) is the main part of the system. Feedback indicators provide the user with necessary information about the current exercise in real time. This should help to enhance the user's execution performance and to successfully accomplish the exercise. Feedback during the exercise is given via the following indicators and updates in real time:

- Checklist about key elements of an exercise (center left)
- Number of repetitions (bottom left)
- Correctness of the performance of an exercise (blue bar on the right)
- Elapsed time during which the user had been performing the exercise (right to the trainees silhouette)
- Successful completion of a repetition (audio signal, timer color, success text, and incrementing repetition counter)
- Unsuccessful repetition attempt (audio signal and timer reset)

Exercise Summary. After each successful exercise execution, the trainee is forwarded to a summary screen (see Figure 5). She then receives an overview about performance parameters like the execution time, attempts, and the confidence for each repetition. Averaged values summarize these three factors.

5 USER STUDY

The system was evaluated in a real-life scenario, teaching novices to walk on a slackline. We compared *Slackliner* to a classic approach with a trainer.

Figure 4: During the exercise the user receives real-time feedback like a checklist of specific instructions, a timer, a repetition counter and a gauge which displays how well the movement is performed.

TIME	ATTEMPTS	CONFIDENCE
5.1 | 1st rep	1 | 1st rep	96 | 1st rep
4.7 | 2nd rep	1 | 2nd rep	96 | 2nd rep
4.8 | 3rd rep	1 | 3rd rep	96 | 3rd rep
4.9 sec | Average	1.0 | A ge	96.0 % | Average

Figure 5: After each exercise, the user is presented a summary of her exercise performance considering time needed, number of attempts, and quality of execution.

5.1 Participants

A total number of 12 participants were recruited (four female). The ages ranged from 21 years to 42 years ($M = 28$, $SD = 6$), the body heights from $154cm$ to $197cm$ ($M = 177cm$, $SD = 12cm$), and the weights from $45kg$ to $112.5kg$ ($M = 75kg$, $SD = 19.5kg$).

More details on demographics are summarized in Table 1. The participants' dominant leg was determined with a Lateral Preference Inventory Questionnaire by Coren [4]. All participants had a moderate to strong preference for the right leg. The physical activity level was determined with the Physical Activity, Exercise and Sport Questionnaire (Bewegungs- und Sportaktivität Fragebogen - BSA-F) by Fuchs et al. [11]. It is divided into physical activities including their job, free time, and sport activities.

The participants were not familiar with intermediate slacklining or further balance training. They showed no history of musculoskeletal disorders that may have affected training or testing. All participants were briefed and gave their consent to take part on the study, and agreed to audiovisual data recording. The present study was approved by the local ethics commission.

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[3] https://bit.ly/2v5S4np

	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 Foot Preference [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)

Table 1: Demographic data of the participants. *ISG*: Interactive System Group; *HTG*: Human Trainer Group. Data is indicated as AVG with standard deviations (SD). Lateral foot preference index ranges from strong left (-4) to strong right (+4). *BSA*: Physical activity index ranges from low active (0) to highly active (+3)

5.2 Conditions

Participants were randomly assigned to either the interactive system group using *Slackliner (ISG)* or the human trainer group *(HTG)*. Both groups were provided with the same levels, exercises, detailed description about the execution, and amount of training. The difference in each conditions lies in the training method itself, how instructions are provided to the participant, and how feedback about the execution is given (i.e. *Slackliner* vs. human trainer). All participants agreed to train without shoes but with socks to provide consistent training conditions.

5.2.1 Interactive System Group (ISG).

The participant interacts by herself with the system, which teaches her how to interact with it and guides her through predefined exercises as described in Section 4. It explains to the user how to execute the exercises with a step-by-step description and a looping video of the correct execution as well as how often and how long a certain pose has to be held. It provides real-time feedback about the current execution performance with several indicators. The participants were encouraged to think aloud while interacting with the system. However, no hints or answers concerning the exercise execution were given by the experiment leader to ensure the autonomy of the user with the system.

5.2.2 Trainer Group (HTG).

In this condition, the participant is instructed by a human trainer. All exercises, descriptions, repetitions, and time to hold the exercises correspond to the ISG condition. At first, the trainer provides instruction on the ongoing level of exercises. Then, the specific exercise is explained regarding how to execute the exercise, how many repetitions to do, and the minimum number of 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.

5.3 Design

We used a 2×2 mixed factorial design for the study, more specifically with 2 group level (group: ISG, HTG) × 2 measurements (time: PRE, POST). Within subject, a PRE-measurement (before the training) and POST-measurement (after the training) was performed. 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 using a stopwatch, and second and third, measuring the steps and distance the participant can walk on the slackline with the left and right foot as starting point. For this, the slackline was divided into 12 parts with tape marks at a distance of 0.5 meters each, to ensure an accurate measurement. Three consecutive attempts on each foot and method were executed and measured to compare the results. All PRE- and POST-measurement were video captured for later analysis.

5.4 Procedure

At first, the participant was briefed about the study and the procedure in respect to her assigned group, and informed consent was obtained. Next, she had to answer a questionnaire for collecting demographics and her prior experience with slacklining. Participants of the *ISG* had to answer one more question about the prior experience with interactive devices (e.g. Kinect, Wii, PlayStation Move, etc.). The physical activity level as well as the lateral preference was determined as stated above.

The general balance ability of the participant was verified before the actual PRE-measurement to exclude participants with a balance disorder. To do this, she had to execute a single leg stance on the right, and then the left foot, at first on the ground, and then on a towel for a maximum of ten seconds with three trials. This ensures the participant had no problems with holding her own balance on a stable and uneven surface.

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, and second, trying to walk with as few steps as possible on the entire slackline with the left as well as the right leg as starting points. For each measurement and leg, the participant had to accomplish three trials, resulting in a total of 12 trials.

After the participant passed the PRE-measurement test, a short introduction about the ongoing procedure was provided to her. For all exercises, she had to start on a marked position on the ground. Depending on the training method, the introduction, repetitions, and time to hold each exercises, was provided by the trainer or *Slackliner*. During the execution, either the trainer or the system gave feedback to the participant concerning the correct execution of the exercise. If an execution was not accurate, she had to repeat it until all repetitions of the exercises were accomplished successfully. The participant had the possibility to skip the exercise if it was too difficult to accomplish. During the training, she was allowed to take breaks at any time. When accomplishing an exercise set, the participant was asked to rank the exercise she just completed on a 5-point scale of 1 (very easy) to 5 (very hard). When finished with the training part, a POST-measurement was conducted with the same procedure as in the PRE-measurement described 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. Participants of the ISG were additionally asked about the slackline learning system user interface and their experience with the interaction.

5.5 Apparatus

The apparatus was set up as described above (see Section 4). The slackline was placed directly in front of the Kinect, which was attached on a tripod with a height of 90 cm. It was placed in front of a wall that is used as a projector screen. The camera faced in the direction of the slackline. A projector mounted on the ceiling of the room projected the system's interface on the wall.

The setup for the human trainer group was the same but without utilizing the projector and the Kinect. To record the execution, a video camera was placed behind the participant to record her actions as well as the interface interaction. The setup was not changed during the study in order to have the same condition for every participant.

6 RESULTS

Results are provided as means with standard deviations. Each 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) × 2 (time: PRE and POST) mixed-design analysis of variance (mixed ANOVA) was performed. To match the requirements of the mixed ANOVA, all parameters were tested on normality with the Shapiro-Wilk test. Except for walking steps performance in the post measurement for the left and right foot, all data were normally distributed with $p > 0.05$. Furthermore, the homogeneity of error variances was assessed by Levene's test with $p > 0.05$ and the homogeneity of covariances was calculated by Box's test with $p > 0.05$. Given these requirements, the mixed ANOVA was used for testing interaction effects with sphericity assumed since the group level is < 3, global differences in the dependent variables between PRE and POST, and possible differences between ISG and HTG. Level of significance was set at $p < 0.05$. Effect size was shown by using partial eta squared (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 $\eta_p^2 \geq 0.14$.

The measurement results can be seen in Table 2 and the results of the analysis in Table 3. In the following, the requirements and results of the mixed ANOVA testing will be reported for each condition separately as well as for the left and right leg.

6.1 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 $F(1.0, 10.0) = 0.0694$, $p = 0.798$, 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 $\eta_p^2 = 0.001$ right leg, $F(1.0, 10.0) = 0.008$, $p = 0.931$, partial $\eta_p^2 = 0.001$.

6.2 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 $\eta_p^2 = 0.034$).

6.3 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 $\eta_p^2 = 0.001$) or the right leg ($F(1.0, 10.0) = 1.235$, $p = 0.292$, partial $\eta_p^2 = 0.110$). Since no statistically significant interaction effect has been found, the main effects within the tests of within-subject effects will be reported.

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

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

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

	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

Table 3: Interaction, time, and group effects on single leg stance, steps walking, and distance walked

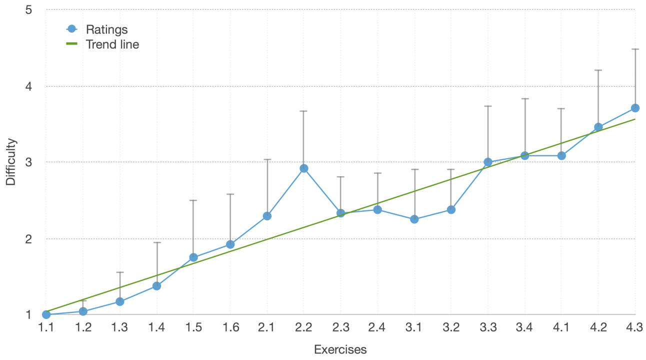

Figure 6: Averaged exercise difficulty rating of the participants. Blue points: rating, green line: trend line, gray bars: standard deviation

6.4 Rating of Exercise Difficulty

Participants were asked to rate each exercise after finishing a set of exercises with both legs. They could choose a difficulty on a 5-point scale from 1 (very easy) to 5 (very difficult). Figure 6 shows the average ratings of each exercise (blue line) as well as a trend line which is a linear interpolation of the values (green line), and the standard deviation of each rating (gray bars).

The exercises on the first level follow a smooth increase in difficulty. For the second level, there is a large increase in difficulty for the first two exercises. The ratings for the exercises 2.3, 2.4, 3.1, and 3.2 show comparable difficulty results because they were the same but exercise 3.1 and 3.2 were different in the time the user had to hold the exercise. Furthermore, the ratings follow a linear ongoing trend.

6.5 Semi-Structured Interview

The general experience with the training method showed similar outcomes for both groups. They mentioned positive learning progress during the training and had a sense of accomplishment through challenging but practicable exercises, e.g. *"The exercises were well-framed. I felt a learning progress. At the beginning I was not aware of the whole body balance but after the training, I could feel how the body balance changed and how I could keep my body's center of gravity."* (HTG-10).

All participants who used the ISG liked the environment design, clear description, and especially the looping videos of the exercises as well as the appropriate feedback during the execution. *"I liked the user view because you can see how you act by yourself. It is also a positive that I can use the system without any further help."* (ISG-P6). *"[...] There is no need to watch YouTube tutorials with such a system. It displays all relevant information and provides appropriate feedback"* (ISG-P3). However, it was also mentioned that a personal trainer could be more helpful by giving more specific advice on aspects which the Kinect could not detect (ISG-P4, IDG-P6).

All participants had fun during the training and enjoyed playing with the system. They were also motivated to accomplish the current exercise so that they could unlock the next exercise. The checklist seen in Figure 4 on the left was mentioned as a very useful feedback indicator. Finally, a variety of application scenarios for the interactive training system were mentioned. Among others, the most often stated were physical therapy, rehabilitation, training for sports activities, gyms, and home training.

6.6 Observations

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

Beside these, there were also a number of problems that are related to the Kinect tracking. First, the general tracking performance with the Kinect was affected by participants' clothing color (i.e. black clothing absorbs the infrared light of the Kinect which resulted in well-known tracking problems [4]. Second, for some exercises the gesture detection was not optimal. Exercises that involve sitting on the slackline lead to wrongly tracked legs or confuse the leg and the slackline. And third, stepping onto the slackline sometimes leads to tracking problems. When the participant put her outer leg too close to the slackline while stepping up, the Kinect did not track it appropriately. The exercise execution was therefore sometimes not counted as successful

7 DISCUSSION

7.1 Interaction Effects

No interaction effect for *group* × *time* can be shown for any measurement variable for the *ISG* or the *HTG*. Therefore, it cannot be shown with a statistically significance that the interactive system shows better results than a human trainer. This could have been due

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[4] https://support.xbox.com/en-BZ/xbox-360/kinect/body-tracking-troubleshoot

to 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 advanced slackline skills were taught. For learning more complex exercises and techniques, the introduction and feedback given during the execution are very important because these are key elements of understanding how the exercise works and how to perform it correctly. Therefore, further exercises and training over a longer time period could lead to a more specific result.

Another reason might be that participants could have been too exhausted to show a relevant effect. Participants trained at least 45 minutes on the slackline. After this, the POST measurement had been executed. Taking the time of the training into account, the results of the measurement after the training could have been affected by the exhaustion of the participants. As a result, no real improvement could be shown.

Lastly, there was no distinction in general balance skill of the participants. Subjects were chosen if they had no intermediate slackline experience or no further balance skill through special sports activities. The results show a large standard deviation for all variables in the difference of PRE to POST. This is because participants improved differently after the training respectively to their PRE-measurement. The participants had different levels of balancing skills and abilities.

However, one trend can be observed; 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 when detecting the exercise execution than a human trainer. Whereas a trainer provides more tolerance concerning the users' exercise execution, the system has a predefined gesture database to which the user has to adapt her execution. It leads to more trials from the participants because of the strict recognition of the system.

7.2 Time Effects

Time differs significantly from PRE to POST (see *Time* column in Table 3) in both groups. The results state for all measurement conditions, a significant improvement except for standing left leg. This proves that the training exercises used in both groups are useful and have an effect on the learning progress of the participant.

The time standing on the left leg showed no statistically significant result. It is more difficult to hold one's balance on a weaker leg because it is less familiar with handling these situations than the dominant 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. Furthermore, the physical strain could have exhausted the functionality of the leg since POST results were measured directly after training. In contrast, the right leg shows significant results. For all participants the right leg was found to be their primary leg. The general balance skill for this leg is built up through everyday physical effort and, therefore, it shows more stable data for balance improvements.

7.3 ISG vs. RTG

Although the ISG is numerically slightly better than the HTG, this is not sufficient to represent a statistically significant difference. Both groups were provided with the same exercise structure, description, repetitions, and time to hold the exercise. Only the method for how the information is provided to the user and the feedback during the execution of the exercise differed. It could be the case that both training methods provide a similar amount of information and feedback such that neither group had an advantage. This, again, results in similar group effects. However, it indicates that both training methods show similar results and can be compared with each other.

8 LIMITATIONS & FUTURE WORK

While we did not experience any significant technological problems during our study, one limitation of this camera-based approach is the problem of occlusion, especially of the legs and feet. We tried several different positions in which to place the Kinect and found out that placing the camera in front of the slackline leads to the best results. However, this occasionally results in tracking problems when one leg if in front of the other. This problem could be solved by either a more complex multi-camera setup or an IMU-sensor suit which does not rely on optical tracking. Furthermore, the presented study does not take into account long-term training effects. This could be investigated in a future user study.

9 CONCLUSION

In this paper, we studied the design and implementation of *Slackliner* an interactive slackline training assistant. The system was implemented using a slackline facing a large projection and a Kinect v2. In a user-study, we compared learning basic slackline skills (e.g. walking on a slackline) using *Slackliner* to the classical approach of a human trainer. While we could not show a significant difference between the two groups, the performance of both groups improved significantly before and after the training. Observations and semi-structured interviews indicate that the enjoyable game environment gives a playful character to the training situation and the challenging exercises motivated the participants to reach their goal of accomplishing the exercise. The results indicate that using an interactive slackline trainer can be a good alternative for autonomously learning the basics of slackline training. Given that the participants felt motivated by the system, we suggest that the use of a gamified approach in balance training should be studied more to better understand its influence on learning and motivation.

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