Interactive Football-Training Based on Rebounders with Hit Position Sensing and Audio-Visual Feedback

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Abstract
The last decade’s advancements in computer technology have facilitated a growing interest in the development of interactive sports-training equipment. This development has provided athletes and coaches with measurement and training tools, with performance analysis or skill improvement as purpose. However, most of these tools are created with a single goal, either to measure or train, and are often used and tested in very controlled settings. In this paper, we present an interactive football-training platform, called Football Lab, featuring sensor-mounted rebounders as well as audio-visual feedback. Football Lab enables the creation of novel training games, which aim to improve players’ technical skills, and simultaneously function as a tool for measuring player performance and development over time. A logging of the Football Lab was conducted through 92 weeks, where the platform was available for the general public, analysis of a subset of the 20,000 games played in the period are discussed. Moreover, the paper contains a discussion covering challenges in data collection, transferability issues for interactive training equipment, as well as examples of experiments conducted with the platform. Finally, directions for future research within the area of interactive training equipment are proposed.

KEYWORDS: SERIOUS GAMES, INTERACTIVE TRAINING EQUIPMENT, TRANSFERABILITY, DATA COLLECTION, HUMAN-COMPUTER INTERACTION

Introduction
The last decade’s advancements in computer technology have facilitated a growing interest in the development of interactive sport-training equipment (Baca, Dabnichki, Heller, & Kornfeind, 2009). The main part of these systems utilizes ubiquitous computing technologies to collect and process data from athletes’ performances as a tool for analyzing sport-specific techniques or movement patterns. Besides using technology merely to measure athletes’ performances and provide informative feedback, recently systems have emerged, which utilize technology to create dynamic interactive training environments, e.g. in (Liljedahl, Lindberg, & Berg, 2005; Ludvigsen, Fogtmann, & Grønbæk, 2010).

This paper presents an interactive football-training platform, called Football Lab, which aims to improve players’ ability to pass, receive, and turn with a football (soccer ball), and
simultaneously measure their game performances. The installation is based on sensor-mounted rebounders as well as audio and light feedback, which is utilized to create gamified training exercises. In close collaboration with football coaches, the authors developed Football Lab, which is part of a greater football training facility established by a Danish football club called Herning Fremad. The facility and the installation are publicly accessible night and day all year, and in this paper, we show the results of 92 weeks of Football Lab use.

Moreover, this paper opens a discussion that touch upon challenges that occur when making experiments in a public accessible platform in terms of data collection, transferability issues in interactive sport-training platforms, alternative use of the platform, and three future research questions. But first we briefly introduce state-of-the-art of existing football-training equipment to illustrate how Football Lab differs and contributes with new types of real-time feedback-based training games for football.

**Existing Digital Football-Training Equipment**

For several years it has been possible to use radar techniques to measure ball speeds (e.g. provided by [http://www.sportssensors.com](http://www.sportssensors.com)), which have been used to measure the speed of kicks to a football from a stationary position providing immediate feedback. This enables a quick evaluation of kick speeds as part of training sessions, but this is a very limited aspect of football training, omitting precision and other tactical techniques.

In recent years precise position tracking and camera-based training systems such as InMotio ([http://www.inmotio.eu](http://www.inmotio.eu)) and ZXY ([http://www.zxy.no](http://www.zxy.no)) have been installed in a number of training facilities around Europe to improve training. These systems features precise tracking and recording of player activities on the field during a match or during training. However, these systems only supports post-hoc analysis for coaches and players to discuss, aiming at improvements for the next training/match, thus, there is no real-time support for the training activities with these systems.

In contrast, the Footbonaut is an interactive football-training platform created by Christian Güttler, and it consists of an artificial grass field surrounded by a wall with 64 grids and 8 ball-feeding machines (Bell, 2013; Horncastle, 2012). The player then stands in the middle of the field and receive a ball from one of the machines, whereupon one of the 64 grids illuminate, indicating a designated target, which the player has to hit as fast as possible. After a session, performance data is available to the player and coach.

Footbonaut and the Football Lab platform, discussed in this paper, have several elements in common, such as the layout of the playing field, the use of immediate feedback, and the aim of improving players’ ability to receive, pass and turn with the ball. However, the two systems differ in their approach to the training of passes, where Footbonaut focus solely on pass precision by having 64 targets that capture the ball. In contrary, Football Lab’s four rebounders, stimulate a more controlled passing, where the perfect ball speed is essential, due to the feature that the player has to receive and handle his own pass, instead of having a target that consumes the ball and a ball-feeding machine that provide the player with a new ball. Furthermore, Football Lab is based on a gamification of training exercises, supported by hit position detection, a scoreboard, and an online high-score list, which is used as a motivational and social tool, whereas the Footbonaut primarily focus on skill improvement and measurement.
The Football Lab Concept

Football Lab is an interactive football-training platform that enables players to train the ability to pass, receive and turn with a ball. In this section, we describe Football Lab in detail, explaining the physical setup of the installation, the sensing and actuation abilities available and the game platform that is facilitated. The entire Football Lab concept have been developed and created by Munin Sports, Alexandra Institute and Aarhus University in close collaboration with coaches from the football clubs Herning Fremad and F.C. Midtjylland.

The Football Lab consists of a 12*12 meter square field covered with artificial grass and surrounded by boards and net to constitute a limited play field. In the 144 square meter field, four M-Station Pro rebounders from Munin Sports are placed two and two opposite to each other on the boards (see Figure 1). These rebounders are augmented with sensors and actuators connected to a training game computer and an outdoor display.

Football Lab – Sensing and Actuation Platform

Each M-station rebounder is equipped with four piezoelectric sensors, detecting the vibrations of the net when hit by a ball (see Figure 2A). Signal processing based on the sensor signals enables Football Lab to detect positions of ball hits.

The platform architecture is depicted in Figure 3, and it includes an execution software engine that is implemented directly on a controller board on each rebounder in order to ensure immediate reactions to sensor activation. The software and hardware is tuned to have a reaction time between sensor activation and actuator reaction of less than 25 milliseconds, in order to ensure that players can get in flow in the training programs without delayed or lacking sensing and actuation. All detailed measurements are stored in a database and the individual game results are shown on low resolution, but powerful outdoor display (Figure 2B).
Furthermore each rebounder is equipped with weather resistant RGB LED lights for sending visual cues to the players and waterproof loudspeakers to make audio cues to the players. The typical cues to players during training are combined audio-visual cues, where the rebounder loudspeaker says: “play me”, “I’m free” etc. combined with blinking LEDs.

Besides using the sensor and actuation setup merely as a part of training, Football Lab also allows players to login using their mobile phones, enabling both players and coaches to track and analyze performances and development through an online website, where all results are available. Moreover, the website contains a high score list, were top 20 players are shown, and a Facebook interface allows players to post their results to their timeline from the high score list.

**Football Lab – Game Space**

The sensing and actuation possibilities together with the physical setup constitute a unique game space for development of interactive football-training games. Currently, Football Lab contains three available games, all developed in close collaboration with football coaches, who coach young prospect players.
Pass and Turn

In Pass and Turn, the player starts in the middle of the field with the ball. After a countdown the game starts, and an arbitrary rebounder will be marked with light and sound signals. When the marked rebounder is hit, the player is awarded points depending on how fast the rebounder was hit, and a new arbitrary rebounder is marked as the next target etc. The game measures how fast the player receives, turns and passes the ball. The game lasts a minute, and the goal for the player is to get as many points as possible. Points are calculated using the formula:

$$\text{points} = 100 \times \text{targetCount} - \text{totalHitTime}$$

where \( \text{targetCount} \) is the number of rebounders hit, and \( \text{totalHitTime} \) refers to the time used to hit them. The calculation entail that in case of a scenario, where two players hit the same amount of rebounders, time functions as a tiebreaker, where the fastest player is awarded more points than the slower.

Dribble

Before starting a game of Dribble, the playing field of Football Lab is augmented with cones placed on marked spots. Like in Pass and Turn, the game starts after a countdown, and an arbitrary rebounder is marked. The player then has to dribble between the cones to reach the rebounder and hit it with the ball. When the rebounder is hit, a new arbitrary rebounder is marked, and the player has to dribble between the cones to return to the middle of the field and then out to the newly marked rebounder etc. Dribble lasts 30 seconds, where the player aims to maximize the achieved number of points, which are calculated the same way as in Pass and Turn.

3vs2

Contrary to Pass and Turn and Dribble, 3vs2 is a multiplayer game, where five players divided in two teams are present in the Football Lab. The team with three players tries to control the ball, and score by hitting a marked rebounder. The team with two players tries to get the ball and oppose the other team from scoring. The game lasts for two minutes and there is only one rebounder active for ten seconds every fifteen seconds. The goal for the attacking team is to

Figure 4. The Football Lab game space.
score as many goals as possible, whereas, the defending team should minimize the number of goals scored by the other team. From a training perspective, the attacking team should be able to control the ball and at all times direct their game towards the active rebounder.

Result and Analysis of Long-Term Usage

During a period of 92 weeks, we have logged every rebound hit of every game of Pass and Turn and Dribble played at Football Lab. Here, we have registered 8978 Pass and Turn games, where the main part of games is expected to originate from junior player training sessions. The distribution of the 8978 games over the 92 weeks (22 months) is depicted in Figure 5. In peak seasons days up to 180 games (including all three games) have been registered, but even in winter season months 5-10 games are played a day.

For the analysis, we have omitted games, which were found to be incomplete or implausible, from the statistics to avoid disruptions in the result and analysis, and expect the rest of the games to be accomplished according to the rules. We have summarized the statistics collected from the 8978 games in Table 1.

As expected, the result shows that the average player is fastest hitting the same rebounder twice, and slowest in turning 180 degrees. However, the result also shows that the average player is slower turning left than turning right. The significance of the difference in time between average right turns and left turns, where supported by a t-test (p = 0.001).
Furthermore, the standard deviation (STD) reveals that players potentially can improve 45% in terms of speed in receiving, passing and turning with the ball. The gap between quicker and slower players suggests that some players could benefit from training directed towards these specific skills. In collaboration with trainers and coaches, the result and findings were evaluated, and ideas for new tailored training games emerged.

Table 1 also shows that an average player makes 17 passes during a one minute game of Pass and Turn. For comparison the top passers of Premier League average 78 passes per 90 minutes of play (Coverdale, 2013). Hence, an average player playing five one-minute games of Pass and Turn would make more passes than a professional player would in a 90-minutes football game.

Moreover, observations of 12 males players (4 aged 11-13, and 8 aged 13-15) playing three Pass and Turn games each, showed that the elder players in general scored higher per game (µ=27.1; σ=1.64; n=24) than the younger ones (µ=23.1; σ=3.0; n=12). A t-test confirmed the difference between the scores to be significant (p = 0.0001). Furthermore, the player, who the participants agreed to be the best technician, also made the highest score (30 targets hit), suggesting that players, who posses proper ball-handling skills, perform better in Football Lab. All players participating in the observation was considered to be among the best of their classes, explaining why their number of hits where higher than the average number of hits presented in Table 1.

The players and coaches at Herning Fremad have shown great general interest in Football Lab. The game and competitive elements make the players challenge each other and create small competitions, and the extensive number of games played witness of a popular platform. Football Lab is widely used, both as a training tool utilized by coaches in regular training sessions, especially with younger players, as well as by players and schoolchildren outside practice sessions.

### Table 1

Statistics of 8978 Pass and Turn games played on the Football Lab platform. The table shows the median, average, minimum, and maximum time (in milliseconds) players used for turning right, left, 180 degrees, and no-turn. Furthermore, the table shows the median, average, minimum and maximum number of rebounders hit per game. Additionally, the standard deviation is stated for both turn times and hits.

<table>
<thead>
<tr>
<th>Turn</th>
<th>Median</th>
<th>Average</th>
<th>Minimum</th>
<th>Maximum</th>
<th>STD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Right</td>
<td>2964ms</td>
<td>3407ms</td>
<td>78ms</td>
<td>25685ms</td>
<td>1545ms</td>
</tr>
<tr>
<td>Left</td>
<td>3031ms</td>
<td>3485ms</td>
<td>375ms</td>
<td>26282ms</td>
<td>1640ms</td>
</tr>
<tr>
<td>Same</td>
<td>2887ms</td>
<td>3354ms</td>
<td>422ms</td>
<td>22390ms</td>
<td>1643ms</td>
</tr>
<tr>
<td>Behind</td>
<td>3228ms</td>
<td>3603ms</td>
<td>484ms</td>
<td>21578ms</td>
<td>1504ms</td>
</tr>
<tr>
<td>Hits</td>
<td>17</td>
<td>17</td>
<td>11</td>
<td>49</td>
<td>5</td>
</tr>
</tbody>
</table>
Discussion of Experiences with Football Lab

Challenges in Data Collection

By making Football Lab an open-for-all platform with high availability, we encountered two significant challenges in the data collection process: Anonymity and improbable games.

Anonymity

With the creation of Football Lab and the appertaining login system, players were given a unique opportunity to log their games, high scores and development. As an evaluation means of the Football Lab platform for future development, and as player evaluation tool for coaches, a database of individual player results and development would have been desired and ultimately a powerful instrument. However, almost every player, who has used Football Lab, has chosen to play anonymously, which makes it impossible to identify the development of individual players. We believe that the players’ choice of being anonymous is primarily caused by the mobile login system, provided by Football Lab. Most players do not bring mobile phones to the football field, making the login system unavailable. Thus, development of a new on-location available login system has been initiated to utilize the full potential of Football Lab as a player analysis tool.

Improbable games

During the data analysis, we encountered a number of improbable results, where scores seemed impossibly high or suspiciously low. Through an investigation of the use of Football Lab, we found two reasons for the improbable results. Firstly, unexpected use of the platform was observed, were four players played the game together without a ball, but simply hitting the rebounders using their hands immediately after activation. This phenomenon has created a number of games with impossible scores. Secondly, a vast amount of games was found to be incomplete and had very low scores. The low-scoring games are partly a result of various demonstrations of the platform, coaches introducing the platform to new players and test of the platform hardware. Despite the knowledge of these extremities, a complete elimination of all improper results has not been possible, since the obtained result database contains gradual transitions from demonstrations to low-scoring performances, and from high-scoring performances to scores obtained by not conforming the rules of the game. However, in our data analysis we have removed results with a score lower than 11 and higher than 49, and classify results outside these limits to be improbable. Nevertheless, the minimum and maximum values, seen in Table 1, reveals that more fine-grained sorting is desirable, e.g. indicated by an improbable minimum right turn of 78 milliseconds, and a suspicious maximum left turn of 26 seconds. Games with measurements close to the minimum and maximum values, however, only represent an insignificant part of the sorted results.

Transferability in Training Games

Transferability relates to how skills, which are achieved by training with an interactive training system, transfer to the targeted sport, and is found to be the single most important criteria for design of sport-training equipment and exercises in general by Fogtmann et al. (Fogtmann, Grønbæk, & Ludvigsen, 2011). Transferability between lab training and field performance has been investigated in many papers, e.g. (Williams, Ward, & Chapman, 2003) and (Farrow & Abernethy, 2002), where studies are used to determine if perceptual skill training in the lab can improve athletes ability to anticipate situations in a field test. We assert that Football Lab
facilitates a transfer of technical motor skills such as receiving the ball, rapid turning with the ball, and controlled passing of the ball, from a lab environment to the field. The transferability of Football Lab training is ensured by the use of similar equipment (ball and shoes) and surface as in real football, which makes the basic movements identical. However, Football Lab does not cover the entire skillset required to play football, e.g. run patterns or reading and anticipating other players’ actions. The static setting of Football Lab makes it favorable for players solely to focus on technical ball handling, rather than applying intensive run patterns or creating an overview of the playing field. Furthermore, passing the ball to static rebounders is dissimilar from passing to dynamic moving co-players. Nevertheless, we claim that Football Lab is an excellent training tool, especially for younger players. By using a competitive element in a gamified setup, Football Lab encourages players to repetitive training of fundamental ball-handling skills: Receiving, turning and passing, which are motor skills particularly transferable to football.

Platform for Advanced Experimentation

Besides being used for football training, the Football Lab platform has been applied in advanced experimentation with interactive physical games. Jensen et al. (Jensen, Rasmussen, & Grønbæk, 2013) explores opponent formats in computer-supported physical games, and investigate how different ways of competing have different influence on games. Jensen et al. propose a framework, describing various opponent formats, and consecutively present two new games for Football Lab. The new games are created without changing the original Football Lab setup, and merely utilize the multi-colored LEDs as a means for distinguishing marked targets to enable development of multi-player games, where both sides can score, within the same platform. The possibility of rapid development of new games within the framework of the Football Lab setup provides a unique platform for doing idea generation and research with a reliable, easy-to-test and already deployed platform.

Future Research Questions for Interactive Training Systems

In the process of creating and testing the Football Lab platform, we have encountered numerous challenges and obstacles. In this section, we present three questions for future research that focus on improving data collection in public accessible platforms, creating intelligent and adapted training systems, and evaluating skill assessment of athletes using novel training equipment.

How do we create login systems that improve data quality in public accessible platforms?

In order to exploit the full potential of the Football Lab platform there is a need to address the challenge posed by identifying user profiles, which was insufficient in the current SMS based login system. The deployment and long-term testing showed that players do not bring their mobile phones to the football field in order to login. However, we still believe that players and coaches have interest in tracking personal performances over time. Thus, we are currently in the process of developing a login system that allows players to login on the spot, and we are considering making login mandatory in order to play a game, to ensure improved quality of future data collections and analysis. The question is: How do we create an unobtrusive and easily accessible login system and encourage players to use it? Such a login system would be desired within any open interactive training platform to increase the quality of data collected. At the moment, a temporary login system has been deployed, which allows a fixed number of
players to log in without using a mobile phone, which enables tracking of a predetermined group of players in on-going testing of new games for the platform. However, this is not a sustainable solution for the future, and players in the test are obliged to use the login system, not persuaded by the system. In future installations, we will allow players to enter their phone number on a touch display, identifying them before a game, and use the SMS gateway to ask for a confirmation from the player that it was his/her game that was registered. However, typing a phone number before each game is not optimal, and other methods have to be investigated, e.g. using RFID keys for login may be an alternative option. When we get a new simple on-entry login system for the players, it will furthermore allow us to make controlled experiments over various time periods to analyze and determine the exact effects of both long and short-term usage of Football Lab as a training tool.

Can we utilize Dynamic Difficulty Adjustment in interactive training equipment?

If a login system for Football Lab is successfully deployed, not merely does it enable performance tracking, but it also creates the possibility for developing new games for the platform that is tailored to the individual player. The concept of Dynamic Difficulty Adjustment (DDA) has emerged as a way to dynamically match the difficulty of a game to the player’s capabilities, both in design of computer games (Hunicke & Chapman, 2004) and exergames (Sinclair, Hingston, Masek, & Nosaka, 2010). DDA collects performance data from a game, processes the data and adjusts the game difficulty accordingly. In interactive training equipment, a similar approach is possible, where applying an algorithm to analyze collected performance data, could lead to a tailored game for the individual player. As a result, training sessions would focus on the player’s deficiencies and shortcomings based on an objective evaluation by the system, and coerce a concentrated training of these weaknesses. In Football Lab, a DDA approach could for example be used to increase the number of left turns in games for players, who are significantly faster to turn right than left. We suggest future research in the area of applying DDA to interactive training systems and the effects it has on players’ skill improvement.

How do we evaluate transferability from exercise to the field?

As previously mentioned, transferability is widely discussed, e.g. by (Fogtmann, Grønbæk, & Ludvigsen, 2011), (Williams, Ward, & Chapman, 2003) and (Farrow & Abernethy, 2002), in relation to development of training equipment and exercise, and how the training new systems and tools affects the actual performance of athletes. The challenge of determining the level of transferability from training equipment to field performance is present in both perceptual and motor skill training. In addition to the conduction of tests, showing that a training method improves the skill of a player compared to control and placebo groups in controlled settings, there is a need to objectively measure the potential improvement of players’ skills in real game context. The recent advancements in sensor technology promise a future, where every single movement of an athlete is measureable, and this could be utilized to develop a tool and a standard for evaluating training equipment based on in-game performances. However, we are aware that such an evaluation method induces certain challenges, e.g. in team sports, such as football, where no two games are alike, making it troublesome to create a standard evaluation method based merely on movements. Nevertheless, we believe that it is possible to approach an unbiased evaluation of training equipment based on wearable sensors in future research.
Conclusion

In this paper, we presented the novel interactive real-time football-training platform called Football Lab, which is based on large ball rebounders with a sensor-actuator based game engine. We reported on the experiences from one installation of the Football Lab in Herning, Denmark, where the log files indicated that junior players find the Football Lab training games exciting, illustrated by up to 180 games/day in high season and 5-10 games/day in the most low season winter month. The data collection from the games showed potential for design of new Pass and Turn games tailored to individuals such as left foot and right foot players to try to improve their performance. Moreover, we described challenges encountered in the creation and deployment a public accessible football-training platform, where players chose to be anonymous and comprise the rules of the game, which ultimately lowered the quality of data collected. Additionally, we reported on transferability issues found in novel sport-training systems and referred to alternate use of the platform for more advanced experiments with multi-player training games, exploring different opponent formats. Finally we have outlined a few central issues for future research in the area of interactive sport-training games covering improvement of data quality, utilization of dynamic difficulty adjustment, and evaluation of interactive sport-training systems.

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