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TABLE OF CONTENTS

Arnold Baca
Editorial 3

RESEARCH PAPERS

Dwayne Patrick Sheehan & Larry Katz
The Impact of a Six Week Exergaming Curriculum on Balance with Grade Three School Children using the Wii FIT+™ 5

Mike Hughes, Ozzie Fuller, Stafford Murray, Nic James & Goran Vuckovic
The Efficiency and Ergonomics of Selected Different Data Entry Systems in Real-Time and Lapsed-Time Computer Notation Systems 23

SCIENTIFIC REPORTS

Andrew Godbout & Jeffrey Edwin Boyd
Rhythmic Sonic Feedback for Speed Skating by Real-Time Movement Synchronization …………………………………………………………..………….. 37

PROJECT REPORTS

Christian Stockinger, Matthias Pöschl, Anne Focke & Thorsten Stein
ManipAnalysis – a Software Application for the Analysis of Force Field Experiments …………………………………………………………..……………. 52

Martin Tampier, Stefan Endler, Hristo Novatchkov, Arnold Baca & Jürgen Perl
Development of an Intelligent Real-Time Feedback System ....……...…..…….... 58

Editorial

Arnold Baca

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Dear readers:

Welcome to the winter 2012 issue of the **International Journal of Computer Science in Sport (IJCSS).**

Two research papers, one scientific report and two project reports have been included within this issue.

The investigations made by **Dwayne Patrick Sheehan** and **Larry Katz** evaluate the application of exergaming technology and its effect on the balance of grade three school children over a 6-week period.

Mike Hughes, Ozzie Fuller, Stafford Murray, Nic James and **Goran Vuckovic** discuss their comparative outcome of three different match data entry systems in respect to real time and lapsed time analysis in squash.

Andrew Godbout and **Jeffrey Edwin Boyd** introduce a sonic approach integrating an inexpensive system for the improvement of sporting movements of speed skaters based on the real time presentation of interactive auditory feedback.

The paper by **Christian Stockinger, Matthias Pöschl, Anne Focke** and **Thorsten Stein** illustrates the implementation of a software application tool for the simplified analysis of force field experiments including the import and storage of data, computations, visualizations and the export of results.

Martin Tampier, Stefan Endler, Hristo Novatchkov, Arnold Baca and **Jürgen Perl** present the implementation of an intelligent real-time feedback system. The system combines the already realized "Mobile Coaching" and "PerPot" concepts for the automatic generation of feedback during marathon running.

If you have any questions, comments, suggestions and points of criticism, please send them to me.

Best wishes for 2013!

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The Impact of a Six Week Exergaming Curriculum on Balance with Grade Three School Children using the Wii FIT+™

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Abstract

The development of fundamental movement skills (FMS) is at the heart of promoting physical literacy in children. The competence to perform basic motor tasks coupled with the confidence to try new activities will encourage children to embrace a positive attitude about being active for life. Balance is one FMS that can be specifically targeted for improvement and assessment. This paper explores the school-based application of exergaming technology as it relates to balance. Third grade students in this study improved their postural stability significantly over a 6-week period compared to a control group. The improvements in postural stability were also evident in a parallel intervention of children receiving more traditional training in agility, balance and coordination (gymnastics and dance). Gender did not have an effect on the changes in postural stability for either group; however, postural stability in the girls was better than the boys in all tests. Based on the results of this study, it is apparent that for the purpose of improving balance in elementary school children, the use of exergaming is emerging as a practical option available to physical educators. Specifically, the Wii Fit+™ has promising potential as an inexpensive and enjoyable tool for the development of balance.

KEYWORDS: EXERGAMING, ELEMENTARY SCHOOL, CHILDREN, BALANCE, FUNDAMENTAL MOVEMENT SKILLS

Introduction

A well designed elementary school physical education (PE) program plays a vital role in the promotion of basic motor skills learned at home or in preschool. With a foundation of well taught fundamental movement skills (FMS), a child can acquire the competence and confidence necessary to pursue more complicated athletic and fitness pursuits (Atwater, Crowe, Deitz, & Richardson, 1990). Much like with other school skills, there is a learning curve with physical activity known as physical literacy (PL). According to Physical Health and Education Canada (2012), PL is defined as moving with confidence and competence in a wide array of physical activities in various environments that benefit the holistic health and development of the person. The quest for PL requires an early emphasis on learning proper movement skills along with the integration of cognitive, social, and emotional development

(Whitehead, 2005, 2010).

The inclusion of balance instruction in an elementary school PE program lays the groundwork for a child to learn agility, coordination, and an abundance of FMS (Clark, 2007). Teachers use a variety of methods to achieve the outcomes of agility, balance, and coordination. A typical introduction to postural stability in the early grades begins with simplistic static balance (maintaining the centre of body mass over the base of support while standing still) activities with a varying base of support (one leg, two legs). Other activities that require competency in dynamic balance (maintaining the centre of body mass over the base of support while moving) include curricular choices such as gymnastics and dancing.

The introduction of activity-promoting video games (exergames) may be another innovative choice for PE teachers to consider when designing a FMS experience for their students. Exergames have been studied primarily to determine the levels of PA and energy expenditure compared to sedentary behaviors like watching television (Foley & Maddison, 2010; Lanningham-Foster, et al., 2006; Tan, Aziz, Chua, & Teh, 2002; Unnithan, Houser, & Fernhall, 2006). Schools are beginning to consider using exergaming in PE as more evidence accumulates about its use as a calorie burning tool in the fight against childhood obesity (Ni Mhurchu, et al., 2008; Straker & Abbott, 2007). Using exergames as a strategy to develop balance in a school setting underpins the research questions for this paper.

The momentum of the exergaming industry is already starting to influence how Canadian recreation facilities deliver a meaningful PA experience for their members (Staiano & Calvert, 2011). As this technology gains acceptance as an alternative to spin bikes and treadmills in fitness facilities, physical educators may begin wondering about its applications in a school environment. However, not all exergames are designed to meet the same PA outcome. The acquisition of FMS may be possible with the correct selection of an appropriate exergame that emphasizes foundational skills like agility, balance, and coordination.

There is a void in the literature with respect to the application of exergaming and motor development in children. This study investigates the impact of an exergaming curriculum experience on the postural stability of third grade elementary school children.

Physical Literacy in School

The fight against the increasing prevalence of inactive children is a shared responsibility by society in which schools play an important role. Establishing a habit of making healthy choices and pursuing daily PA throughout a lifetime would certainly help in this struggle for children. Mastery of FMS has been shown to be an important factor in preventing unhealthy weight gain among children and youth (Okely, Booth, & Chey, 2004). However, the development of those basic skills is dependent on the ability of physical educators to balance a couple of major considerations. Aside from environmental limitations, the two biggest constraints to motor learning are the difficulty of the task and the skill level of the learner (Hay & Cote, 1998; Okely & Booth, 2004; Okely, et al., 2004).

Developmentally appropriate PE would suggest that a child-centered approach to early childhood movement experiences will provide the best opportunity to explore individual movement potential (Sanders & Stork, 2001). Penney and Chandler (2000) point out that even though motor development is the primary contribution of PE, knowledge, skills, and understanding of body awareness, enjoyment, and expression are all related to the holistic development of children. Therefore, the multi-disciplinary nature of physical development requires consideration of the social and psychological elements when planning and teaching children's physical activities (Penney & Chandler, 2000).

PL should be promoted and explicitly supported for every child. Although all children have the capacity to achieve their own personalized level of PL, not all of them will master the FMS in the same order or at the same age (Malina, Bouchard, & Bar-Or, 2004; Whitehead, 2007a, 2007b). Children learn FMS in a progressive sequence of identifiable milestones that move toward the acquisition of mature movement capacities (Maude, 2001). All individuals have their own distinctive timetable since the pace and level of physical maturation are individually determined (Brady, 2004). The variety and quality of early skill learning experiences and the freedom allowed to each child to experiment and explore may influence that individual child's chance for acquiring skills earlier or later in comparison to other children. Predictable stages of development are common, but there are also periods of ideal readiness when children are physically, emotionally, and cognitively prepared to learn motor skills (Bayli, et al., 2008; Higgs, et al., 2008).

To increase the likelihood of developmental success, children should experience as many different physical activities as they can (McPherson & Brown, 1988). Early specialization in sports may actually limit a child's ability to learn a wide variety of skills that are important for an active lifestyle into adulthood (Rowland, 1998; Tzetzis, Kakamoukas, Goudas, & Tsorbatzoudis, 2005; Wall & Côté, 2007). The message for professionals that teach or coach elementary-age children is clear: teach an assortment of basic skills in multiple environments to maximize the potential of each child. The greatest emphasis should be on movement skill acquisition during the preschool and early elementary grades (Colvin, Egner-Markos, & Walker, 2000). Emphasis should always be placed on learning basic skills in a non-competitive environment and by having children cultivate relationships in a variety of settings (Brady, 2004; Gould, 1996).

Balance and Postural Stability

Evidence shows that many students dread a traditional PE program because they lack the movement foundation (Morey & Karp, 1998; Wrotniak, Epstein, Dorn, Jones, & Kondilis, 2006). Missing out on the vital building blocks for participation could stifle the opportunity for young people to develop confidence and competence during crucial physical skill development stages. Examples of these FMS are running, hopping, catching, and throwing. These skills are often preceded by the acquisition of agility, balance, coordination, and laterality. Children who have not developed these abilities face difficulties later in situations that require a more difficult skill set (Canadian Sport for Life, 2009). Being unable to participate fully in daily school activities can then lead to feelings of exclusion, low self-esteem, and poor academic performance (Tremblay, Inman, & Willms, 2000). This negative cycle can be improved through creative quality physical education programs with an emphasis on FMS (Canadian Paediatric Society, 2002).

Even during quiet standing, body sway occurs and has been the target of interest in several studies throughout the 20th century (Baker, Newstead, Mossberg, & Nicodemus, 1998; Goodenough, 1935; Peeters, Breslau, Mol, & Caberg, 1984; Seils, 1951). As children develop balance, body sway diminishes and by the time they reach the ages of nine to twelve it is comparable to an adult (Riach & Hayes, 1987; Taguchi & Tada, 1988). A highly referenced study (N = 21, age range = 1.25-10 years) using the Sensory Organization Test (SOT) reported that children between the ages of 7 to 10 exhibited adult-like postural stability (Shumway-Cook & Woollacott, 1985). In addition to the small sample size, this study had an excessive age range of participants, which limits its usefulness. Another study by Forssberg and Nashner

(1982) made a similar claim regarding the postural response of children greater than 7.5 years old. However, it, too had a small sample size (N = 18). Conversely, other larger studies reported that the levels of postural sway continued to develop past the age of 10 and possibly until 15 (Hirabayashi & Iwasaki, 1995; Peterka & Black, 1990; Rine, Rubish, & Feeney, 1998; Rival, Ceyte, & Olivier, 2005). A more recent study concluded that adult-like sensory information in children is not demonstrated until age 12 (Peterson, Christou, & Rosengren, 2006). The use of the SOT with a larger sample size (N = 154) and smaller age range (6-12 years) in the Peterson et al. (2006) study suggests children continue to develop balance up to and beyond puberty. A Stanford University study of 92 children discovered that all balance parameters from a piezoelectric force plate improved with age until the age of 16 (Wolff, et al., 1998). The conflicting results are influenced by factors such as sample size and advances in technology.

Mickle, Munro and Steele (2011) found that girls have lower postural sway (displacement of the body at waist-level) in a study of dynamic and static postural balance in 8 and 10 year old children. Holm and Vøllestad (2008) also found girls generally performed better at balance tasks than boys between the ages of 7 and 12 years of age. A possible explanation of this gender difference suggests that neurological, visual, vestibular and proprioceptive systems, which are all used for balance, mature earlier in girls than boys (Mickle, et al., 2011).

Balance intervention programs are often simple exercises an individual can do to increase balance, reduce postural sway, and prevent injury. Emery, Cassidy, Klassen, Roychuck, and Rowe (2005) introduced a 6-week home-based balance intervention program for high school students between the ages of 14 and 19 that used a wobble board with increasing interval levels. The average balance scores for static and dynamic increase by 18 seconds and 3 seconds respectively from the baseline measurements. Kidgell, Horvath, Jackson, and Seymour (2007) compared the effectiveness using a dura disc and a mini trampoline as balance intervention methods for adults who have suffer from functional ankle instability. After a 6-week intervention program, all participants had improved balance and postural stability scores. 1996).

Exergaming

Today's youth have become so familiar with technology that any hope of increasing PA must consider this powerful behavioral influence. For example, cellular phone applications (apps) that track activity levels and promote healthy choices are popular with adults and are now being adapted for children. Schools have also embraced the advantages of technology to assist in the instruction of core knowledge such as literacy and numeracy. Contemporary physical educators must, too, consider how the use of technology can promote PA and the benefits of health related fitness.

Constructivist theory suggests that the learner is constantly engaging with incoming new information by connecting it with past experiences that help construct a meaningful understanding to the individual learner (Zhu et al., 2011). Constructivist understanding of information is created by the individual interpretation, relation and integration (Manely & Whitaker, 2011). The greater sense of autonomy and control that results from this method of processing new information leads to an enhanced persistence to learn, enhanced performance, and a more intrinsically satisfying learning experience (Manely & Whitaker, 2011). Given the massive cultural shift in the engagement of children in video gaming, a constructivist's approach could apply that context in the learning environment since it is a relatable medium to convey new information that connects with a child's previous experiences.

Exergaming activities are videogames that require participants to engage in physical movement in order to play the games (Hansen & Sanders, 2008). This unique concept attempts to link exercise and fun by providing stimulating opportunities for video game players to become more physically active. Traditional videogames have long been viewed as a rival to advocates of increased PA in children. However, there is a realization that these opposing views can, in fact, work together as one small part of a solution to the crisis of inactivity. The trend toward this type of videogame has provided an active alternative to traditional sedentary video gaming, making it an appealing supplement for promoting a healthy, active lifestyle (Graf, Pratt, Hester, & Short, 2009). However, caution must be exercised when using technology in any curriculum area. Exergaming must compliment the prescribed PE program and not simply be an opportunity for free play. Additionally, depending on the type of equipment, exergaming in schools can be an expensive endeavor that must be accompanied by a plan to maintain and upgrade equipment.

With sedentary screen time at an all-time high, some research has shown that exergaming is motivating children to be more active in an environment comfortable to them; one based in technology (Lieberman, 1997, 2001, 2006; Prensky, 2001, 2003). Exergaming has been shown to provide the stimulus for engagement to those students who have started to lose interest in more traditional forms of PA (Widman, McDonald, & Abresch, 2006). The graduated levels of contemporary exergaming allow children to progress at a pace that is individualized to their physiological and psychological readiness. The excitement of advancing to a higher and more difficult level can be a powerful motivational tool and the virtual world of exergaming can provide users with a safe, yet exciting, version of reality. Beck and Wade (2004) stated that the attraction to the gaming world was due to the simplicity of the games, the customized reward system, and the highly stimulating entertainment experience that allowed players to escape from boredom.

Researchers have taken advantage of this new active video game technology as a potential tool for balance intervention programs. In a comparison study of traditional balance intervention program using dura disc exercises to an active video game based intervention program that used DDR® and Wii Fit™, researchers found that both methods had significant improvement in balance with the exergaming intervention group outperforming the traditional intervention group (Brumels, Blaisus, Cortright, Oumedian, and Solber, 2008). Vernadakis, Gioftsidous, Ioannis and Giannousi (2012) found that, although an exergaming intervention is effective for improving balance, they did not find a significant difference in results between traditional and exergaming balance methods. Despite the evidence for the effectiveness of exergaming in balance intervention programs, very little research is available on the effectiveness of exergaming training programs for children developing FMS.

A number of studies have suggested that improvements in adult and adolescent postural stability can be shown using a minimum 6-week intervention period. (Emery et al., 2005; Kidgell, et al., 2007; Mansfield, Peters, Liu, & Maki, 2010; Sefton, Yarar, Hicks-Little, Berry, & Cordova, 2011). However, to date there do not appear to be balance studies with six or more weeks of intervention related to elementary school children. This is important because results from studies with shorter time lengths were generally inconclusive (Zech, et al., 2010) although a study by Kliem and Wiemeyer (2010) showed balance effects after only three weeks of intervention.

The current study was designed to investigate the effect of a PE exergaming curriculum on the postural stability of grade 3 (9 and 10 year old) students in a school setting.

The following questions were addressed:

1. Does a 6-week Wii Fit+™ PE exergaming experience and a custom designed agility, balance, and coordination (ABC) PE experience (three times per week) improve postural stability (compared to a control group) as measured by the HUR BT4™ balance platform?
2. What is the relationship between a 6-week Wii Fit+™ and an ABC unit?
3. What is the gender influence on the postural stability of children in this study?

Methods

Participants

The research was conducted during the winter of 2010 and included 67 third grade students (38 females, 29 males, age range of 83-111 months). Parental consent was required for student participation in the study and students could withdraw from the study at any point. The University of Calgary research ethics board approved this study. Two students did not provide permission to partake in the data collection but participated in the activity as part of their PE experience. No injuries, chronic balance disorders, or long-term lower body impairments were identified by the parents of the children involved in the primary study.

Facility and Exergaming Equipment

A 750ft^2 elementary school stage was converted to a Wii Fit+™ teaching station in a local public school in Calgary, Alberta, Canada. This living lab is currently functioning as the Canadian Exergaming Research Center (CERC; www.ucalgary.ca/exergaming). A privacy curtain was installed to eliminate the visual distractions between the exergaming center and the gymnasium.

Figure 1. Canadian Exergaming Research Centre (CERC).

The Wii Fit+™ Plus (Nintendo, Japan) software was used exclusively with all Wii™ console activities. This exergaming platform offered a variety of activities related to strength, flexibility, balance, and dance (each of which has an element of agility and coordination). Personalized feedback based on basic anthropometric measures is one of the unique customization features of this product. There were twelve Wii Fit+™ stations available in the CERC.

Research Design

A multi-factor, multi-variable repeated measures design with convenience sampling was chosen for this school-based research. The non-equivalent pre-post control group study resulted in minimal impact on student learning and the least amount of disruption for the school. Students participated in this research study as part of their regularly scheduled PE classes which consisted of 34 minutes of activity, three days per week (Monday, Wednesday, and Friday).

Research Groupings

The groups consisted of the pre-existing third grade classes but were randomly assigned to the exergaming intervention, the agility, balance, and coordination (ABC) intervention, or the control group. The ABC group was included in the design to allow for a comparison of the exergaming results to a 6-week unit with similar goals. Both were compared against the control group.

Control Group

Students from the designated grouping referred to as class 3CON. Activities included paddle sports, low organized games, badminton, and fitness Friday circuits. The classes were led by one of the school’s PE specialists who used the same teaching techniques and strategies utilized during the school year. The activities selected were part of the preplanned PE year plan.

Wii Fit+™ Group

Students from the designated grouping referred to as class 3Wii. Children participated in a structured exergaming experience using only the Wii Fit+™ Plus. The classes were led by one of the school’s PE specialists using curriculum designed by the Principal Investigator (PI) and the lead PE teacher. Daily Wii Fit+™ task sheets were created and all game scores and Wii Fit+™ results were self-recorded by the student. The students were expected to follow the prescribed order of activities listed on the daily task sheet (Appendix A). The activities were chosen from the Wii Fit+™ categories found in Appendix B. If the students completed the prescribed activities they used the remaining class time to return to their favorite Wii Fit+™ activity.

Agility, Balance, and Coordination (ABC) Group

Students from the designated grouping referred to as class 3ABC. Children were instructed by one of the school’s PE specialists using a variety of custom designed lessons focusing on agility, balance, and coordination. Dance, gymnastics, and obstacle course activities were included in this unit. A variety of innovative equipment was introduced including duck walkers, jump bands, balance pads, reaction balls, agility ladders, BOSU™ balls, and yoga mats.

Testing Procedures

The pretesting of postural stability with the students was completed in week one of the study. Anthropometric measures and the assessment of postural stability were completed by the PI. Balance testing was done on the HUR BT4™ platform, a sophisticated portable assessment device designed for advanced testing of postural stability (balance). Postural stability is measured using trace length which is how far the participant shifts from the center of pressure over a 20-second period while performing balance tasks. The sum of the successive straight length segments separated in time by one-fifth of a second provides a measure of postural stability in millimeters (mm). The sampling frequency was set to 50 Hz, which was recommended by the manufacturer to balance consistent data acquisition and manageable data size. The HUR BT4™ platform has a sensitivity of 2mV/V +/- 0.25% and an acceptable combined error maximum of 0.03% (HUR Labs, 2009).

All balance testing was done in the elementary school gymnasium with varying levels of noise and distraction. Students with long hair were asked to ensure their eyes were visible during testing. Students performed all balance testing and exergaming activity with socks on. A new rectangular high density (50 kg/m3) closed-cell Airex Balance Pad (47 cm x 39 cm x 6 cm, 0.7 kg) was used for all tests requiring a foam surface. The balance pad was rotated 180° after each test to ensure even wear. Subjects were given a 10 to 15 second opportunity to get used to the foam pad prior to the first trial of balance testing with the foam. Gymnastics mats were placed around the subject for safety and to decrease the impression that a subject was elevated when testing on a foam pad.

A complete description of the balance trials can be found in Sheehan, Lafave and Katz (2011). Briefly, the non-dominant foot was used to balance on during any single leg trial (subjects were asked which leg they would use to kick a soccer ball in order to establish their non-dominant foot). Subjects were asked to maintain the contra lateral limb in 20° to 30° of hip flexion and 40° to 50° of knee flexion during the single-leg balance tests. During the tandem stance, students were asked to stand heel to toe with their feet as close as possible without touching with the non-dominant foot behind the dominant foot. Hands had to be kept on the hips for all tests.

The study took place over the course of eight weeks, where pretesting occured in week one, the intervention took place in weeks 2 through 7 and posttesting occurred during week eight. There were a total of 18 PE classes involved in this research over the 6-week period.

Data Analysis

Data were analyzed using SPSS for Windows version 17.0 (SPSS Inc., 2009). A two-way analysis of variance with one repeated measure was conducted to explore the interaction effect for Time by Group and Time by Gender. Simple effect testing was conducted to determine the specific relationship between groups and time. A Pairwise comparison was used to evaluate the mean composite score between each sub-group after the balance pretesting. This investigation was done to determine the uniformity between research groupings at the start of the intervention. An additional Pairwise comparison of the pre and posttest mean composite scores determined the significance of change in postural stability for each group. The observed power of Group x Time was .81 and the partial Eta Squared was 0.139. Using η_p^2 as the measure of association, the interaction between Group and Time accounted for 14% of the total variability in the performance score. According to the convention set by Cohen (1988), this constitutes a large effect.

Exclusion Criteria

This study used the exclusion criteria established by Emery and colleagues (2005). Since the physical activity in this study was part of the required school day, these conditions did not exclude a student from participating, but rather only from the data collection.

Results

Descriptive results from postural stability pre and post testing of are presented in Table 1.

Table 1. Means and Standard Deviation for HUR BT4™ Composite Trace Length Scores (mm).

		PRETEST		POSTTEST		OVERALL
Group	n	*M*	*SD*	*M*	*SD*	Range
Control	M = 8 F = 13	7473	3486	7940	4411	3751-19394
Wii Fit™	M = 12 F = 10	8405	3295	6253*	2451	3717-18904
ABC	M = 9 F = 13	7179	2220	5546*	1137	3917-14132
Total	M = 29 F = 36 Total 65	7689	3042	6559	3080	3717-19394

Note. *A decrease in trace length represents an improvement in postural stability

A 3x2 ANOVA (Table 2) indicated that there was a statistically significant interaction effect when using the HUR BT4™ trace length (mm) as a measure of postural stability ($F(2,62) = 14.32, p = <.001$).

Table 2. HUR BT4™ 3 X 2 ANOVA (Time x Group).

Source	df	Mean Square	*F*	Sig.
Time	1	39,710,000	27.720	.000***
Group	2	20,810,000	1.255	.292
Time * Group	2	20,520,000	14.324	.000***
Error (time)	62	1,432,640		
Residual error	62	16,580,000		

Note. *** $p < .001$

Simple effect testing was conducted to determine the specific relationship between groups and time. A Pairwise comparison was used to evaluate the mean composite score between each sub-group after the balance pretesting. This analysis was done to determine the uniformity between research groupings at the start of the intervention. The evaluation of the pretest means indicated that there was no significant difference in the starting point of the three groups (Table 3).

Table 3. HUR BT4™ Pairwise Comparison of Pretest Means by Group.

(I) group	(J) group	Mean Difference (I-J)	Std. Error	Sig.
Control	ABC	294.424	928.785	1.000
Wii Fit™	Control	931.477	928.785	.959
Wii Fit™	ABC	1225.901	917.922	.560

An additional Pairwise comparison of the pre and posttest mean composite scores (Table 4) indicated that there was no significant change in the postural stability of the control group over time (n = 21, $p = .211$). The mean composite score for the Wii Fit+™ group was significantly different over time (n = 22, $p < .001$). The mean composite score for the ABC group was also significantly different over time (n = 22, $p < .001$).

Table 4. HUR BT4™ Scheffe Pairwise Comparison of Pre and Posttest Means by Time.

Group	Pretest	Posttest	Mean Difference	Std. Error	Sig.
Control	1	2	-467.140	369.380	.211
Wii Fit™	1	2	2151.540	360.888	.000***
ABC	1	2	1632.637	360.888	.000***

Note. *** $p < .001$

Percentage of Balance Improvement (by Group)

The students who participated in the exergaming study using the Wii Fit+™ improved their postural stability by 26% (Figure 1). The ABC group had a 23% improvement in postural stability. The improvements experienced by the Wii Fit+™ group were not significantly different from those experienced by the ABC group. The control group had no statistically significant difference in postural stability.

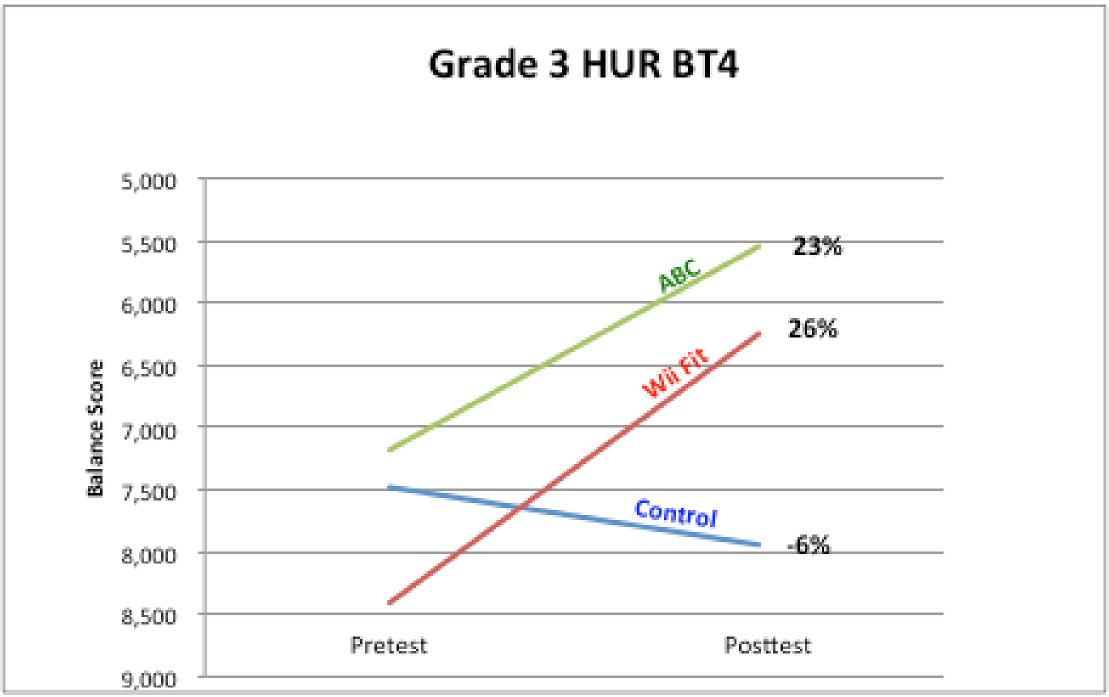

Figure 2. Percentage of balance improvement (by group) using the HUR BT4 balance platform.

Comparing the Percentage of Balance Improvement (by Gender)

The pre and posttest composite mean score of each gender was compared (Table 5). A two-way between-groups analysis of variance was conducted to explore the impact of gender by time, as measured by the HUR BT4™ balance platform (Table 6). There was no statistically significant interaction effect for gender by time ($F(1,63) = .469$, $p = .496$). However, the girls had significantly better postural stability than the boys ($F\ (1,63) = 8.252$, $p < .01$).

Table 5. Mean and Standard Deviation by Gender with HUR BT4™.

Gender	Time	Mean	Standard Deviation
Male	Pretest	8712	2835.85
	Posttest	7780	3795.32
Female	Pretest	6914	2999.75
	Posttest	5635	2005.78

Table 6. HUR BT4™ 2 X 2 ANOVA (Time x Gender).

Source	df	Mean Square	F	Sig.
Time	1	38,980,000	19.052	.000***
Gender	1	123,900,000	8.252	.006**
Time * Gender	1	959,396	.469	.496
Error(time)	63	2,046,132		
Residual error	63	15,010,000		

Note. ** $p < .01$; *** $p < .001$

Discussion

The Canadian Exergaming Research Centre (CERC) was established to investigate the potential of using exergaming technology to develop fundamental movement skills (FMS) in children. Agility, balance, and coordination are at the core of FMS and are the groundwork that other more complex motor skills rely on (Bell, Gibbons, & Temple, 2008; Berry, et al., 2002; Fisher, et al., 2005; Malina, 2008; Okely & Booth, 2004; Okely, et al., 2004). Improving balance can translate to greater confidence and an increased likelihood of participation in physical activity (Claxton, Troy, & Dupree, 2006). The use of exergaming in schools is a novel approach to embedding the training of FMS in the PE curriculum.

To understand the use of exergaming for balance improvement in elementary-aged children to the fullest, three groups of grade three children were studied: an exergaming group (using the Wii Fit™), an enhanced agility training group (ABC) and a standard PE curriculum group which provided a control. The control group posttest assessment of postural stability using the HUR BT4™ platform was similar to their pretest scores. The Pairwise comparison indicated that the change in the control group over time was not significant. The intervention groups of Wii Fit+™ and ABC improved their balance substantially (26% and 23% respectively). As a result of there being no change in the postural stability of the control group, a significant interaction effect occurred among the groups over time. The graph in Figure 1 demonstrates the substantial impact of both training interventions, especially considering there was no statistically significant difference in the starting point of all three groups.

The Wii Fit+™ and ABC data indicates that the use of the Wii Fit+™ three days per week (for 6-weeks) in PE class was relatively equivalent to the traditional ABC training offered for the same amount of time. Both classes were taught by the same physical education specialist. Students in the CERC were participating in a structured class with a combination of designated tasks and free time that had outcomes similar to that of the ABC group. The Wii Fit+™ appears to be an effective tool for helping to improve balance in third grade children. Comparing the intervention results to the control group demonstrates the importance of focusing on the introductory skills of agility, balance, and coordination regardless of whether exergaming equipment is available. The superior balance performance demonstrated by the girls in this study was consistent with the findings of similar research with children.

Congruent with the findings of Brumels et al. (2008) and Vandernakis et al. (2012), exergaming is an effective tool in PE for balance training. Brumels (2008) stated that participants found the exergaming intervention more engaging, and therefore yielded a higher compliance rate to the program. From a constructivist perspective, this is consistent for children, as this digital generation is already familiar with the technology used in the study. The use of exergames for improving balance builds on existing schemas children already hold about video games. By incorporating them into the class room, it can demonstrate to students that videos games can be both fun to engage in and beneficial to their health.

Based on the results of this study, it is apparent that for the purpose of improving balance in elementary school children, the use of exergaming is emerging as a practical option available to physical educators. Specifically, the Wii Fit+™ has promising potential as a relatively inexpensive and enjoyable tool for the development of postural stability.

Limitations

There were a number of limitations that may limit widespread generalization of the research conclusions. The most obvious constraint is the challenge of conducting scientific research in a functioning school environment. As such, the testing environment cannot be considered clinical as conditions changed on a regular basis (i.e. noise levels). Cost to purchase and maintain equipment may be a limiting factor in widespread uptake of exergaming in schools. Moreover, there is limited technical support available in Canada. However, the students themselves are often helpful and trouble shooting and resolving matters related to the set up and playing of games.

Conclusions and Future Considerations

The development of FMS is at the heart of promoting PL in children (Fisher et al., 2005). It is the competence to perform basic motor tasks coupled with the confidence to try new activities that will encourage children to embrace a positive attitude about being active for life. Balance is one such FMS that can be objectively evaluated and specifically targeted for improvement. Pedagokinetics is the art and science of teaching FMS, and is becoming a key consideration in the evolution of PE curriculum for both practitioners and researchers (Sherman, 1987). Innovative methods that embed the development of FMS into activities that children enjoy are being introduced in schools (i.e., Bosu™ balls, yoga mats, duckwalkers).

The exergaming movement is another such practice that is being studied as an alternative method of increasing PA levels without regard for the potential as a tool to develop FMS (Lanningham-Foster et al., 2006; Mellecker & McManus, 2008; Unnithan et al., 2006). The evidence provided in this paper suggests that balance is one FMS that can be improved by the strategic and intentional use of exergames. Additionally, the potential for a beneficial change in postural stability and other basic motor abilities may affect children's perceptions of PA by involving them in activities that they enjoy (Sheehan & Katz, 2010).

Subsequent studies should expand the investigation about the potential use of exergaming to develop other FMS such as laterality, coordination, and agility. Simple methods of assessing those skills in PE classes using exergaming technology may also be a topic for future consideration.

Parents, teachers, and recreational leaders can confidently know that based on the discoveries of this study there is a measurable benefit to balance development when using the Wii Fit+™ exergame. Future studies may want to consider studying balance in children by isolating other exergaming equipment and determining the long-term effects of the intervention. Building on that knowledge, subsequent studies may also want to consider the effect of home-based exergaming use on the acquisition of FMS.

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The Efficiency and Ergonomics of Selected Different Data Entry Systems in Real-Time and Lapsed-Time Computer Notation Systems

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Abstract

Most professional sports teams or individuals use some form of video analysis through a computer and software packages. However there is little research into the efficiency of match analysis systems, furthermore, the areas of human-computer interaction and artificial intelligence in match analysis systems have also been neglected. This paper therefore investigates the efficiency and ergonomics of selected squash match analysis systems. The three systems analysed were Focus X2 manual system using a mouse, Focus X2 Voice Interactive system and the SWEAT (Murray and Hughes, 2001) system using keyboard data entry. The systems were analysed, $N_{matches}$=4 each, in real time match analysis and lapsed time. The study investigated data inputs per minute and analysis time, in lapsed time analysis. Whereas in real time analysis the paper examined the analysis times, errors made, error corrections, error correction times and total analysis time. A percentage difference calculation was used to perform an intra-operator reliability investigation in real time analysis and lapsed time analysis, overall highest errors being 3.9%, which were deemed satisfactory. It was found that the Focus X2 manual system was the most efficient in both lapsed time and real time analysis, further research should include an analysis of the movements and energy expended in human computer interaction.

KEYWORDS: EFFICIENCY, ERGONOMICS, DATA ENTRY, COMPUTERISED NOTATION

Introduction

As new technology is developing, sports can benefit through the application of performance analysis to provide detailed information during and after the performance. Furthermore, performance analysis and analysts can benefit through the improvements in Human Computer Interaction (HCI). Human-computer interaction is a discipline concerned with the design, evaluation and implementation of interactive computing systems for human use and with the study of major phenomena surrounding them (Baecker et al., 1992). From a computer perspective, the focus is on interaction and specifically on interaction between one or more humans and one or more computational machines. It should be clear that the role of HCI in system design is to enhance the quality of the interaction between human and computer systems (Preece et al., 1994). Furthermore, it can be said that artificial intelligence has a part to play in the development of performance analysis data efficiency through computer systems.

Artificial intelligence (AI) is concerned with the design of intelligent computer programs, which simulate different aspects of intelligent human behaviour. In particular, the focus has been on representing knowledge structures that are utilised in human problem solving. AI knowledge and methods, such as the use of production rules, have been applied to HCI in connection with the development of tutoring and expert systems with intelligent user interface. However, the relationship of AI and HCI is mainly concerned with user interaction with an intelligent interface (Preece et al., 1994).

The implementation of ergonomics in system design should make the systems work better by eliminating aspects of system functioning that are undesirable, uncontrolled or unaccounted for, such as inefficiency, fatigue, user difficulties and apathy.

The aim of this study was to build efficiency profiles of the three match analysis systems:

- Focus X2 manual (mouse),
- SWEAT (keyboard) system and
- Focus X2 Voice Interactive system,

to enable efficient and reliable data to be completed in lapsed time and real time analysis and identify ergonomic positive or negative characteristics for the operator‘s usage of analysis systems.

This paper therefore investigates and discusses the efficiency and ergonomics of selected squash match analysis systems. The three systems analysed were Focus X2 manual system using a mouse, Focus X2 Voice Interactive system and the SWEAT (Murray and Hughes, 2001) system using keyboard data entry.

Methods

Introduction

The three input systems were analysed in real time and lapsed time data gathering using data gathering notation systems based upon winner and error analysis (Murray and Hughes, 2001). Four matches were analysed in both modes each system. Whilst the analysis procedure was being completed, videos of the data entry were recorded. The study investigated data inputs per minute and analysis time, in lapsed time analysis. Whereas in real time analysis the paper examined the analysis times, errors made, error corrections, error correction times and total analysis time. A training study was conducted prior to the efficiency analysis to enable the researcher to gain sufficient learning of systems and prevent bias. The same researcher conducted all match analysis. To provide valid and reliable results a training study was conducted using all three systems in lapsed time and real time until the researcher's learning continuum curve 'plateaued' to indicate that the learning phase was over.

From the training study an intra-observer reliability test was conducted to examine whether this study valid and reliable. To prevent the researcher memorising the match play and affecting the results of the study, the matches were randomised to improve validity and reliability.

To analyse ergonomic characteristics of the match analysis systems data entry procedure, video recording of the procedures were recorded. These video recordings enabled the researcher to identify ergonomic positives and negatives such as repetition stress on wrist whilst inputting data. Furthermore, the video enabled the researcher to identify areas of analyses that added increasing time to the analysis procedure and finally error correction and correction time.

From the lapsed time efficiency analysis method the results investigated the time taken to analyse the matches (broken-down into games), data entries per minute, shot statistics, court positioning and game statistics. Subsequently, the real time analysis investigated analysis times (per game), errors made, error corrections, error correction time, total analysis time, game statistics, court positioning and shot statistics. To analyse efficiency, times between rallies for all matches were recorded.

Equipment

Hardware	***Software***
Sony Vaio Laptop	Excel
Microphone Head set	Focus X2 manual Analysis System
Stopwatch	Focus X2 Voice Interactive Analysis System
Panasonic Wide Lens HD Camcorder	Squash 2000 Analysis System
Tripod	

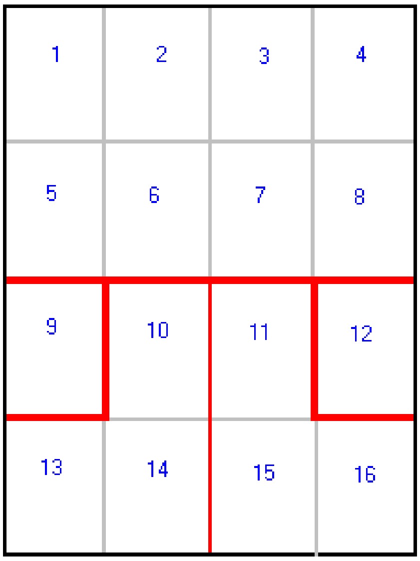

Figure 1. The squash court divisions (Murray and Hughes, 2001).

Data Collection System

To prevent the analyst becoming too familiar with the match play, randomisation of the order of matches being analysed changed during each software package analysed.

For each software package a similar performance indicator template was devised to produce consistency of the study.

The performance indicators used in the study had operational definitions set to provide specific indications of all actions of performance to enable reliability in analysis (Murray and Hughes, 2001). The squash court was divided into a 4 x 4 cell, labelled 1 – 16 (figure 1), this was the same as that used by Murray and Hughes (2001).

'Real Time' Analysis Procedure

Before the commencing of the analysis a Panasonic Wide Lens Camcorder was set up, to video the match analysis procedure, and was stopped at the completion of the data entry. In the use of the two Focus systems the matches were captured onto the computer before commencing the analysis.

Due to the analysis being conducted real time the match duration was taken as the analysis time. However, if error corrections had to be completed after the match finishes a stopwatch was started and stopped on completion. Then the two times were added together to give overall analysis time. The analyst commenced the analysis on the start of the game.

This procedure was completed for all the real time analysis systems investigated within this study.

'Lapsed Time' Analysis Procedure

Before the commencing of the analysis a Panasonic Wide Lens Camcorder was set up, to video the match analysis procedure. As the match analysis starts, a stopwatch was started to measure the time taken to complete process. In the use of the two Focus systems the matches were captured onto the computer before commencing the analysis.

The analysts commenced the match analysis, using the template devised for each system. During the lapsed time match analysis the analysts was able to use the power of pause and rewind to enable correction and justification of shots and positioning. When the data entry was completed the stopwatch was stopped and the time taken was recorded. Following this the video camcorder was stopped.This process was then completed for all the analysis systems being investigated in the lapsed time match analysis study.

Training Study/Reliability

To enable the analyst to have an equally efficient knowledge of the use of these analysis systems, a training period was set up to enable improvements in using each of these systems. During the training period a single match was analysed, then every other day the match was re-analysed until the time in which it took to analyse the match stabilised and errors reduced to an acceptable level, which was deemed 10% for this study (Hughes et al, 2002). This was conducted for all the real time and lapsed time match analysis systems. A percentage difference calculation, suggested by Hughes et al. (2002), was used to perform an intra-operator reliability investigation in real time analysis and lapsed time analysis, overall highest errors being 3.9%, which were deemed satisfactory.

Data Population

The actual data population used in this study was not deemed very important, but as most analysis is of elite athletes, then this was thought appropriate. The data population were matches of international standard professionals, all ranked within the top ten in the world rankings. The matches were taken from 2004-2008 season tournaments around the world. The broadcast coverage is public domain information that the subjects give permission to be broadcast. This was a condition of their entry to the tournaments. Nevertheless, player identities were kept confidential.

Training Study/Reliability

The training allowed the investigator to complete an inter-observer reliability study. The variables that were central to this investigation, and their reliability, were examined using an intra-operator percentage difference calculation. The three specific variables were, whether the player hit a winner or error, let or stroke, shots played and finally rally number.

Reliability Study

Table 1. Lapsed time reliability results.

	T1 v T2 %	T2 V T3 %
Rallies	0	0
Type of shot	1.9	0
Volley Drop	3.9	0

Table 2. Real time reliability results.

	T1 v T2 %	T2 V T3 %
Rallies	0	0
Type of shot	3.7	0
Volley Drop	0	1.8

Results and Discussion

Table 3. Times taken for data gathering in real and lapsed time.

LAPSED TIME

Lapsed time Analysis (Focus x2 Manual) Training Study

	Test 1	Test 2	Test 3	Test 4	Test 5
Analysis Time	18 mins 30 secs.	14 mins 47 secs	10 mins 16 secs	7 mins 34 secs	7 mins 36 secs

Lapsed time Analysis (Focus Voice Interactive) Training Study

Analysis Time	20 mins 12 secs	18 mins 35 secs	14 mins 28 sces	12 mins 31 secs	11 mins 54 secs

Lapsed time Analysis (SWEAT) Training Study

Analysis Time	19 mins 52 secs	16 mins 18 secs	13 mins 42 secs	12 mins 37 secs	12 mins 36 secs	12 mins 27 secs

REAL TIME

Match Analysis (Squash SWEAT system) Training Study 'real time'

	Test 1	Test 2	Test 3	Test 4	Test 5
Analysis Time	10 mins 32 secs	10 mins 32 secs	10 mins 32 secs	10 mins 32 secs	10mins 32 secs

Real Time Match Analysis (Focus x2 Voice Interactive) Training Study

Analysis Time	7 mins 36 secs	7 mins 36 secs	7 mins 36 secs	7 mins 36 secs	7 mins 36 secs

Real Time Match Analysis (Focus x2 Voice Manual) Training Study

Analysis Time	11 mins 10 secs	11 mins 10 secs	11 mins 10 secs	11 mins 10 secs	11 mins 10 secs

Table 4. Lapsed time analysis training study using the 3 systems.

	Focus x2 Manual					SWEAT						Focus Voice Interactive				
	Test 1	Test 2	Test 3	Test 4	Test 5	Test 1	Test 2	Test 3	Test 4	Test 5	Test 6	Test 1	Test 2	Test 3	Test 4	Test 5
No. of Rallies	17	17	17	17	17	21	21	21	21	21	21	18	18	18	18	18
W's Played	9	8	8	8	8	10	10	10	10	10	10	9	8	8	8	8
Errors Played	7	8	8	8	8	6	6	6	6	6	6	8	9	8	8	8
Drives	5	5	5	5	5	8	8	8	8	8	8	2	3	3	3	3
Boasts	2	2	2	2	2	3	4	4	4	4	4	2	2	2	2	2
B Wall Boasts	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cross Drives	0	0	0	0	0	2	1	2	2	2	2	3	3	3	3	3
Cross VDrives	0	0	0	0	0	1	1	1	1	1	1	1	1	1	1	1
Volley Drive	2	1	1	1	1	1	1	1	1	1	1	1	0	0	0	0
Drop	6	6	6	6	6	3	3	2	2	2	2	4	4	4	4	4
Volley Drop	1	2	2	2	2	1	1	1	1	1	1	3	3	3	3	3
Cross V Drop	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Kill	0	0	0	0	0	1	1	1	1	1	1	0	0	0	0	0
Volley Kill	1	0	0	0	0	0	0	0	0	0	0	1	1	1	1	1
Lob	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cross Lob	0	0	0	0	0	1	1	1	1	1	1	0	0	0	0	0
Lets	0	0	0	0	0	3	4	4	4	4	4	0	0	0	0	0
Strokes	1	1	1	1	1	2	1	1	1	1	1	1	1	1	1	1

Table 5. Real Time Training Study using 3 systems.

	Focus x2 Manual					SWEAT					Focus Voice Interactive				
	Test 1	Test 2	Test 3	Test 4	Test 5	Test 1	Test 2	Test 3	Test 4	Test 5	Test 1	Test 2	Test 3	Test 4	Test 5
total rallies/shots/rallies	18	18	18	18	18	178	183	172	173	173	17	17	17	17	17
W's Played	9	9	8	8	8	12	12	12	12	12	7	8	8	8	8
Errors Played	8	8	8	8	8	4	4	4	4	4	9	8	8	8	8
Drives	3	3	3	3	3	5	4	4	4	4	5	4	4	4	4
Boasts	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
Cross Drives	0	0	0	0	0	4	3	3	3	3	0	0	0	0	0
Cross VDrives	3	3	3	3	3	0	0	0	0	0	0	0	0	0	0
Volley Drive	1	1	1	1	1	0	1	1	1	1	0	0	0	0	0
Drop	0	0	0	0	0	3	2	3	3	3	0	0	1	1	1
Volley Drop	3	4	4	4	4	1	3	2	2	2	5	5	6	6	6
Cross V Drop	5	4	4	4	4	2	2	3	3	3	3	3	2	2	2
Kill	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
Volley Kill	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Lob	0	1	1	1	1	0	0	0	0	0	0	0	0	0	0
Cross Lob	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Lets	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Strokes	0	0	0	0	0	1	1	1	1	1	0	0	0	0	0

Efficiency Study Results

Lapsed Time Efficiency

Table 6. Lapsed time Analysis Time Match 1.

	Game 1	Game 2	Game 3	Total Analysis Time
Focus X2 Manual	8	7.2	12	28
SWEAT	10	10.1	13	33.3
Focus X2 Voice Interactive	9	10	13.2	33.2

Table 7. Lapsed time Analysis Time Match 2.

	Game 1	Game 2	Game 3	Game 4	Total Analysis Time
Focus X2 Manual	10.6	13	10.8	9.2	45.6
SWEAT	14	15	13.2	10.8	54.2
Focus X2 Voice Interactive	13	15	13.1	10.2	52.82

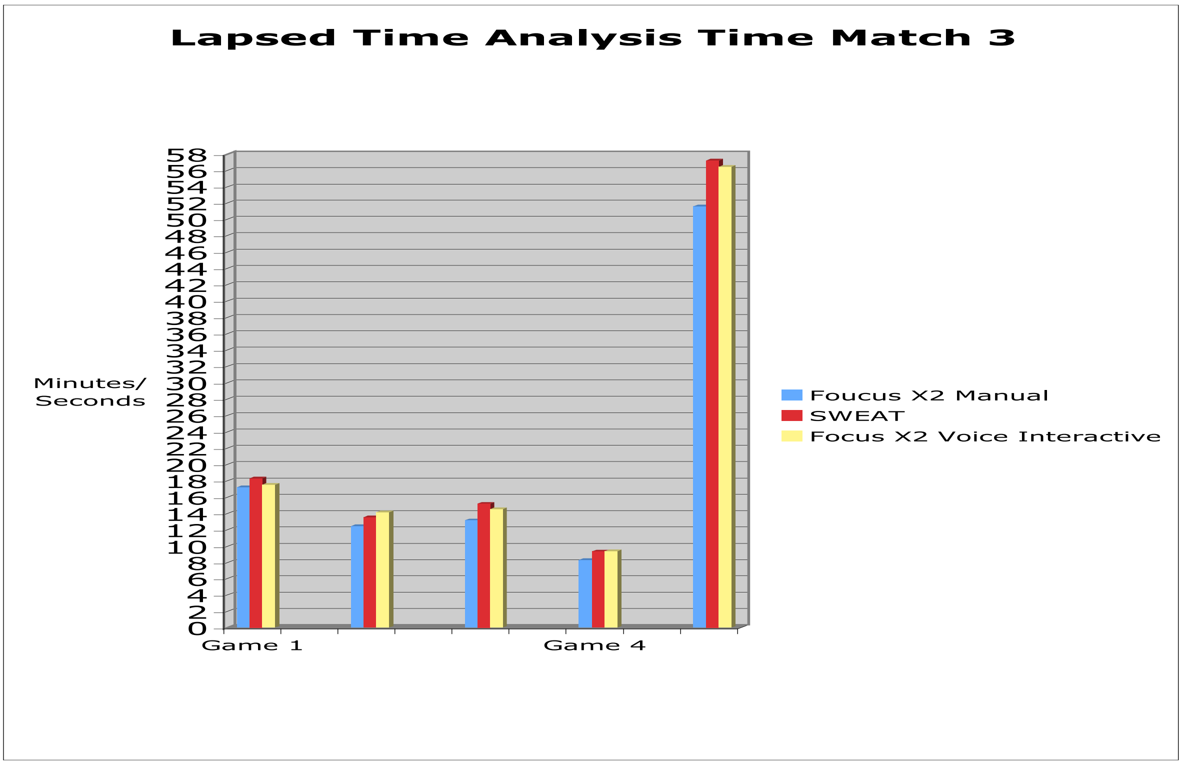

Figure 2. Graphical model of Lapsed time Analysis Time Match 3.

Table 8. Lapsed time Analysis Time Match 4.

	Game 1	Game 2	Game 3	Game 4	Total Analysis Time
Focus X2 Manual	16	8	13	16	53
SWEAT	17.2	10	14.2	16.8	58.2
Focus X2 Voice Interactive	17	9	12.8	16.2	55

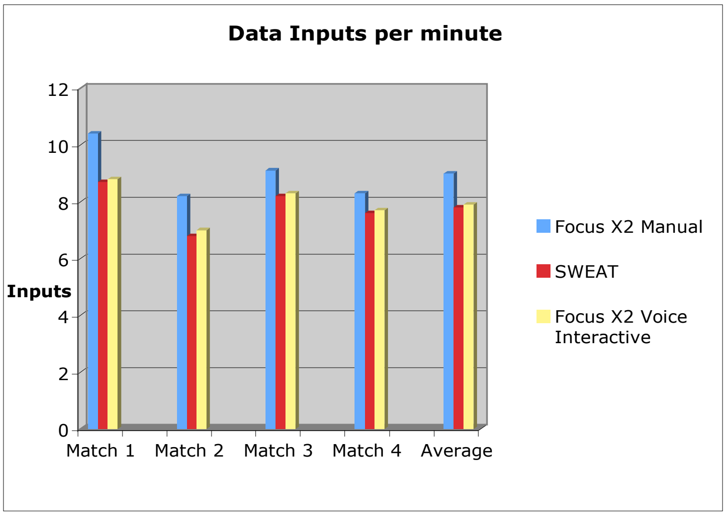

Figure 3. Graphical model of Data Inputs per minute.

Real Time Efficiency

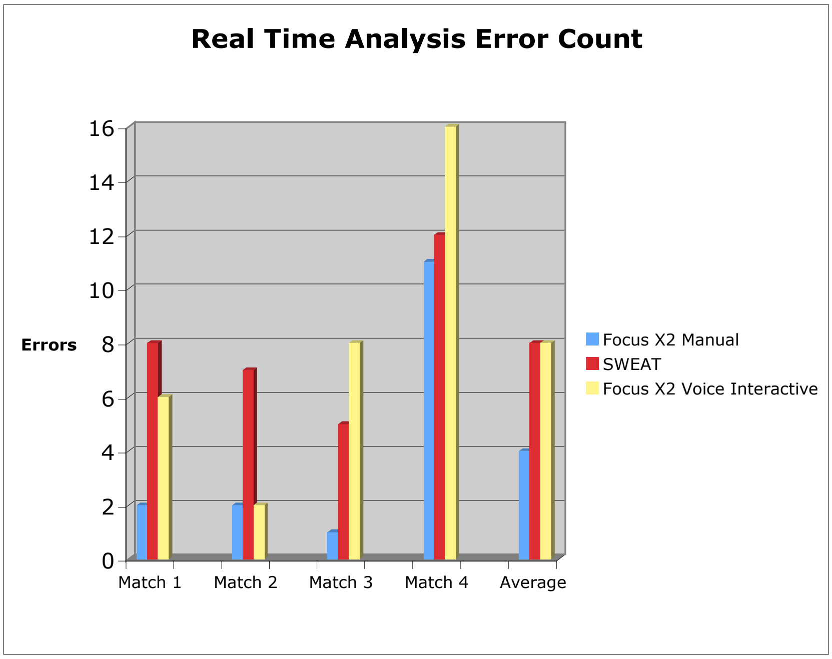

Figure 4. Graphical model of Real Time Analysis Error Count.

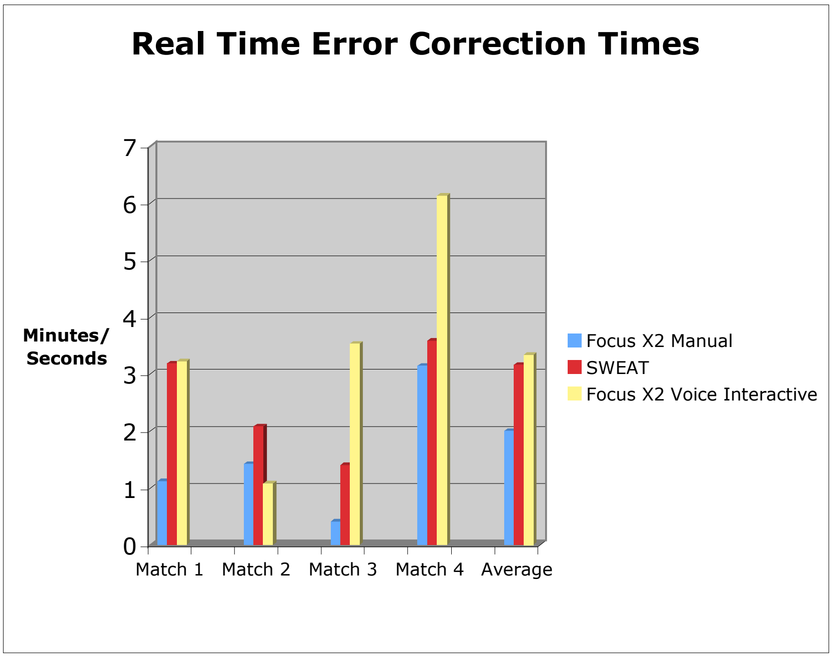

Figure 5. Graphical model of Real Time Analysis Error Correction Time.

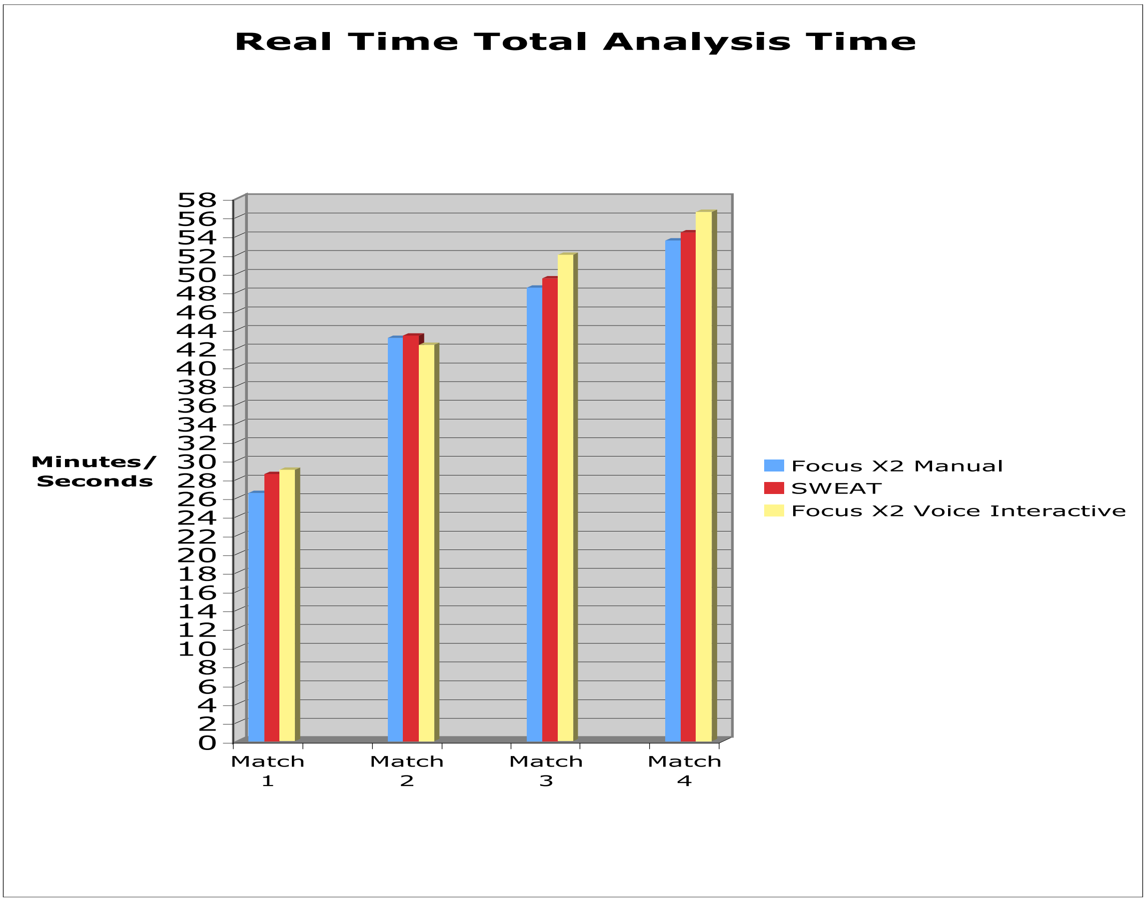

Figure 6. Graphical model of Real Time, Total Analysis Time.

Focus X2 Manual System

The results produced from this investigation highlighted that the Focus X2 manual input through a mouse is the most efficient in the study. This is witnessed through both the lapsed time analysis and real time match analysis. This could be suggested to be due to the researcher having previous usage experience of this system. However, to reduce bias in the study there was significant training on the SWEAT system and Voice interactive system that enabled valid and reliable results.

The times shown in the lapsed time tests show the greatest efficiency rating (Tables 6 and 7; Figures 2 and 3). The lapsed time analysis times, 28 mins 33 secs (match 1), 45 mins 58 secs (match 2), 51 mins 57 secs (match 3), and 54 mins 58 secs (match 4), do not show much of a difference to those of the real time analysis times (25 mins 38 secs ; 41 mins 27 secs ; 48 mins 08 secs; 54 minutes 58 secs respectively). These small diferences highlight the efficiency.

From the lapsed time tests the results furthered the suggestion of the efficiency of the Focus X2 system, through the number of data inputs completed every minute with an average of 9 (inputs a minute) - in comparison SWEAT system produced an average data input a minute of 7.8 (inputs a minute) and voice interactive 7.9 (inputs a minute) retrospectively (Table 8).

The real time match analysis results showed the systems‘ efficiency through the error count being continuously lower than that of the corresponding analysis system. The Focus X2 manual average error count was 4, whereas the SWEAT system had an average of 8, and the voice interactive average also being 8.

SWEAT System

On the completion of the tests the results showed that the SWEAT system required the most training, (see Table 3), 6 tests required. This could be a consequence of the researcher having minimal contact with this system before the study, unlike in the two corresponding systems where the researcher had previous experience. The difference between the SWEAT system and the Focus X2 Manual and Voice Interactive is the ease of immediate use. Both the mouse and the microphone are easier to pick up and use than the keyboard with short cut keys. This reiterates the importance of training, to train the use of short cut keys and the coordination of processing inputted data. A study by Debaere et al (2003) investigated changes in brain activation during the acquisition of a new bimanual coordination task and it was observed that activation changes account for the transition from highly attention-demanding task performance, involving processing of sensory information and corrective action planning, to automatic performance based on memory representations and forward control. This shows that through training the brain in task performance can improve human memory of task and coordination, this is also demonstrated in the training study results.

The real time analysis results produced some findings that were opposite to the expectations. The hypothesis stated the real time analysis to be the most efficient system but the results showed this was not the case. Analysis times produced from the tests showed that in real time analysis SWEAT system was the second faster system (Figure 6) with times of 28 minutes 56 seconds (match1) compared to 26 minutes 50 seconds (match1) using Focus X2 Manual. However, the results did highlight that the analysis conducted using the SWEAT system produced the most amount of errors in match 1: 8 and match 2: 7 input errors (Figure 4). This could be a result of a slip of a finger by the operator, in addition when using SWEAT system one would have had to scroll to find the appropriate shot key in the short period of time between the rallies. The most efficient characteristic of the SWEAT system was the time in which it took to edit the errors made. The editing facility is very quick as all the operator had to do was highlight the error and key the correct statistic into the data timeline.

From the lapsed time analysis of the SWEAT analysis system it was shown that there was a great difference between the Focus X2 manual system (Tables 6 and 7; Figures 2 and 3). and the SWEAT system. Though this wasn't expected from the results at the beginning of the study, the researcher found that the time was taken in the lapsed time analysis from the system not having the footage as part of the system. As a DVD player was required, it meant that every time a rally ended the DVD player had to be paused, data had to be inputted and if required, footage rewound and then the DVD being started again. Whereas, on the Focus X2 manual system and the Voice interactive system the video is on the software allowing quick pause and rewind and data can be inputted there and then. These results demonstrate that the SWEAT analysis system is most efficient as a statistical system used in real time analysis to allow the athlete to gain game data to help improve performance. Nevertheless, if video footage feature would be added to the SWEAT system then the efficiency and feedback characteristic would be enhanced. This would allow a coach to use the video footage as a tool for player development in the review stage after the performance to back up statistics with actual footage this was a view described in a study by Brown et al (2008) into Split Screen System to Analyse Coach Behaviour: In a Case Report of Coaching Practice, it was found that the coach found the video sequence feedback to be more useful than the quantitative information produced. This backs up what is suggested in this study that the SWEAT system requires a video input device to improve feedback to player and will enhance efficiency of analysis. Allowing the athlete to visualise corrections required and new tactical profiles on opponents.

Focus X2 Voice Recognition System

Through the investigation it has been shown that the results from the Focus X2 Voice Interactive system are the least efficient in winner and error match analysis in squash real time analysis. This is witnessed through the error count being largest in match 3 and 4 (Figure 4) 8 and 16 input errors retrospectively. Nevertheless, it has been calculated and, the average error count for the study was Voice Interactive 8 error inputs SWEAT 8 (error inputs) and Focus X2 Manual 4 (error inputs). This shows identical error inputs to that of the SWEAT system, however, from analysing the error correction times the Voice Interactive System has the largest average correction time (3 minutes 50 seconds) than that of the SWEAT system (2 minutes 56 seconds). This highlighted the Voice interactive system as being the least efficient system in real time winner and error squash match analysis.

However, from the results of the Lapsed time match analysis the Voice Interactive system is suggested to be the second most efficient system of the study. This is illustrated from the systems data input per minute capabilities.leading to an average of 7.9 data inputs a minute which is larger than that of the SWEAT systems average 7.8 data inputs a minute, though smaller than Focus X2 manual 9 data inputs a minute. Whilst the Voice Interactive system had a larger data entry average, the actual analysis times seen in the results show some anomalies to the suggestion that the Voice Interactive system is second most efficient. In match 1, games 2 (10 minutes 36 seconds) and 3 (13 minutes 41 seconds) (Table 6) it can be seen that the actual analysis times are larger than that of the SWEAT analysis times (Table 6). Nevertheless, as game 1's time was smaller this meant that the Voice Interactive system having the larger data input, a minute statistic. Further anomalies were found in the results data for match 4 game 3 where the analysis times were greater in the Voice Interactive analysis, it is suggested that this is because of error whilst rewinding footage leading to enhancing of time causing the anomaly.

Conclusions

From this investigation it can be concluded that there are differences in the efficiency profiles of the three match analysis systems analysed. The Focus X2 manual (mouse) system was most efficient in real time and lapsed time analysis. Furthermore after conducting a comparative case study on the three-match analysis systems, indications of ergonomic characteristics, both positive and negative, were very apparent during the usage of these systems.

This study confirms that future technological development can influence the efficiency and ergonomics of squash match analysis systems, further research should include an analysis of the movements and energy expended and/or movement of body parts.

Finally it was suggested by Bartlett (2004) that to optimise performance and human computer interaction of match analysis systems, the application of artificial intelligence be investigated for athlete/coaching analysis. We are still waiting for some of these ideas to be applied in many of the fields of performance analysis, but it is suggested that the application of artificial intelligence be investigated for extending the automation of data entry in performance analysis as a first step in this process, and it is hopedthat other researchers can use some ideas put forward here as a starting point for expanding the research in this area.

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Rhythmic Sonic Feedback for Speed Skating by Real-Time Movement Synchronization

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Abstract

A unique problem associated with the movements of a speed skating athlete inspired this practical work, looking into the question of using interactive auditory feedback to improve sporting movements and sporting movement acquisition. Presented here is a method for synchronizing the periodic movements of a subject against the movements of a model and sonifying that synchronization data in real-time. The sonic feedback is designed to convey information related to how the movements of a subject match against those of a model. A simple, inexpensive sensor system is created to capture speed skating movements and facilitate the sonification. The effectiveness of the system is demonstrated with two case studies. The first case study involves an experienced skater who had developed a significant anomaly in his technique, who uses this system to become aware of and correct his undesired movements. The second case study involves a new and inexperienced speed skating athlete who accelerates the acquisition of speed skating skills by listening and reacting to the relationship between his movements and those of a skilled speed skating athlete. While speed skating is used to demonstrate this sonic feedback technique, the algorithms can be applied to any repetitive movements.

KEYWORDS: SONIFICATION, MOTION ANALYSIS, AUDITORY FEEDBACK, AUGMENTED REALITY

Introduction

Walking, running and skating are all examples of repetitive movements. In therapeutic, sporting and everyday settings people attempt to refine, improve and correct these types of movements. The kinematics associated with a repetitive movement is periodic and so measurements of these movements lead to periodic waveforms (Figure 1). We can compare periodic waveforms to measure how closely they match. A comparison of waveforms produced from measurements of two people performing a repetitive movement will give an indication of how closely the movements of those people match.

We present here a signal processing technique to compare and synchronize relative data taken from multiple people performing a repetitive movement. We use the synchronization data to form the basis of real-time interactive sonic feedback. The sonic feedback comes in a discretized format synchronized to periodic movements. In addition, we show how the comparison information can be used to identify key windows when corrective or instructive sonic feedback can be provided, coaxing or correcting certain behaviors.

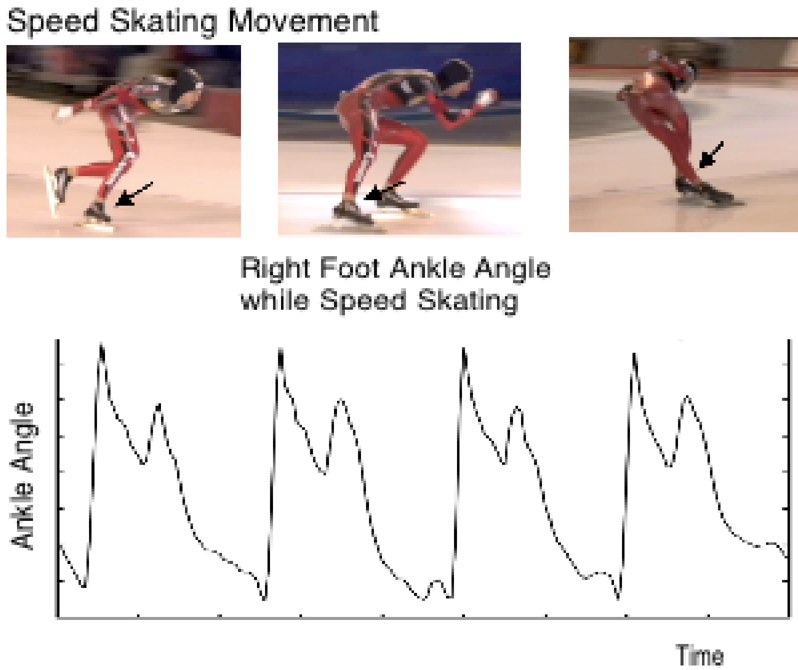

Figure 1. Measuring repetitive motions, produces periodic waveforms.

Our methods are unique in that we create a rhythmic sonic feedback by synchronizing two signals in real-time. We can communicate corrective information regarding a specific movement with little specific knowledge about that movement. The system we demonstrate requires little calibration and makes use of relative data, allowing for simple and cost effective sensors to be employed.

We demonstrate the methods with an economical, custom built sensor system designed to track speed skating movements. We synchronize the movements of a model skater to those of a subject skater in real-time and broadcast rhythmic sonic feedback synchronized to the periodic movements. The sonic feedback is designed to elicit in the subject skater the behaviour of the model skater.

We present results from use of the system on two specific speed skating subjects. Our first subject, hereafter referred to as Subject A, displays a particular anomaly in his stride. We are able to synchronize his movements to our model and use that information to identify the anomaly and broadcast corrective feedback to help him ameliorate his stride. Our second subject, hereafter referred to as Subject B, is new to speed skating and lacks the fluid and relaxed movements of an established skater. We use our system to synchronize his movements to our model, creating a feedback that describes the differences between he and the model.

The following three important aspects of our method should be noted.

- We do not require absolute measurements of pose (joint angles and body positions). This reduces the cost and complexity of sensor systems.

- We show that relative data from two repetitive motions is sufficient to synchronize them. While we demonstrate this with speed skating, it can be applied to any repetitive motions.

- We give a framework for how to provide sonic (or other) feedback sychronized to a periodic motion.

Relative Data

A measurement system that can consistently reproduce a measurement under identical conditions is said to be precise, while a sensor that produces a measurement that closely matches the true value is said to be accurate. A measurement that may not be accurate but is precise within a single session we call a relative measurement. Relative measurements preserve the shape of a signal but not the absolute value or scale. Our methods require only signal shape to be preserved and as such relative measurements are sufficient.

Background

We became aware of a speed skating athlete, Subject A, who was previously a national calibre speed skating athlete, but after developing an anomaly in his stride was struggling in the sport. This athlete repeatedly made the same error during the same part of the speed skating cross-over stride. Although rare, instances in which an athlete struggles performing a previously known movement is called *Lost Move Syndrome* (Day et al., 2006). While we were investigating synchronization and sonification, the unique opportunity posed by this skater provided motivation for our work.

Speed Skating

Subject A, displayed his erroneous movements only while executing a speed skating cross-over stride. As such we'll focus specifically on that repetitive periodic movement in this paper. Figure 2 shows a plot of right ankle angle versus time in a cross-over from our model skater. The plot is divided into the three components that make up a cross-over.

- **Right Foot Pushing:** the skate is in contact with the ice as the skater pushes (Figure 2 - A),

- **Right Foot in Air:** the skater lifts his skate off the ice and moves it across the left skate (Figure 2 - B), and

- **Right Foot Prepares to Push:** the skate blade contacts the ice (the set-down) as the skater prepares to push again (Figure 2 - C).

Efficient cross-overs are critical to achieve top performance in speed skating and ankle angle is an important factor in determining the amount of pressure being applied into the ice and subsequently the speed being generated by a skater (Jun et al., 2007).

Figure 3 illustrates the problem associated with the cross-over of Subject A. Described briefly, he plantar flexes immediately before putting his skate onto the ice during Component B of a cross-over. While plantar flexion is a desired movement in certain portions of the speed skating cross-over movement, Subject A is plantar flexing at a time in the stride that causes his skate blade to dig into the ice. This results in instability, loss of speed and risk of crashing. His problem persisted for 14 months and he was unable to correct his problem using traditional coaching methods. During those 14 months our subject describes that he was unable to perform any cross-over strides in a correct manner. Moreover he describes that in each instance he feels surprised when his toe digs into the ice, he perceives that his foot is in a proper position to execute a correct cross-over.

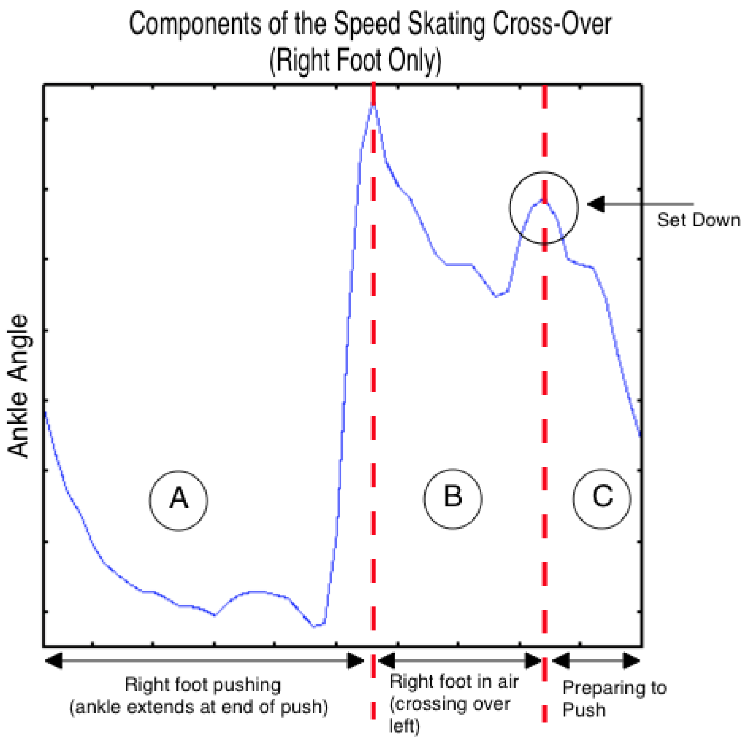

Figure 2. The Speed Skating Cross-over – Ankle angle versus time.

We detail another speed skating subject later in this paper. But it was Subject A who inspired and motivated many of our methods and decisions. Our methods have application on repetitive movements in general but our system was tailored to work with this special case.

Figure 3. Consecutive frames in video of Subject A during Component B of a cross-over. The skate blade is highlighted to show the open clap skate upon set down.

Sound in Sport

We focused on sound as our communication medium, sound has the potential to integrate in a non-distracting manner for an athlete that is taxing their visual, tactile and balancing senses. Naturally occurring sounds like a skate blade gliding on ice or a golf club impacting a ball are common in sport and can influence an athlete (Roberts et al., 2005). In recent years we have seen numerous instances of sporting data being sonified to provide additional information to athletes and coaches. Running pace (Hockman et al., 2009), rowing boat velocity (Schaffert et al., 2009; Schaffert and Mattes, 2011) and karate movements (Takahata et al., 2004) have all been electronically analyzed and used to control or create a sound that is communicated back to the athlete. The ability of a subject to mimic the jumping height of another subject using sonified jumping data (Effenberg, 2005) shows the potential for sound as a teaching tool. Especially for repetitive motions like walking, music and sound have successfully been employed in therapeutic ways for Parkinson's and Tourette's patients (Sacks, 2007). Sonifying the differences between an optimal movement and a subject's movement have been shown to increase abilities with complex motor tasks like shooting (Mononen, 2007; Konttinen et al., 2004).

As noted by Sigrist et al. (2011), when comparing augmented auditory feedback during a rowing task against augmented visual feedback, auditory feedback has the potential to be less distracting but also more powerful as a learning tool. This seems especially true for tasks related to movement timing (Doody et al., 1985). Staying within the speed skating domain in a recent study by Stienstra et al. (2011), the recordings from sensors attached to a subject's skates were mapped to sound characteristics like sound intensity. This informed the athletes in real-time of quantitative data such as skate orientation, speed and force. Loud or intense sounds were mapped to data relating to powerful speed skating strides and in this way athletes could augment their perception of how much power they were generating in each stride, with what was actually happening.

Humans quickly learn and predict sounds and rhythms. This predictive nature of our brains is often exploited by musicians allowing them to change patterns and create melodies that we perceive as surprising or interesting (Levitin, 2006). While the music world has been exploiting the pattern matching and predictive nature of our brains, the sporting world has lagged behind in taking advantage of our sonic entrainment. We are cautioned however, that as musical complexity increases, our abilities to synchronize to those complex sounds is strained (Chen et al., 2006). We are striving to use simple sounds that allow us to take advantage of both human entrainment and the predictive nature of our brain to teach and correct sporting movements. Sonifying the synchronization of two athletes is what sets our work apart. We do not convert physical data related to one person into sound, we convert the relationship between the movements of two people into sound, thus allowing one athlete to experience and explore that relationship in an interactive auditory-based manner.

System Description

This section describes the system we created to measure ankle movements of our speed skating subjects along with descriptions of both our synchronization methods and sound generation algorithms.

Apparatus

We use a single variable-resistance elastic, depicted in Figure 4, attached between the toe and shin of a skater to continuously measure ankle angle. As the athlete skates, a netbook computer carried in a backpack measures the elastic's resistance, R_s, at 30 Hz. The plot in Figure 2 was obtained from this apparatus. At less than \$500, the cost of our entire system is only a fraction of what other options like video based motion capture or motion capture suits cost. The simplicity of the system and little requirements for calibration or time consuming manual body measurements make this system practical for use with real athletes in the sporting environment.

Synchronization

The most important aspect of our system, is its ability to accurately synchronize a subject's skating stride to that of our model's stride. The following is a description of our brute-force method to estimate the phase of a speed skating stride from a single sensor stream.

Let g be the model signal of n samples containing a single cycle of data from the sensor. If f is an n-sample segment from the on-line sensor data (we use the most recent n samples when synchronizing on-line in real-time), we can use a correlation (Gonzalez and Woods 2008) to compare f to the model signal, g, i.e.,

$$h = f \otimes g,$$

$$= \sum_{i=0}^{n-1} f(i)g(i)$$

The magnitude of h is a measure of how well f matches g. However, f is periodic, and there is no guarantee that the phase of f will match that of g, so we must consider the set of models given by $g((i+s)\bmod n)$ where $0 \le s < n$ determines the phase shift of the model.

Now consider the correlation

$$h(s) = \sum_{i=0}^{n-1} f(i)g((i+s)\bmod n)$$

Therefore, phase, ϕ, of f is

$$\phi = \frac{1}{n}\arg\max_{s} h(s)$$

and $\max_s h(s)$ indicates how well f matches the model. Note that $0 \le \phi < 1$.

Now suppose that we know the shape of each cycle of the signal, but we do not know the frequency. In this case, we need a set of models, g_n,where the subscript n indicates the number of samples in g_n. Assuming constant sampling rates, n, being the number of samples in one full cycle, determines the period (and therefore the frequency) of the stride. The matching function becomes

$$h(s,n) = \sum_{i=0}^{n-1} f(i)g_n((i+s)\bmod n).$$

We can determine the correct period of the model, $\hat{n}$ with $\hat{n} = \arg\max_n \max_s h(s,n)$, and the phase with $\phi = \frac{1}{\hat{n}}\arg\max_s h(s,\hat{n})$. The absolute measurements from the sensor vary with temperature, length of sensor, and where it is mounted on the toe and shin of the athlete. Given that we cannot control these factors, it is essential to *normalize* f and g with a linear transformation such that:

$$\sum_{i=0}^{n-1} g(i) = \sum_{i=0}^{n-1} f(i) = 0$$

$$\sum_{i=0}^{n-1} g(i)^2 = \sum_{i=0}^{n-1} f(i)^2 = 1$$

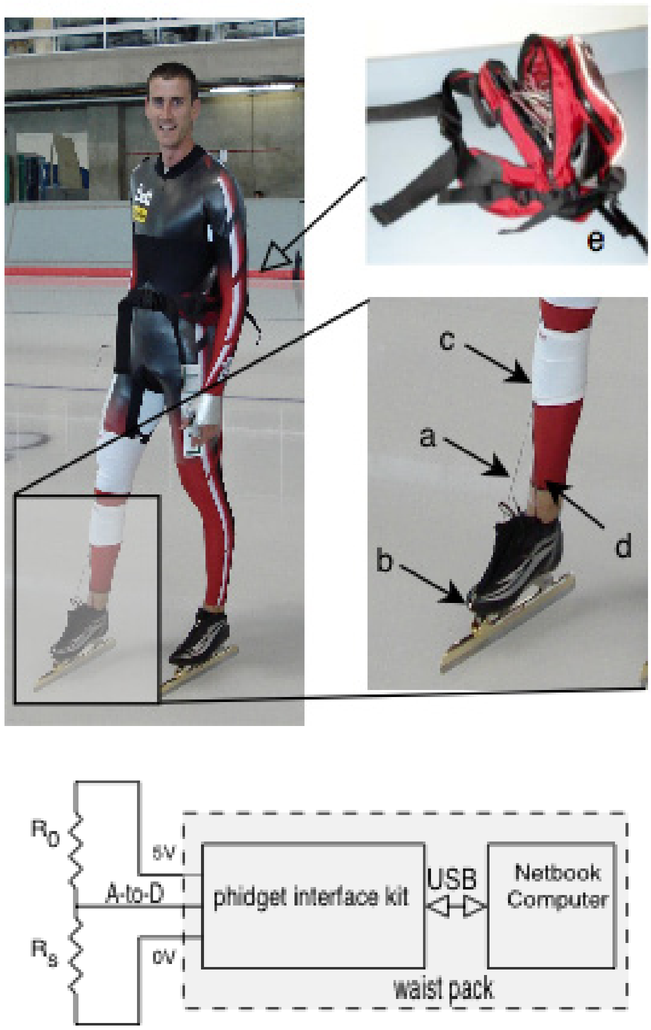

Figure 4. Top: The sensor installed on the model skater: The variable-resistance elastic (a) is connected between a skate lace near the toe (b) and an elastic joint-support band (c) (used only to fasten the sensor). In this configuration, R_s (and therefore the voltage measured by the interface kit) increases with ankle extension. Leads (d) connect the sensor to the phidget interface kit (http://www.phidgets.com) and netbook computer worn by the skater in a waist pack (e). Sound is broadcast using headphones (not shown). Bottom: The sensor circuit.

Note that a perfect match between skater and model yields $h(s,n) = 1$ when f and g are normalized this way. Computing the phase match for successive samples f, results in a ramping from $\phi = 0$ to $\phi = 1$.

Sonification

Rhythmic Arpeggio

Once the phase is matched successfully the stride cycle can be sonified. We worked within the Pure Data (http://puredata.info/) environment to do the sonification. We take advantage of the rhythmic nature of a periodic movement and use that to control the cadence of musical notes we broadcast to a subject. Breaking the speed skating stride into four equally spaced sections, we mark milestones on the boundaries of these sections. We have milestones at: $\phi = \{0.25, 0.5, 0.75, 1\}$. We embed musical notes at these milestones, so that as the phase of the stride passes a milestone a musical note is broadcast. We select four sine tones from a C-major chord as the notes. The frequencies of the four tones are: 261.6 Hz, 329.6 Hz, 391.9 Hz, and 523.2 Hz. We assign each note to a corresponding phase milestone in order:

$$\phi = \begin{cases} 0.25 \rightarrow 261.6hz \\ 0.50 \rightarrow 329.6hz \\ 0.75 \rightarrow 391.9hz \\ 1.00 \rightarrow 523.2hz \end{cases}$$

The result is that as a subject performs the same movement as a recorded model an arpeggio of musical notes is broadcast. The arpeggio provides both an order and relationship for the information the subject is receiving, allowing him to determine not only which part of the model stride he is currently aligned with but also how long it took him to execute the movements associated with that phase as compared to the model. If the model and subject are perfectly synchronized then the subject will hear equally spaced musical notes, but if the subject slows or speeds up as compared to the model for a given phase window it will be reflected in the time between musical notes. As an example if a subject rushes through movements that fall in the phase window between phases, $\phi = 0.25$ and $\phi = 0.50$, then he will hear musical notes that are closer together in time. The sine tones are improved for asthetic purposes, by adding an attack to the tone using an envelope.

Exploiting the Phase Information

A reliable and accurate phase matching gives us the ability to focus on any part of the stride. We can use this synchronization to identify key phase windows when a subject is likely to perform an erroneous movement or omit a desired movement. The data need not come from the same sensor or body area that is being synchronized against but it is the phase matching from that sensor that allows us to know the phase of the subject. In the case of Subject A, we use this phase information to determine when he is in the key time period when he digs his toe into the ice, that time immediately preceding set-down.

Our system is designed such that the ankle sensor we used to synchronize with is also sufficient to monitor his ankle movements, specifically determining when he is plantar flexing. We use the phase information to tell us when he is in the problematic window of time and then consult the sensor to determine if we think he is exhibiting too much plantar flexion. We can then augment the rhythmic arpeggio feedback the subject is receiving with additional auditory feedback to help the subject correct his movement. Figure 5 shows a graphic representation of how phase information combined with ankle angle data is used to trigger corrective sawtooth tones. We employed three different training methods with Subject A, each making use of the phase matching and rhythmic arpeggio in combination with another auditory feedback.

Methods

During this section we focus only on Subject A, we use our system to improve his skating. We outline three different ways we used our system to help Subject A. Subject A had the consistent problem of digging the toe of his skate blade into the ice. We worked with him for a period of two months with approximately two one hour training sessions per week. The athlete also conducted his regular training regime and competed in a number of competitions during this time. We aimed to have the athlete use the system for as long a continuous period as was practical during a session. Ultimately we determined that fitting as many 3 - 4 lap repetitions in the one hour ice time was the most practical training method. Four laps last approximately 2.5 minutes total.

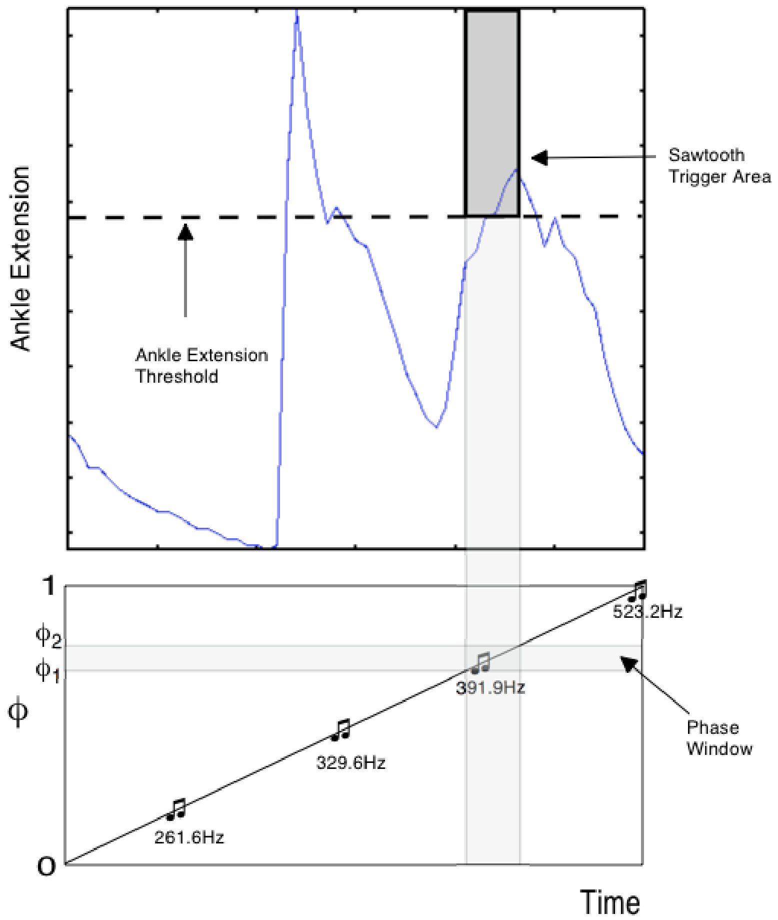

Figure 5. Phase is used to identify the window of time (highlighted rectangle) when we check if the subject is performing an incorrect movement.

We progressed through three main deployments of our system during the two months. We used our observations and feedback from the athlete to make necessary adjustments. Consistent throughout all our work with him, was the rhythmic arpeggio.

Corrective Feedback Training

Corrective feedback is the name we give to the training set-up we described in the Sonification Section. In this training we synchronize the subject against a model producing the rhythmic arpeggio but we use the synchronization and subsequent knowledge of the phase of the subject to identify the key window when the subject may plantar flex too much and thus dig his toe into the ice. During that key window we monitor the ankle sensor setting a threshold on the amount of plantar flexion we allow and broadcast a sawtooth tone if the threshold is surpassed. The sawtooth tone is scaled in intensity relative to the amount of plantar flexion measured. Figure 7 shows Subject A's skating stride before any training. Subject A was instructed to try to avoid making the sawtooth tone. We began with a modest threshold, slightly less ankle extension than what the subject was already doing. We gradually decreased the threshold allowing less and less ankle extension until we reached a level that would result in a correct cross-over.

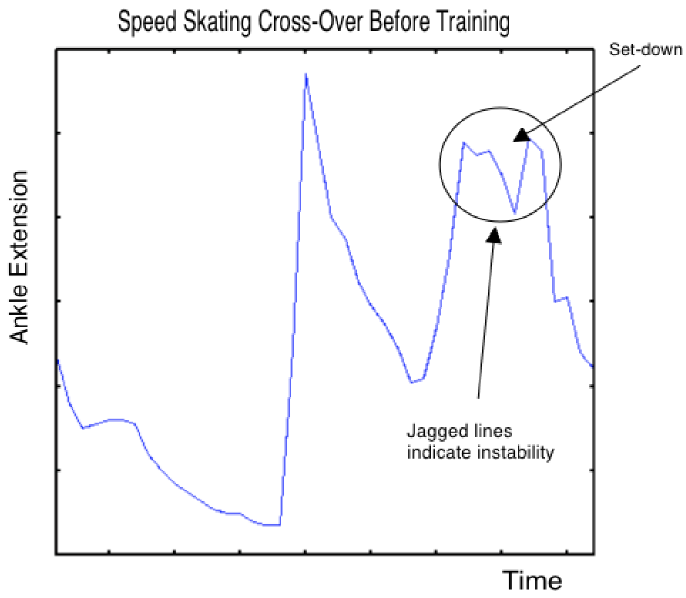

Figure 6: The skating stride of Subject A before training.

Awareness Feedback Training

Awareness feedback training is the name we give to the training we did with Subject A that required him to spend as much time as possible in the key window of time before setting his skate back on the ice. This requires no alterations to the hardware or software that is used in the corrective feedback set-up described above. Here we exploit the system and its ability to remain synchronized to a signal even when the subject is purposely performing non-standard movements. We instruct our subject to purposely create the sawtooth tone during the period before he sets his skate onto the ice. More specifically, we instruct the subject to turn the sawtooth tone on and off as many times as possible before setting his foot back down. The system is robust enough to continue computing phases that are in the key window of time when we want to examine the ankle angle and thus each time the threshold is surpassed the sawtooth is broadcast, and upon ankle angles that retreat below the threshold the sawtooth disappears. We are using the system to create an awareness of the acceptable range of movements. The skater did not skate normally doing this, it was a modified skating stride that allowed him more time with his right skate in the air. The skater went slower and was more upright to allow for this additional movement.

Instruction Based Training

Instruction based training changes our system from reactive to proactive. Rather than giving feedback after the ankle extension exceeds a threshold, we provide a prompt telling the skater when we predict he should extend his foot to meet the ice. We try to manufacture the set-down point. The aim here is to not allow the athlete enough time to perform his incorrect movement. Instead we prompt the athlete to set-down before he has made the incorrect movement. There no longer is a corrective feedback aspect but rather we use the phase matching information to determine when we think the skater should try to set down his foot.

We produced a bell tone at what we thought was the appropriate moment to start setting the right foot on the ice. The skater was instructed to extend for the ice with his right skate each time he heard the bell. We did not want to allow the skater enough time to extend his ankle pointing his toe to the ice. With enough training the manufactured set-down point might become the athlete's natural movement.

Results

General Results

The system was successful at synchronizing the movements of different athletes. Each of Subject A and B received the same rhythmic arpeggio feedback based on the synchronization data. Prior to training with the system each subject displayed a discomfort with the cross-over movement. This discomfort manifest itself in a rushed and hurried movement. Our model skater typically executed a cross-over during a period of 1.5 seconds which in contrast, at similar speeds, our subjects executed the movement in 1.3 seconds. Our model was covering more distance per stride than each of the subjects. Almost immediately upon training with the system each subject modified their cadence to match that of the model. Figure 7 shows a plot of Subject B's skating stride, first the untrained stride and then the stride at the second training session. Although the athletes slowed their cadence, they maintained their skating speed by increasing the distance they covered per stride.

Discussion

Each athlete displayed improvements relating to their stride rate within a few training sessions with the system. Given that Subject B was new to the sport, his improvements were not surprising. We were however surprised at the quick progress of Subject A. Subject A had problems with his cross-overs during a continous 14 month span. During this time he repeatly executed incorrect cross-overs and that incorrect movement became ingrained into his motor pattern. Knowing that the subject had tried many different possible solutions to this problem without success, we anticipated a slow improvement process.

Regarding Subject B, it is important to note that he was an accomplished athlete in other sports, but he was new to speed skating. We anticipated that he would improve quickly at speed skating regardless of the type of training he received. We were aiming to aid his comfort level on the ice and further accelerate his learning. His racing results improved with each race in a dramatic fashion, however it would be impossible to determine a measure of which training was responsible for his improvements.

We attribute the slowed and controlled movement to an increased comfort level afforded by the rhythmic arpeggio. The athletes were able to maintain their speed while slowing their cadence due to an increase in the duration of the pushing phase of the stride. They were spending more time on the beneficial portions of the stride, applying the positive attributes of the model's timing to their own stride. In Figure 7, we see less erratic or jagged lines during component A of the cross-over when comparing the second plot to the first. This indicates a more efficient right foot push and thus increased generation of speed.

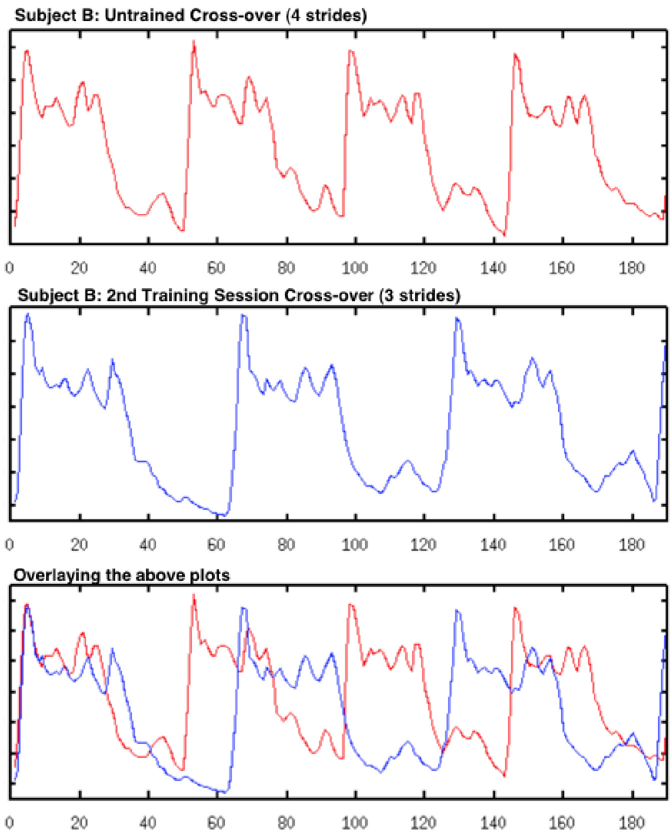

Figure 7. Evolution of Stride for Subject B.

Specific Results Relating to Subject A

The quick stride amelioration relating to the timing of the movements of Subject A, was not as evident with regards to his ankle angle problem. We trained the athlete with the three methods described changing the method if it became apparent that the training was not effective or if we determined it was not beyond what the subject had achieved with prior traditional training.

During Corrective Feedback Training, he did reduce the severity of the problem by reducing the amount of problematic plantar flexion but was never able to reduce it enough to solve the problem. The subject had achieved similar results during prior traditional training, a reduction but not extermination of the problem.

Awareness feedback training produced promising results. Using this training method the skater achieved flawless set-downs, as seen in Figure 8. The skater could immediately tell that his set-downs were proper and described it as the ``first successful set-down in 14 months".

The skater moved at a slower pace and with a more upright posture during this training to allow time for the deliberate ankle extension. Attempts at having him skate at a faster pace while doing these extraneous motions were unsuccessful. We were also not able to replicate the flawless set-down without first doing the purposeful ankle extension. The system proved extremely robust during this training, maintaining synchronization despite the attempts to alter the skating movement.

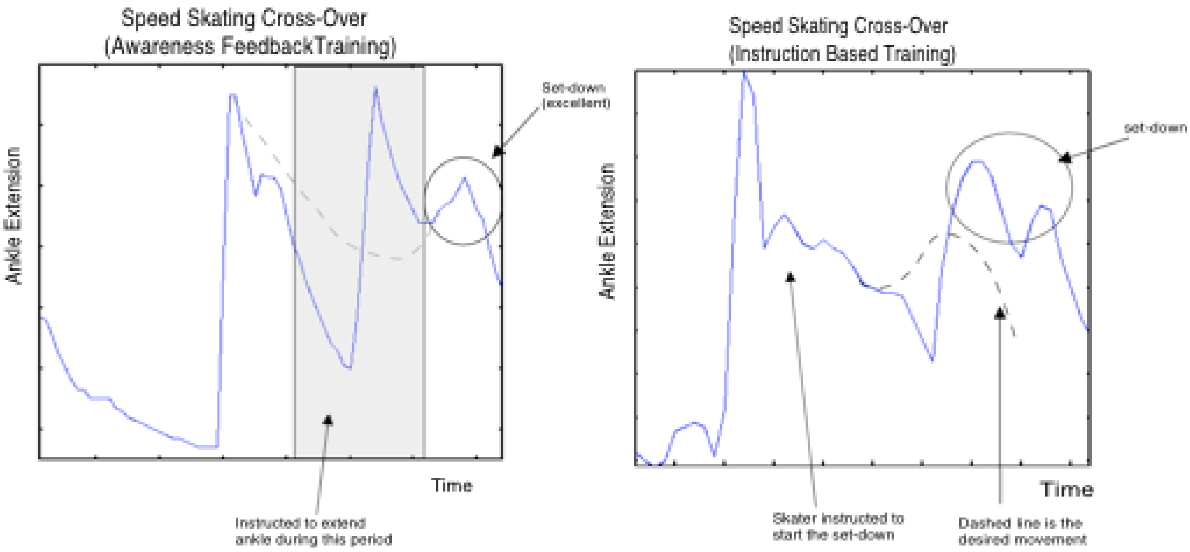

Figure 8. The skating stride of Subject A during training.

During Instruction Based Training we attempted to manufacture a right foot set-down for the subject. Upon hearing a bell tone the subject is instructed to begin setting his blade back onto the ice. We want the subject to avoid the chain of events that produce a flawed set-down. The struggles associated with modifying a previously learned movement are shown in Figure 6. Our subject attempts to override his ingrained movement upon hearing the bell tone, and while his initial movements look promising, he ends up reverting back to his old movement enduring similar results. Our subject achieved strong set-downs using this training method, however was unable to replicate the flawless set-down previously produced.

Discussion

With respect to our corrective feedback training our subject was able to mitigate but not solve the problem. In prior, traditional training our subject often attempted to pull his toes up as much as he could but was unable to avoid digging his toe into the ice. The fact that we broadcast a sawtooth tone predicting that his toe was going to dig into the ice, did not change the abilities of the skater to flex his ankle to a larger degree. He was not able to have a clean set-down but only mitigate the problem. Given that we did not observe results beyond what we knew the subject had achieved with traditional training methods we moved on, using the system in another manner.

The introduction of changes into the middle of the cross-over (the purposeful ankle extension), provided awareness to the athlete about proper ankle extension. These additional movements being new to the athlete were hard for him to control. It became obvious that we would need more training time for him to become more comfortable with the extra movement and to eventually eliminate it. During this training two things became clear:

- this training method fixed the problems occurring at the set-down point, and

- reducing the amount of purposeful ankle extension while maintaining a flawless set-down required a long training period.

We got to a point during this training, where the subject was able to avoid digging his toe into the ice. Unfortunately the manner in which he was skating to facilitate the extra movements were not conducive to efficient speed skating. Ideally we would have continued to pursue these promising results, and slowly reduced the extraneous purposeful ankle extension, but the time requirements for this did not fit the training schedule of the athlete.

Instruction based training was a challenging movement for the athlete, as we were asking him to execute a critical part of the cross-over earlier than he was accustomed to doing it. We were asking him to execute the set-down before he felt he was ready to do it. This placed a large stress on the athlete to try to execute the movement when the system wanted but also to make adjustments so that he was able to execute the movement without crashing.

We did observe some strong set-downs during this training, however on the whole the skating was unpredictable. It was clear that like awareness feedback training we required more than the two month window of training time to fully evaluate the effectiveness of this type of training.

Conclusions

A promising outcome from this research is the successful synchronization and sonification of the speed skating movement. While we attempted to aid specific skaters with their training, we were also exercising and demonstrating the capabilities of our augmented audio feedback system. We used case studies to evaluate the potential of real-time sonic feedback and to demonstrate the system with a real world problem.

With that said, we are encouraged by the progress we witnessed with each of the subjects. About his progress Subject A commented, ``The device was the only thing that was able to improve my skating." We only worked with Subject A during a two month period (after 14 months with the problem) as he was preparing for a race at the end of that time. After that race the athlete retired from the sport. We are confident that had we continued to work with him we would have continued to see improvements in his form.

Subject B, demonstrated the potential for using a system like this for people learning a new movement. The system allows a trainee to experience the timing of an experienced athlete in an interactive manner. This facilitates comfort with the movement and subsequently improves their movement.

We are encouraged by the potential for this type of feedback and plan to continue developing the algorithms to work on different movements and applications.

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ManipAnalysis – a Software Application for the Analysis of Force Field Experiments

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Abstract

Force field experiments are a common tool for research on internal models which are an issue of great interest in human movement science. In this paper we introduce the software ManipAnalysis which was developed for the analysis of such force field experiments. Thereby, we extracted common requirement specifications from recent studies and our own practical experience. Only depending on .NET framework, SQL-database, and MATLAB, ManipAnalysis offers a hand-in-hand solution ranging from data import and storage, up to visualization and export possibilities of calculated adaptation parameter values. Hence, ManipAnalysis fills the gap between data acquisition with the help of a robotic device and statistical analysis with statistics software applications.

KEYWORDS: MOTOR LEARNING, INTERNAL MODELS, ROBOTIC MANIPULANDUM, BIOMOTIONBOT, DATA ANALYSIS

Introduction

Motor learning is one of the core problems of human movement science. The last couple of years, especially computational approaches have led to rapid advances in our understanding of the mechanisms involved in motor learning (Wolpert et al., 2011). One of the key concepts in this context are so-called internal models. Internal models are neural representations of the mechanical properties of the limbs and objects in the environment. In a seminal paper by Shadmehr and Mussa-Ivaldi (1994), an experimental paradigm was introduced in which subjects had to adapt to a dynamic perturbation induced by a robotic manipulandum while performing point-to-point reaching movements in the horizontal plane. At the beginning of the force field training, the trajectories of the subjects revealed large distortions compared to the null field condition indicating that the internal model is not suitable anymore. With practice the distortions decreased and the subjects showed trajectories similar to trajectories they produced before the force field was turned on. This behavior was taken as evidence that the internal model was adapted. The theory of internal models and the experimental paradigm of force field experiments are now being transferred to the fields of neurorehabilitation (Huang & Krakauer, 2009) and sports training (Reinkensmeyer & Patton, 2009).

Our group developed a new 3D robotic manipulandum with end-point force control, called BioMotionBot (Bartenbach et al., 2011), that can be used in the context of internal model learning and additionally enables the development of tailor-made robotic-assisted training programs in rehabilitation and sports. However, in learning experiments and robotic-assisted training sessions, a great amount of data is accumulated. The recorded data sets have to be organized and stored in a way that is secure and enabling a fast access to the data to be able to analyze the conducted learning experiments or training sessions. To our best knowledge, there does not exist any commercial software application for the analysis of force field experiments. Therefore, the software ManipAnalysis has been developed which is presented in this paper.

ManipAnalysis

Requirements

In the case being considered, all relevant parameters of force field experiments (Cartesian coordinates, time stamps, etc.) are captured by the software of BioMotionBot and stored as text files. These text files are the basis for the analysis of the force field experiments and thus for the software application ManipAnalysis to be developed. This application has to satisfy various requirements. First of all, there are general requirement specifications such as reliability, maintainability, adaptability, portability, efficiency, and usability. However, there are additional requirements for the analysis of force field experiments:

- Convenient storage of collected data for efficient access for further processing steps.
- Computation of preprocessing steps like filtering, calculation of movement velocities, segmentation and time normalization of recorded data.
- Calculation of so-called baseline trajectories which are recorded while no forces affect subjects' hands. These are commonly used as reference to movements conducted under force field conditions.
- In research on internal models, the adaptation to perturbations induced by the robotic manipulandum is of general interest. Therefore, the magnitude of adaptation has to be quantified and the software application should provide common algorithms to quantify the degree of difference or similarity to baseline trajectories.
- Opportunity to visualize the results.
- Flexible data selection of specific subjects or trials for distinct calculations.
- Export alternatives for further external analysis (e.g. SPSS, R, MATLAB).

Architecture

ManipAnalysis is programmed in C#, which requires .NET Framework (v.4.0). All captured data sets are imported into a SQL-database, which in our case runs on a university server. Due to the SQL-database, all ManipAnalysis calculation results are consistently organized and centrally backed up. Therefore, different users do not have to repeat previously conducted calculations since these are stored in the database. This enables several users to work simultaneously on the same data set without being forced to use the same computer. By locally executing calculations on the users' computer and subsequently backing up the results in the database, ManipAnalysis offers a perfect trade-off between performance and security.

Mathematic calculations are executed by MathWorks MATLAB. ManipAnalysis runs stable with MATLAB V7.12 (R2011a) or newer. Using MATLAB makes the implementation of algorithms easy and comparable because most algorithms are already implemented. Additionally, these MATLAB algorithms are well-proven, efficient, and numerically stable. For the reasons of performance and usability, all MATLAB calculations are performed in the background meaning that the MATLAB graphical user-interface is not shown. This is managed by C# accessing MATLAB COM interface. However, switching to manual mode provides detailed control within the MATLAB workspace.

Modules

ManipAnalysis has a modular structure. Thereby each module is a component designed to cover a specific task. This separation of tasks ensures the greatest possible flexibility of the application which enables research-specific adjustments throughout data processing.

Input

The BioMotionBot records raw data at a frequency of 100 Hz. At each sample point, time stamp, Cartesian coordinates as well as forces and torques acting at the handle of the robotic manipulandum are recorded. Additionally, information about the experimental setup (e.g. type of force field, movement number and direction, subject-related information) is registered. The import tool automatically distinguishes between these different types of data. Selected raw data is automatically imported, classified, and stored in a SQL-database.

Preprocessing

The preprocessing procedure consecutively computes the steps filtering, calculation of movement velocities, data segmentation, and time normalization. In biomechanical research, recorded data is often affected by high-frequency noise which has to be attenuated by filtering or smoothing the signals. ManipAnalysis handles this using a Butterworth low-pass filter (Robertson et al., 2004). Filter order and cut-off frequency can be adjusted on the user-interface. Based on the filtered data movement velocities are calculated. All time derivatives are numerically computed by central difference method (Robertson et al., 2004). In force field experiments, usually point-to-point reaching movements are analyzed. Our segmentation algorithm is based on the idea that the movement starts if the cursor leaves the starting point and ends if the cursor reaches the target point. Afterwards, the segmented data sets are time normalized to make them comparable. Time normalization is executed by cubic spline interpolation of recorded data points and subsequent rescaling the sampling rate as a percentage of the duration (Robertson et al., 2004). Additionally, the baseline trajectories are calculated by averaging selected trajectories that were recorded while no forces affected subjects' hands. All processing steps can be performed manually or automatically. The results of each processing step are stored in the database.

Analysis

The centerpiece of ManipAnalysis is the calculation of several adaption parameters to quantify the magnitude of adaptation. Even though the experimental setup mentioned above is well-established, there is no consensus concerning the adaptation parameters. Rather, in recent studies both plenty of different adaptation parameters and calculation methods were used. ManipAnalysis enables the calculation of the most frequently used adaptation parameters. On the one hand this allows a specified analysis depending on the underlying experimental setup. On the other hand this might illustrate to what extent results are affected by the chosen analytical method. Hence, ManipAnalysis supports the following parameters: (1) Velocity vector correlation coefficient, estimating the similarity of trial and baseline trajectories (Shadmehr & Mussa-Ivaldi, 1994; Caithness et al., 2004). (2) Orthogonal reference functions, estimating the similarity of trial and baseline trajectories (Stein et al., 2010). (3) Area enclosed by trial trajectory and straight line joining start and target points (Caithness et al., 2004) using Gauss' area formula for polygons. (4) Maximal and mean perpendicular displacement from straight line joining start and target points (Davidson & Wolpert, 2004). (5) Perpendicular displacement at 300 ms after movement start (Shadmehr & Brashers-Krug, 1997) based on non-normalized data. (6) Length ratio of trial trajectory and line joining start and target points.

Visualization

ManipAnalysis supports three types of visualizations: (1) Mean movement time plots to control if subjects stick to the required movement time. This is necessary because in most experiments the force field is a function of hand velocity (Figure 2). (2) Typical center-out plots showing movement trajectories under null field and force field conditions (Figure 1). (3) Plots visualizing changes in selected adaptation parameters in the course of time. These can be shown for a single subject or as mean curve of a selected group of subjects (Figure 2).

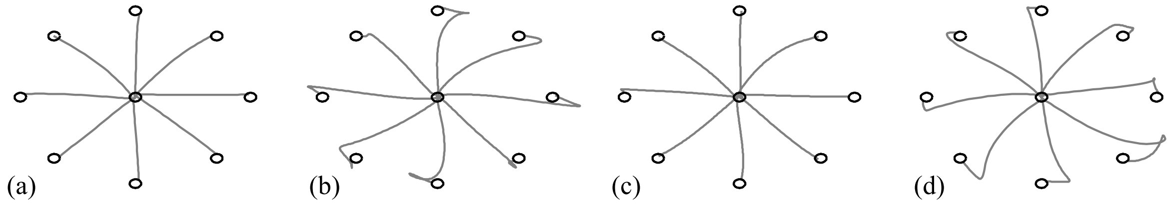

Figure 1. Typical trajectories of a subject at BioMotionBot executing reaching movements. Under null field condition, trajectories are straight (baseline trajectories, a). When exposed to a force field, trajectories are perturbed (b). With training, hand trajectories regain their prototypical shape (c). If the force field is removed after training, subjects show aftereffects (d). These aftereffects can be interpreted as overcompensation for the expected dynamic perturbation.

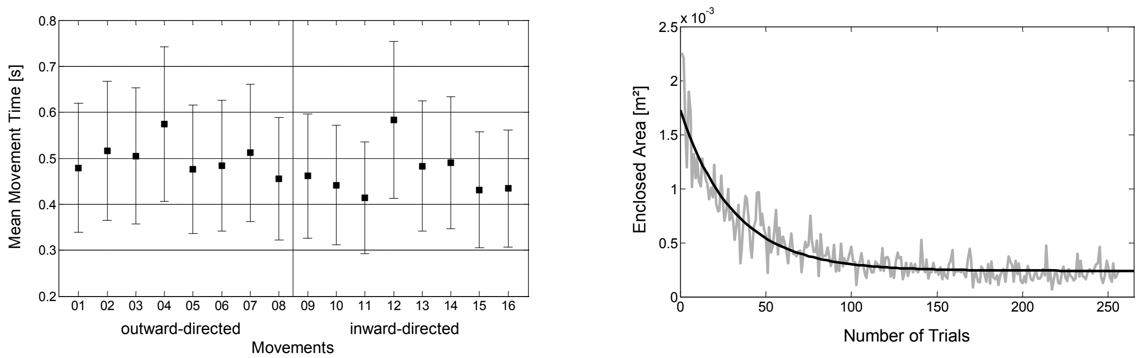

Figure 2. Mean movement time and standard deviation for each of the 16 types of movements over 16 sets: eight outward-directed (01-08) and inward-directed (09-16), respectively (left). Change in enclosed area by trial trajectory and straight line as a function of time. The shape of the curve indicates adaptation to the force field condition with increasing number of trials. Additionally, an exponential fitting curve is inserted (right).

Export

For further analysis with specific statistical software applications, ManipAnalysis provides three different kinds of exports: (1) csv-files containing preprocessed movement data for all subjects enabling manual and database unrelated calculations; (2) adaptation parameters averaged over selected movement intervals for individual subjects for the calculation of further statistical comparisons of different subjects at selected points of time; (3) adaptation parameters for each single movement of selected groups of subjects enabling both the analysis of homogeneity within a group and the comparison of different groups. For all exports the requested data can be selected individually. The csv-files are structured in a way that enables straightforward processing using common statistical software applications.

Conclusions

The purpose of this paper was to introduce the software ManipAnalysis and to consider it against the background of force field experiments. First, we pointed out general requirement specifications. Because only .NET framework, MATLAB, and SQL-database are needed, ManipAnalysis is portable, reliable and allows convenient storage of data. Due to its modular architecture, ManipAnalysis is adaptable and expandable in case of research-specific changes like differing experimental paradigms. That means ManipAnalysis is not limited to the analysis of traditional two-dimensional center-out movement tasks. Secondly, we considered a list of specific requirements for the analysis of force field experiments. Both computation of preprocessing steps and calculation of common adaptation parameters used in recent studies are executed by using MATLAB interface. Furthermore, ManipAnalysis offers flexible visualization and export opportunities. Altogether, ManipAnalysis handles all analytical steps beginning with the import and storage of data, up to adaptation parameter computation, visualization, and export of results. Therefore, the application fulfills all requirements mentioned above and fills the gap between data acquisition and statistical analysis.

Most importantly, ManipAnalysis is compatible to other robotic manipulanda. In general, recorded data of robotic manipulanda contain the same type of information. In case of another structure of recorded data, only the import module needs to be customized to use ManipAnalysis.

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Development of an Intelligent Real-Time Feedback System

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Abstract

A system for optimizing athletes' sport performances has been designed and partially assembled on the basis of the already implemented "Mobile Coaching" and "PerPot" concepts. The intention of Mobile Coaching is to assist sportsmen via feedback information derived from physiological and biomechanical parameters recorded during physical activity. PerPot is an antagonistic model for predicting load-based performance developments. By combining the main features of both approaches, the newly developed framework is able to automatically provide athletes with live-feedback during marathon running, thereby optimizing the performance by avoiding overload and underperforming.

KEYWORDS: SPORT APPLICATION, BODY SENSOR NETWORK, REALTIME FEEDBACK, SIMULATION, PERFORMANCE

Introduction

Sport applications for smartphones are modern and increasingly used by many sportsmen during physical exertions like running. The large number of "sport tracker apps" available on the market (such as Runtatstic™ or Skimble™) implies that there is a great interest in the public in improving the personal fitness and health levels. These frameworks offer various routines for descriptive evaluations and visualisations of measured parameters like heart rate, speed and GPS coordinates illustrated by street maps.

As a consequence of the rapid spread and establishment of various technologies (especially in the smartphone sector), the development of intelligent real-time feedback systems for a wide spectrum of possible sport applications becomes increasingly essential.

Methods

Idea and Concept of the Mobile Coaching System

The concept of the "Mobile Coaching" system (Baca et al., 2010) involves the idea of supporting users with feedback information during sport activities without the need of the presence of a coach. Based on the use of appropriate technologies (hardware and software) the following goals can be accomplished:

- Assistance during sport activities through real-time feedback and training improvement on the basis of feedback loops

- Generate automatic feedback based on techniques like artificial intelligence (AI)
- Increasing motivation by promoting individual performance
- Preventive measures to avoid overload

Following this concept, a real-time feedback system called “Mobile Motion Advisor“ (MMA; Preuschl et al., 2010) intended for the needs of physical education lessons at schools has been developed. As shown in Figure 1, a smartphone equipped with the ANT+ protocol (an already well-established standard for wireless sensor data transmission used by many manufacturers of sport equipment) is used as bidirectional data communication interface. In this way, measured parameters like, for example, acceleration, heart rate, respiratory rate, position and speed of the performing user can be captured via the ANT+ module of the smartphones and sent wirelessly (via UMTS / GPRS) to a central server.

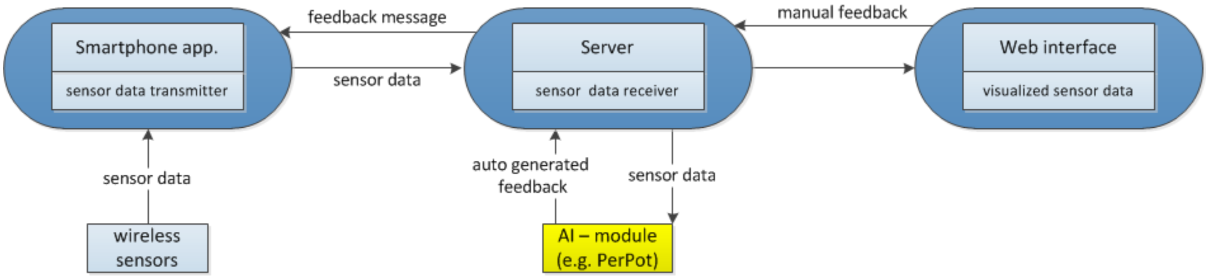

Figure 1. Basic concept of the Mobile Motion Advisor.

Further Development of the MMA

Regarding the implementation of the MMA, a generic approach was chosen in order to be able to integrate different sensors for various sports, and to avoid the need of additional implementation changes for the integration of newly developed sensors (Tampier et al., 2012). Due to the necessity of more specific research questions and requirements, however, a specialised version of the MMA has been developed solely for running. The new design of the framework has been improved in terms of its usability (in particular the usability of the smartphone application) as well as the visualisation of sensor data (Figure 2 and Figure 3). Furthermore, the antagonistic model PerPot (Perl & Endler, 2006) was integrated into the system. The embedding of this meta-model allows the simulation of load and performance limits during marathons and provides a first successful trial for the generation of automatic feedback messages, giving general insights on the integration of AI modules.

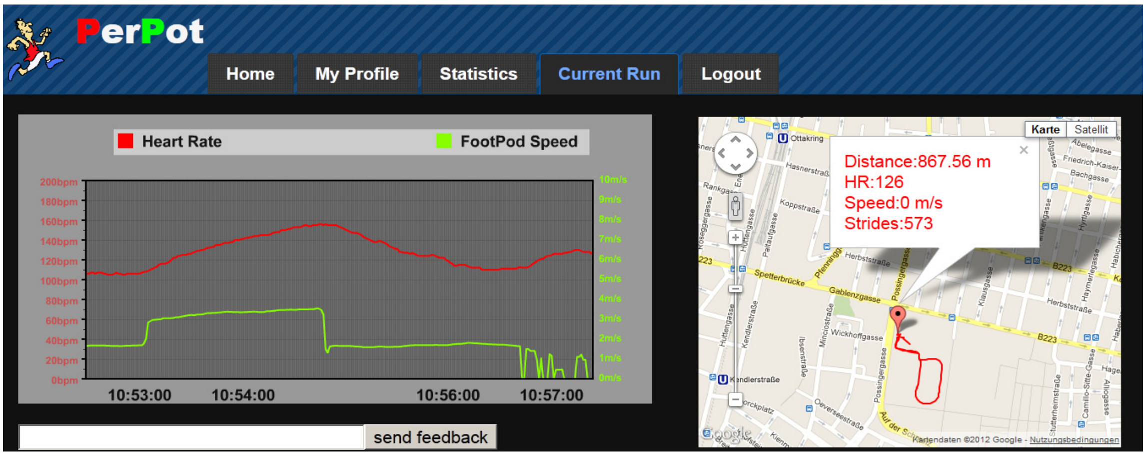

Figure 2. Web frontend of MMA.

Figure 3. Smartphone application adapted for PerPot.

The Meta-Model PerPot

The meta-model PerPot (Perl & Mester, 2001) maps the interaction between load and performance (Figure 4). The load affects the performance in an antagonistic way, where two internal potentials buffer positive and, respectively, negative effects, which affect the performance potential by delayed flows. As a result, several phenomena of sport physiology like the super compensation effect can be simulated.

According to the limitation of load-bearing capacity of organisms, PerPot has been completed by an overflow mechanism: Once the fatigue potential exceeds a limit, another strong negative and delayed effect on the performance is generated, which causes a delayed collapse of the performance.

The reserve describes the available fatigue potential up to the limit. This parameter can help simulating load and performance limits. It is also important for the simulation of practice and competition, because exceeding the limit should be avoided (i.e. the reserve shouldn’t undercut zero).

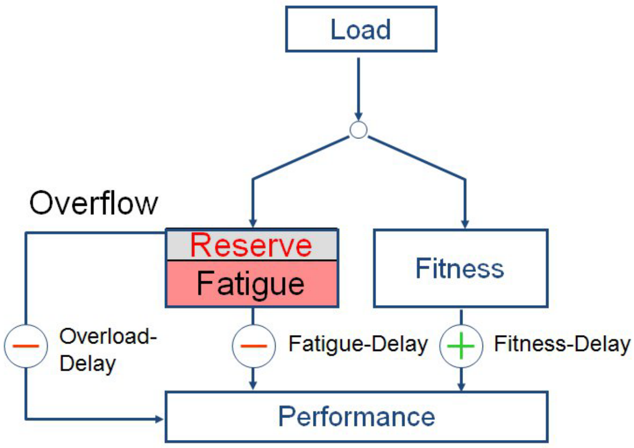

Figure 4. The meta-model PerPot.

PerPot and Running

First of all, load and performance are abstract terms, which depend on the specific application. For running, speed is taken as the load and heart rate as the performance determinant.

The model has to be adapted to the individual athlete using a calibration run. The calibration run is similar to a step test used in performance diagnostic analysis in sports science. The step length and increasing level of speed per step should be adapted to the capability of the athlete.

Normally the step length is fixed to 3-4 minutes. The speed at the beginning of the step test is about 6-8 km/h. The increase of speed per step is about 1-2 km/h. The athlete is requested to raise the speed until the subjective exhaustion is attained. After this, the athlete has to run a cool down cycle in the starting speed for 3-4 minutes. Figure 5 shows a typical step test of a well endurance-trained athlete (step length: 4 minutes; starting speed: 8 km/h; speed increasing steps: 2 km/h).

Figure 5. Typical step test for the calibration of PerPot.

The specific parameters of the model can be individually determined for the athlete by means of the calibration run. The most important determinants are, amongst others, the fatigue- and the fitness-delay, which control the delayed effect of the load on the performance.

An application of PerPot is the simulation of competitions. Based on the determined internal parameters, the speed can be optimized for the athlete individually for a given track. During the optimization process the speed level is increased gradually until the reserve is exhausted at the end of the simulated competition. The optimal target time can be determined out of the optimized speed level and the track length.

This optimization was used for 17 competitions in 2011. The mean deviation between the simulated target time and the real target time was 1.63%. However, there were also single competitions with relatively high deviations. One reason for this occurring can be the point in time of the calibration run. The simulation of the competition is based on this calibration run. Changes of conditions, such as the change of weather, are therefore not considered in the simulations (Perl & Endler, 2006). A further cause can be associated with the delay parameters, which may change during a run. As described above, however, these variations are considered only marginally in the optimization process. A combined system of MMA and PerPot solves those problems.

The Combined System

The integration of real time measurements including speed and heart rate determinants gathered during a competition appears to be one particular approach for solving the problems discussed above. The MMA framework measures all necessary information that is needed by PerPot. The data collection is accomplished via ANT+ compatible sensors and the acquired signals are sent via the smartphone to a server component.

The determined parameters from the calibration run, which should always take place a few days before the competition, provide the basis for the simulation of the competition. PerPot uses this information to optimize the approximation of the simulated heart rate compared to the currently measured heart rate by slightly changing the delay indicators.

The first optimization adjusts the starting value of the delay parameters to the conditions of the day of competition. For instance, if the weather is much warmer than on the day when the calibration run took place, a fatigue in the performance will occur much faster. In addition, the fatigue delay will be smaller, which also has an effect on the performance.

The second optimization tries to determine the progress of the delay parameters. Basically, the longer the duration of the run is, the greater is the influence of the fatigue compared to the fitness. Consequently, the fitness delay increases and the fatigue delay decreases, respectively, over time. The first version of the combined system assumes a linear gradient of the fitness delay.

The rest of the not yet completed running track is simulated on the basis of the adjusted delays and their progress. The athlete receives a feedback message with the estimated target time. Further messages are sent automatically, if the athlete leaves his optimized speed zone or if the heart rate exceeds the individual anaerobic threshold (IAT), which is another application scenario of PerPot (Endler & Perl, 2012). The feedback messages can be represented by full sentences, being played back by the voice synthesiser of the smartphone. This routine brings two advantages compared to a conventional heart rate monitor:

(1) The athlete gets simultaneously feedback on the heart rate as well as the speed.
(2) The feedback messages convey much more information compared to a heart rate monitor, which only alerts a beep sound, if a certain range is exceeded or has fallen below the fixed target zone.

At the moment, in order to limit the number of permanent messages, the optimization of the parameters is accomplished every 5 minutes by taking into account all collected data of the current run. Feedback messages regarding the leaving of the individual ranges are generated every 15 seconds at most.

The system was tested for the first time in a competition over 11.1 km. The accurate target time was determined already after 5 minutes, whereas the classical version of PerPot had a deviation of 4.1% in comparison to the target time.

Outlook and Discussion

Based on the obtained findings, current work concentrates on further developments of the combined MMA and PerPot project. All field tests conducted so far confirm the assumption that the adaptation and reduction of the functionality of the system (especially of the smartphone application) have positive effects on the handling of the entire framework. The challenge now is to develop a new version of the MMA, which maintains its usability and, at the same time, supports a variety of movement activities.

Therefore, as shown in Figure 6, the idea is to design a modular framework providing several reusable key components (standardized modules, data protocols, smartphone application, website etc.). The integration of new activities will be then primarily accomplished by the reuse of existing modules, and - only if necessary - by the implementation of additional components.

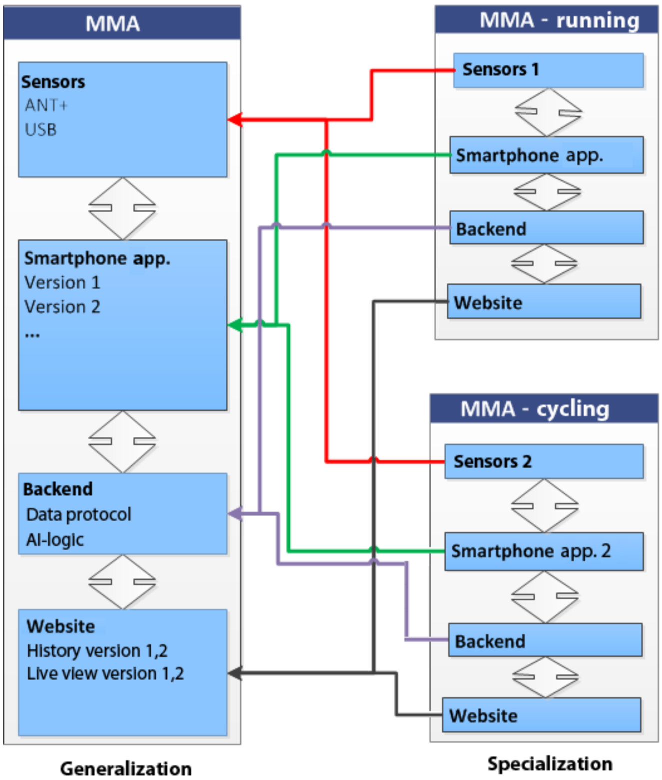

Figure 6: Generalization versus specialization of MMA.

Conclusions

The integration of PerPot provides an initial basis for the generation of practicable feedback messages. Based on that, important factors are not only related to the optimization of the athlete's performance, but also to the ideal transfer and presentation of the (automated) instructions. Therefore, additional test runs are planned in order to gain further experience about the right timing as well as the type of feedback. Moreover, the implemented method for the optimization of the parameters used by PerPot shall be improved.

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