Synchronised metronome training: The effects on soccer players’ lower-limb motor dynamics and performance in a soccer-related stepping task.

Rachel Irene McDonald
I would like to thank the soccer players who participated in this study and to Marius Sommer for his work in collecting data and facilitating the training program presented in this paper. I would also like to my supervisor, Louise Rönnqvist for designing this study, and for all her great guidance and feedback throughout this writing process.

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Synchronised metronome training: The effects on soccer players’ lower-limb motor dynamics and performance in a soccer-related stepping task.

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Good timing is important for all daily motion, even more so for athletes where the smallest movements can make the difference between a goal and miss. Despite this, there has been little research into just how timing ability is related to sport performance. Therefore the present study used a between-within groups experimental design with a sample of female elite- and semi-elite soccer players to describe the effects of a synchronised metronome training (SMT) intervention on lower-limb movement, and accuracy and speed, in a soccer-related stepping task. Participants were randomly assigned to receive SMT (n = 12) or to the control group (n = 12). The SMT group received 12 hours of Interactive Metronome (IM) training over four weeks. Pre- and post-test results showed a strong effect of SMT in improving timing and rhythmic ability. An effect of SMT on accuracy in the stepping task was seen, signifying an effect on motor planning ability. Correlational analyses showed some evident effects of IM on the kinematic parameters, as indicated by relationship between timing and rhythmicity ability with increased movement segmentation, though this did not reach significance. These results present new information and provides support for kinematic analysis to be used in future studies to address the effect of SMT.

Keywords: Interactive Metronome, synchronised metronome training, motor timing, 3D kinematic analysis, soccer, football, female athletes, movement dynamics

Interest in the efficacy of training programs that claim to have an abundance of positive and worthy impacts is always high in both public and academic minds. The Interactive Metronome® (IM) program is no exception, and since its development in the 1990s, IM training has been investigated in over 125 published articles (Google Scholar, accessed
The IM training program is a specific method of synchronised metronome training (SMT), it claims that after IM training, one can see improvements in numerous situations, whether that is a child struggling to pay attention in school or an adult recovering from a brain injury (Interactive Metronome, 2012). Soccer players' ability on a specifically design stepping task is the variable of interest in the present study. In SMT participants make specific, repeated, and rhythmic, movements to a metronome. The most basic forms of SMT involve tapping a finger to a steady beat, but more complex forms can involve whole limb or body movements.

The aim of SMT is to reduce one's mean asynchrony, or in other words, improve one's timing and rhythmic ability. When SMT achieves reduction in asynchrony, it results in sensorimotor synchronisation (SMS). SMS is most often thought about in regards to music and dance, where one's ability to coordinate perception and action to a beat are necessary (Repp, 2005; Repp & Su, 2013). However, with the increasing popularity of SMT programs such as the IM along with the growth of neuroimaging studies, there is now a small research base showing that SMS has transfer effects that are potentially much wider than just for musicians and dancers. For instance, imaging studies from both observational (Bengtsson et al., 2009; Chen, Penhune, & Zatorre, 2008) and experimental (Sommer, 2014) studies, where participants have listened to metronomes while undergoing fMRI analysis, have shown that brain areas responsible for motor performance, such as the cerebellum are activated even when no motor planning or action is performed. These findings, especially from Sommer (2014) are preliminary and thus need to be taken with caution, yet they are still important additions to the literature and provide a basis for further research with SMT and motor performance. Because these findings do indicate that listening to a metronome and motor performance are likely linked by neural pathways in the brain. Subsequently, these studies provide support for the idea that SMT can improve spatial-temporal networks within the brain, and thereby induce changes in motion performance.

The functionality of the brain’s spatiotemporal network, that is to say the brains internal timing mechanisms, are inextricably linked with not only motor performance, as discussed above, but even to executive functions (see Diamond, 2003; Mauk & Buonomano, 2004; Rossini & Pauri, 2000; Stemmer, 1996, for an overview). This relationship between timing, motor performance, and executive functions, can most obviously be seen in children diagnosed with developmental coordination disorder (DCD). Children with DCD are described as having difficulty with motor planning and control, timing, maintaining attention, and working memory (American Psychiatric Association, 2013). Further, studies of individuals with cerebellum damage have shown that these individuals often suffer problems in executive functions such as learning and memory (Bellebaum & Daum, 2007) and Koziol, Budding, and Chidekel (2012) provide a sound argument, from an evolutionary perspective, for understanding why these two brain areas would be linked. These neural relationships contribute to the explanation of the positive results that SMT has had on children with attention-deficit disorder (ADHD) and reading disorders (Shaffer et al., 2001; Taub, McGrew, & Keith, 2007), both
are disorders that involve deficits in executive functioning and which traditional interventions target executive functioning. Further it has been suggested that choice discrimination (ability to ignore distracting information) which is also a feature of executive functioning is an effect of SMT (Diamond, 2003). These relationships between timing, motor performance, and executive functions, are central to the design of the present study because the stepping task was specifically designed not only to be relevant to soccer players but also require the use of inhibition, updating, and shifting, thereby creating a state of high cognitive load. Inhibition, updating, and shifting are three of the most studied constructs within cognitive psychology and according to Miyake and Friedman (2012) these three executive functions are required to complete complex tasks. Cognitive load and these three executive functions are related because they all rely on working memory to process information (Johannsen et al., 2013), and the stepping task in the present study recruits working memory. The stepping task is described in detail in the methodology sections.

Taking into consideration the theoretical knowledge and understanding of neural pathways between timing, rhythmicity and motor planning and control in the brain, it has been proposed that training participant’s timing and rhythmicity can lead to improved motor planning and performance through strengthening these neural pathways (Beckelhimer, Dalton, Richter, Hermann, & Page, 2011; E, Chen, Ho, & Desmond, 2014; Johansson, Domellöf & Rönnqvist, 2012, 2014; Libkuman, Otani, & Steger, 2002; Sommer & Rönnqvist, 2009). A brief review of scientific articles where SMT was used as an intervention has indeed shown support for this. For instance, Shaffer et al. (2001) found that SMT training led to improvements in attention regulation and motor control in both children with special needs and children with ADHD; Beckelhimer et al. (2011) showed improved upper-limb functionality in two participants who had suffered stroke, and Johansson et al., (2012; 2014) saw improved upper-limb movement in a two different case studies of children with hemiplegic and diplegic cerebral palsy (HCP / DCP). Moreover, in the field of sport science, although existing scientific research on the topic is very limited, many professional and amateur sport teams have used the IM training method, and they have reported that their athletes have improved on skills assessments, and even in scores on educational assessments (Notre Dame and the Interactive Metronome, 2011.; Interactive Metronome® performance training, 2001; Massad, n.d.). For example, Massad has described how the IM training program has been used and praised by top PGA tour golfers, American football team Notre Dame, and NBA team Miami Dolphins. Although there are many reports from these sports teams and coaches that the IM training program is effective, there is still a lack of scientific research published on the relationship between SMT and athletic performance. From the available empirical research, Libkuman et al. (2002) and Sommer and Rönnqvist (2009) have both shown that SMT training improved golf shot accuracy, and as to the author’s knowledge, the only other soccer-skill specific study in this field, by Sommer (2014) showed that elite and semi-elite soccer player’s performed better on a cross-pass kick after four weeks of SMT. Further research with SMT by Johannsen et al., (2014) has shown that children
with DCP reported higher levels of subjective functionality of their hands and arms after four weeks of SMT.

As described there is support from the current scientific literature for positive results after SMT in a variety of populations. However there is a need for further scientific research in order to understand the pathways and changes in the brain that leads to better motor performance after SMT. Therefore the present study builds upon Sommer’s (2014) research on female soccer players by using data that was collected from the participant’s in his study but which has not yet been analysed or presented. Thus the aim of the present study is to show how the SMT impacts performance on a soccer-related stepping task but also by applying kinematic analysis methodologies to identify changes in lower-limb kinematics in these soccer players after SMT. The impact of SMT on kinematic properties of motor movements have recently been published by Johansson et al. (2012, 2014) and Sommer although neither of these studies has focused on lower-limb kinematics. Kinematic analyses in Johansson et al. showed that SMT resulted in some positive results in participants with DCP. The participants in this study showed smoother and faster movement in upper-limb trajectories in a rhythmic arm movement task after four weeks of SMT, and the golf players in Sommer’s study also developed more coordinated and dynamic movements as seen in kinematic trajectories of their golf swing after four weeks of SMT.

The IM training program was selected for use in the present study because it is unique from other SMT programs in that provides almost instantaneous visual and auditory feedback to participants (Interactive Metronome, 2012). Specifically, IM training involves a set body movement to be completed as close to a steady beat for many repetitions and the training program provides instantaneous feedback which tells the participant if they are on time, late, or early, in regards to the beat played by the metronome. (Johansson et al., 2012; Sommer, 2014). Movements most commonly include hand clapping or feet tapping, while wearing gloves or using footpads that register when the clap or tap is completed. This data is collected and stored electronically. IM training can be individualized and customized depending on personal ability and the goal of the training.

The existing literature and theory shows support for the mediating effect of timing and rhythmicity in regards to one’s attention and motor control, but it is still difficult to pinpoint exactly how these mechanisms work together. There is especially a shortfall of well-designed and sensitive, empirical, research (Johansson et al., 2014). Therefore, the present study aimed to contribute to the literature through using an experimental design to show the changes seen in soccer players’ performance on a high cognitive load stepping task after receiving an SMT intervention. Additionally, the proposed study will add to findings by Sommer (2014), who showed improvements in a soccer cross-pass and changes in brain activation after SMT, by investigating the lower-limb kinematics and performance of these elite and semi-elite players when completing a soccer-related stepping task before and after four weeks of SMT. This population is interesting to study.
because when providing top-level athletes with a brief intervention one would not expect to see great improvements after four weeks of training, seeing as they already partake in regular agility, strength, and fitness training. However, as Sommer have shown SMT lead to improved performance on a cross-path task and changes in neural activity. Therefore it is worthwhile to investigate if there is any change in these player’s lower-limb kinematics and/or performances as an effect of SMT.

The objective of the present study was to further investigate the effect of the IM training program in Sommer’s (2014) sample of elite- and sub-elite female soccer players. The hypotheses are twofold: that the players who undertook the SMT program would perform faster and more accurately on the stepping task. Additionally, that SMT would achieve this improvement through inducing less segmented, more controlled, and coordinated movements in the players; by means of shorter duration and more time effective movement trajectories, as evaluated with 3D kinematic analysis.

Methodology

Participants
Twenty four female sub-elite and elite outfield soccer players, who played for teams based in Umeå, Sweden, participated in the present study. At the time of pre-testing the participants’ age ranged from 16.2 to 25.8 years ($M = 19.5$, $SD = 2.7$) and they had between 5.5 years and 19 years ($M = 12.7$, $SD = 2.6$) of experience playing soccer. All participants were randomly assigned to either the control group or the intervention group. All participants partook in normal pre-season training during the study. Additionally, the intervention group received three sessions of SMT training over four weeks. For group demographics see Table 1.

Table 1. Participant’s mean age, weight, and height, years of experience ($\pm SD$), and the number of elite/sub-elite players in both groups.

<table>
<thead>
<tr>
<th></th>
<th>N</th>
<th>Age (years)</th>
<th>Weight (kg)</th>
<th>Height (cm)</th>
<th>Experience (years)</th>
<th>Elite-/ Sub-elite players (n)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SMT</td>
<td>12</td>
<td>18.6 (2.4)</td>
<td>62.5 (5.1)</td>
<td>168.9 (5.0)</td>
<td>12.0 (2.2)</td>
<td>8/4</td>
</tr>
<tr>
<td>CTRL</td>
<td>12</td>
<td>20.3 (3.01)</td>
<td>60.7 (6.5)</td>
<td>169.7 (6.05)</td>
<td>13.3 (2.87)</td>
<td>6/6</td>
</tr>
</tbody>
</table>

Note: $N =$ number of participants.

Apparatus

Tests of timing and rhythmicity
The IM system was used to assess both the control and SMT group’s timing and rhythm skills at the pre- and post-test sessions. The IM test is run in connection with a Windows based computer program that plays a metronome beat into headphones worn by the participant. The IM assessment used at both pre- and post-test sessions was delivered according to standardised protocol included in the instrument manual (Interactive
Metronome, 2012). For the present study the participants wore headphones to listen to the metronome, on their hands they wore contact-sensing gloves, and they used their feet to tap contact-sensing floor mats. These contact-sensing triggers rely information back to the Windows program about the difference between the time at which a participant makes a tap and the metronome beat. For the purposes of the present study there were two soccer related tasks included in addition to the 14 standard tasks (16 tasks in total). Before starting the tests participants viewed a video demonstration of the 16 tasks. For the tests the metronome was set to 54 bpm, with an inter-onset interval of 1100 ms between each task. The participants received no guide sounds or feedback on their performance. The tests took approximately 20 minutes to complete. The 16 tasks involve completing both uni- and bilateral hand and foot movements to the metronome beat, e.g. bringing both hands together to clap in time with the metronome. The additional two tasks were a stepping task using both feet to step onto floor sensors in synchrony with the metronome and also to performance a kick with their dominant foot at a sensor placed 0.5 metres above ground (see Sommer, 2014 for further information). For the present IM measures from the pre- and post-test sessions were analysed. These two measures were the mean rhythmic ability and the mean timing ability of the participants. The mean rhythmic ability measures the inter-response interval, which is measured as how close the participant’s response is to their previous response, and the mean timing ability measures the millisecond discrepancy between the metronome beat and the participant’s responses, which describes the participant’s SMS or motor timing skill.

![Figure 1A](image1.jpg) A. The lay-out of the stepping task; the distance between each tennis ball was 45 cm, the distance between each tennis ball and a mark in the centre was 50 cm. Participants were asked to stand on a mark in the centre of the tennis ball set-up. B. Photograph taken during stepping task showing labelled ProReflex markers (Table 2 provides description of the numbers and provides anatomical description of the placement of each marker). Photograph reproduced with permission.

**The stepping task**

Figure 1A depicts the lay-out of the task. The instructions that each participant was asked to follow is briefly summarised here, for further detail see Appendix 1 (instructions were provided in Swedish). Firstly, the participants were asked stand in the centre of a circle of tennis balls, and then to tap the markers with their feet in accordance with a specific digit-series shown to them, as many times as possible, while
maintaining accuracy, within a 20 s timeframe. The digit-series contained the digits 1-6 (e.g., 1-6-5-2-3-4) and were projected on a screen in front of them throughout the trial, so that they could refer back to the sequence at any time if they forgot the sequence. In other words, the participant had a 20 s period to repeat the sequence (e.g. 1-6-5-2-3-4) as fast and accurate as possible. The participants were instructed to use their left foot to touch markers 1, 3, and 5, and their right foot for markers 2, 4, and 6, and it was emphasised that they needed to not only move as fast as possible, but also to ensure that they minimised mistakes by being precise and accurate. Eight different digit-series were presented, in a randomized and counterbalanced design, after one another, with a small pause between trials. That is to say each participant completed eight trials at both pre- and post-test sessions. In addition, two warm-up trials were completed by each participant directly before they had completed their pre- and post-tests, data from the warm-ups were not collected.

**Recording and data collection**

For each trial, the participant’s performance was recorded both in 2D and 3D. The 3D data was captured with an Optoelectronic motion capture system (ProReflex, 240 Hz, Qualisys Inc., Gothenburg, Sweden) with four cameras, placed around the player, at a distance of 3.5 m from the centre of the tennis ball set-up, and the 2D recording was captured with a standard video camera placed in front of the participant recoding at 30 fps. The four camera motion capture system by Qualisys Inc. tracks the real-time position (X, Y, and Z, coordinates) and orientation data in 3D space of small, reflective, markers attached to the participants. The sampling frequency was 120Hz for all trials, and the quoted accuracy for this system is better than 1 mm for position and 1° for orientation (Qualisys, 2012). The cameras were linearized and the system calibrated before the measurement sessions began.

<table>
<thead>
<tr>
<th>Label used</th>
<th>Anatomical Position</th>
<th>Segment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Left/right foot</td>
<td>1. Lateral of the base of the fifth metatarsal</td>
<td>Forefoot</td>
</tr>
<tr>
<td></td>
<td>2. Medial side of the distal phalanx of the hallux (toe)</td>
<td>Hallux</td>
</tr>
<tr>
<td></td>
<td>3. Proximal base of the first metatarsal</td>
<td>Foot</td>
</tr>
<tr>
<td>Left/right ankle</td>
<td>4. Lateral calcaneus</td>
<td>hind foot</td>
</tr>
<tr>
<td>Left/right knee</td>
<td>5. The most prominent part of tuberositas tibiae</td>
<td>Thigh/shank</td>
</tr>
<tr>
<td></td>
<td>6. Lateral epicondyle</td>
<td>Shank</td>
</tr>
</tbody>
</table>

A total of 16 spherical Velcro ProReflex markers were attached to each participant before completing the stepping task, each marker had a diameter of 10 mm. These were placed on each of the knees, ankles, and feet, of the players, anatomical position is described in Table 2, and Figure 1B shows where these markers were placed. Participant’s completed the task with soccer boots on, and so markers for the feet were attached at three positions on each of the soccer boots, other markers were attached to
a pair of MoCap pants which have Velcro compatible fabric. In addition, markers were placed on the far side of each tennis ball to aid the 3D analysis (see Figure 1A). Six of these 16 markers were selected from each participant to be used in the kinematic analyses. Due to technical difficulties at data collection, it was not possible to take the same six markers from each participant. However, as markers from the knees (2) and feet (3) were positioned in clusters, tests on the data extracted from the Qualisys software showed that there were no significant differences in the average displacement nor velocity profile between each of these markers within one cluster. Thus, one marker with the best data quality was selected from within these clusters. Figure 2 provides illustration of the raw velocity data collected from the cluster of feet markers from one participant, to show that all three markers show the same pattern of velocity profiles throughout the task.

![Velocity Foot Markers](image)

*Figure 2. Velocity profile of all three markers from the left foot. Black: marker 1 (hallux), blue: marker 2 (forefoot), and pink: marker 3 (foot).*

**Procedures**

The testing and intervention took place during January and February, before the start of the competitive Swedish soccer season. Although not playing games during the study time, all participants participated in their regular team trainings under the test period. At the pre-test session all participants completed a screening questionnaire. At the pre- and post-tests all participants completed both the stepping task and the IM assessment of rhythm and timing.

Both pre- and post-testing of the IM assessment and the stepping task took place under controlled and similar conditions: on an indoor soccer field (with artificial turf) with a controlled temperature and lighting, the participants wore the same clothes, used the same soccer boots, the testing areas were blocked off with black curtains to minimize distractions, and all experimental protocol was the same. Also, there was a 100% retention rate, with all participants completing both the pre- and post-test sessions, and those in the intervention group completed all SMT training sessions.

**Ethical considerations**

All participants read and signed an informed consent protocol approved by the Umeå Research Ethics Review Board. This research proposal is part of a larger research
The intervention
Participants in the SMT group received three individual sessions per week of IM training provided over a period of four weeks, conducted by a qualified instructor. Each training session lasted 45-50 minutes, resulting in each participant receiving 9-10 hours of IM training between the pre- and post-test assessments. Unlike the IM test, in the training sessions the participants receive feedback on whether their hand/foot contact with contact-sensing triggers was on beat, early, or late. This feedback is provided by guide sounds in the headphones worn by each participant. An on beat contact is defined as being within 15 ms of the metronome, and a high pitched tone is simultaneously played into both ears of the headphones. An early contact, one that is 16 ms or earlier before the metronome results in a low pitch tone in the participant’s left ear only. Meanwhile, a late contact, 16 ms or later than the metronome results in a low pitch tone in the participant’s right ear only. This feedback is almost instantaneous and guides the participant to make their movements in time with the metronome through allowing them to adjust and correct their errors continually throughout the IM training session. Each training session began with three or four basic warm-up tasks i.e. clapping both hands together, or a one hand tap to the thigh, and then moved on to the 32 intervention tasks which consisted of both lower-limb and upper-limb movements, many of the movements were designed to employ soccer-specific skills. The metronome speed varied during the training sessions from 54 – 100 bpm. At the end of each session the participant would receive a breakdown of their performance as a form of feedback that would motivate them to improve on their scores at the next session. After the 12 training sessions the SMT group had completed à 27,000 movements in time to the metronome.

Data extraction and analysis
To establish the training effects from the IM intervention, the participant’s mean timing ability and mean rhythmic ability from the pre- and post-test sessions were extracted from the IM computer program. To investigate the effect of the IM intervention between pre- and post-test, differences were analysed by running repeated-measures ANOVAs with group as the between participants factors and test as the within-participants factor.

To illustrate the player’s performance on the stepping task, two variables were extracted from the 2D video recording of the pre and post-test. These variables were number of correct taps and time taken to complete first six taps. Each trial was firstly analysed one-by-one to count the total number of successful taps made by the participant and to assess how many of these taps matched the specific digit-series they were instructed to follow for that trial. A successful tap was defined by the soccer boot making clear contact with the tennis ball, taps beside or behind the ball, which did not make contact with the ball were not counted. Due to technical issues during the testing
session, not all trials for all participants were recorded correctly and therefore there are some missing data. In total, two trials (or 1% of all pre-test data) from the pre-test (both from SMT group) and four trials (or 2% of all post-test data) from the post-test (three from SMT and one from control). This was such a low percentage that no action was taken before statistical analysis. To analyse the effect that SMT had on elite soccer player’s performance in the stepping task, two repeated-measures ANOVAs were used, with the pre- and post-test results from the stepping test as within-participants factors, and group as the between-participants factors.

Due to the variation in total number of taps made by each participant in the stepping task it was decided that the kinematic data from each participant’s first six taps would be used for analysis, so that all participant’s had equal amounts of 3D data. The kinematic data from each camera were first transformed into three-dimensional (X, Y, and Z) coordinates by the system software (Qualisys Track Manager, 2012). The sampling frequency was 120 Hz for all trials. 3D data was smoothed prior to analyses using a second-order 10Hz dual-pass Butterworth filter, and then analysed offline with custom written software in MATLAB (The Mathworks Inc.). The two variables that were extracted for statistical analysis were cumulative 3D distance (mm) and the total number of movement units (MU). Cumulative 3D distance is the total accumulated distance extracted from each marker to gain insight into the energy efficiency of the movement paths (Figure 3). Movement units describe the segmentation of the movement trajectory and are based on tangential velocity data. For the present study the algorithm for calculating MUs was taken from previous studies of movement segmentation by von Hofsten (1991) and Rönnqvist and Domellöf (2006); where one MU is defined as a change from an acceleration or deceleration phase with a rate of change in accumulated velocity of at least 20 mm/s and change in acceleration / deceleration of at least 5 mm/s^2.

![Figure 3](image)

*Figure 3. Illustration of the cumulative 3D distance of the movement trajectory of the feet when completing six taps in the stepping task. Figure 3A is from the pre-test and figure 3B from the post-test from the same participant.*

Due to problems at the time of data collection, (for example, the ProReflex markers not being picked up by recording equipment) the total number of successful kinematic
recordings that were extracted and ready for analysis was 103 for the pre-test (or 53% of all pre-test data), and 166 for the post-test condition (or 86% of all post-test data). In total a 131 of kinematic recordings from the trials had to be excluded due to poor recording quality. Because of this large amount of missing data, participants were excluded from further statistical tests when they had data from less than two trials at each pre- and post-test. Participants who had data from two trials but for which the trials were the first, or last, two (of the eight trials) of the pre- or post-test were also excluded. This exclusion criteria excluded seven participant’s from the pre-test analysis (four SMT/three control) and two from the post-test analysis (two control). To test the differences ANOVAs and ANCOVAs were also used to show the effect that SMT had on the kinematic profile in the stepping task. Each variable was run in separate tests; the variables were cumulative 3D distance and number of MUs with pre- and post-test results from each participant as within-participants repeated-measures. Vertical bars on graphs denote 0.95 confidence intervals.

Statistical assumptions
Tests of homogeneity of variance, normality, and between-groups t-tests supported that the sampled data were approximately normally distributed and that the two groups were equal at pre-test in regards to demographic variables, performance on the stepping test, and in kinematic measures. Further, both groups had no significant difference in timing or rhythmic performance on the IM pre-test. Where the assumption of homogeneity was not met, Greenhouse-Geisser corrects were applied. An alpha level of 0.05 was set as the level of significance for all statistical tests. Due to the intervention focus of the study effect sizes (partial eta-squared: $\eta^2_p$) are provided where applicable, interpretations of these are steered by Cohen’s (1969) guidelines: $\eta^2_p > 0.01$ or 1% = small effect, $> 0.06$ or 6%, medium effect, and $> 0.14$ or 14% = large effect.
Results

The IM pre- and post-test
To assess the intervention effect of SMT on the participant’s mean timing ability a 2 (group: Control and SMT intervention) x 2 (test: pre- and post-test) repeated-measures ANOVA was performed. The ANOVA revealed a significant main effect for group; F (1, 22) = 5.24, p < .05, η²p = .19, a significant effect of test; F (1, 22) = 21.83, p < .001, η²p = .50 and a significant interaction between group and test; F (1, 22) = 21.40, p < .001, η²p = .49. Partial eta-squared showed that 49.3% of the variance in the improvement of the participant’s timing ability can be related to the IM intervention. A second 2 (group: Control and SMT intervention) x 2 (test: pre- and post-test) repeated-measures ANOVA was performed to test the impact of the IM intervention on the participant’s mean rhythmic ability. The ANOVA revealed a significant main effect for group; F (1, 22) = 8.20, p < .01, η²p = .27, a significant effect of test; F (1, 22) = 17.60, p < .001, η²p = .44, as well as a significant interaction between group and test; F (1, 22) = 14.91, p < .01, η²p = .40. Partial eta-squared showed that 40.4% of the variance in the improvement of the participant’s rhythmic ability can be related to the IM intervention. The change in mean timing and rhythmic abilities between pre- and post-test are illustrated below in Figure 4. The two ANOVAs indicate that the SMT intervention lead to a large improvement in the participants timing and rhythmic abilities, and that this improvement was not seen in the control group. Scheffe’s multiple comparisons test supported these hypotheses, and showed a significant improvement between pre- and post-test for timing ability for SMT only (SMT p = 0.000, control p = .99) and rhythmic ability (SMT p = 0.000, control p = 1.0).

Figure 4. Mean timing ability (average difference from metronome beat) and mean rhythmic ability (inter-response interval) as a function of group and test. Vertical bars on graphs denote 0.95 confidence intervals.

Accuracy and speed on the stepping test at pre- and post-test
It was expected that both groups would improve on this test since, at pre-test the task was novel to all participants, and there was only four weeks between the tests, but it
was hypothesised that the rate of improvement between the two groups would differ, favouring the SMT group. To analyse this, a repeated-measures ANOVA was completed. The 2 (group: Control and SMT intervention) x 2 (test: pre- and post-test) repeated-measures ANOVA completed for the number of correct taps in the stepping task (at trial level) showed a non-significant main effect for group; F (1, 186) = 3.21, p = .07, η²p = .02, a significant effect of test; F (1, 186) = 25.4, p < .001, η²p = .12, and a significant interaction between group and test; F (1, 186) = 5.20, p < .05, η²p = .03. Partial eta-squared showed that 2.7% of the variance in participant's accuracy in the stepping task can be related to the IM intervention. These results support the hypothesis, as illustrated in Figure 5A. Scheffe’s multiple comparisons tests were run to confirm the hypotheses; this showed that in the SMT group there is significant change between pre- and post-test (p = < .001) and this is not seen in the control group (p = .24). Although, Scheffe’s test showed that the difference between the two groups at post-test is not significant (p = .06).

To identify what effect the IM intervention had on the participant’s speed in the stepping task a 2 (group: Control and SMT intervention) x 2 (test: pre- and post-test) repeated-measures ANOVA was completed for the duration of the first six taps. This showed no significant main effect for group; F (1, 135) = 1.82, p = .18, η²p = .01, a non-significant effect of test; F (1, 135) = 1.96, p = .16, η²p = .01, as well as a non-significant interaction between group and test; F (1, 135) = 1.96, p = .16, η²p = .01. As illustrated in figure 5B, there is some difference in the speed of the SMT group between pre- and post-test, while there is no change for the control group, but this difference between the two groups was not found to be statistically significant.

![Graph A](image1.png)

**Figure 5.** Graph A displaying average the number of correct taps during the 20 s stepping task as a function of group and test, and graph B displaying the average time taken to complete first six steps (three with each foot), in stepping task as a function of group and test. Vertical bars on graphs denote 0.95 confidence intervals.
Table 3. Bivariate correlations of changes in duration to complete first six taps, and accuracy (number of correct taps over the 20 s stepping task), with changes in timing and rhythmic ability on the IM test, as well as changes in kinematic measures, between pre- and post-test.

<table>
<thead>
<tr>
<th>SMT</th>
<th>Control</th>
</tr>
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<tbody>
<tr>
<td></td>
<td>3D Distance$^3$</td>
</tr>
<tr>
<td>Duration$^1$</td>
<td>Accuracy</td>
</tr>
<tr>
<td>.41</td>
<td>.44</td>
</tr>
<tr>
<td>p = .10</td>
<td>p = .10</td>
</tr>
<tr>
<td>Accuracy</td>
<td>.41</td>
</tr>
<tr>
<td>Timing</td>
<td>.44</td>
</tr>
<tr>
<td>p = .10</td>
<td>p = .20</td>
</tr>
<tr>
<td>Rhythm</td>
<td>.09</td>
</tr>
<tr>
<td>p = .41</td>
<td>p = .10</td>
</tr>
<tr>
<td>MU</td>
<td>.69</td>
</tr>
<tr>
<td>p = .06</td>
<td>p = .28</td>
</tr>
<tr>
<td>3D Distance</td>
<td>-.05</td>
</tr>
<tr>
<td>p = .46</td>
<td>p = .15</td>
</tr>
</tbody>
</table>

Note: **p < .01, N = 12, $^1$N = 10, $^2$N = 6, $^3$N = 7, $^4$N = 8.
It was even hypothesised that there would be a correlational relationship between participant's scores on the IM and their improvement on the stepping task after completing the SMT intervention. In other words that those who improve most on the IM test would improve most in the stepping task. To test this, Pearson’s correlations were conducted between all four variables for both groups. These outcomes are presented below in Table 3. There were no significant correlations for either group, indicating no statistically significant correlational relationship between improvement on the stepping task and in the IM test. However, a near-significant, medium, correlation between improvement of duration and timing ability was seen (r = .44, p = .1). As would be expected there was a strong and significant correlation between timing and rhythm, this is because these are two related measures of overall motor timing ability.

**Kinematic analysis at pre- and post-test**

MUs and cumulative 3D distance (cumulative distance of the movement trajectory) were extracted from the 3D kinematic data. To assess the intervention effects at pre- and post-test on the participant's actual kinematic profiles the following repeated-measures ANOVAs were completed. Participants were excluded from this analysis if there they made significant errors in the stepping task and / or if data on less than two trials (of eight) were collected. Five outliers, all of which were outside of the expected range of MUs (more than 1 standard deviation above than the mean), were excluded for analysis of MU.

**Movement units**

A 2 x 2 repeated-measures ANOVA was completed for the mean number of MUs made by participants’ during their first six taps as a function of group and test. This showed no significant main effect for group; F (1, 74) = 0.63, p = .43, η²p = .01, a significant effect of test F (1, 74) = 4.72, p < .05, η²p = .06, and a non-significant interaction between group and test; F (1, 74) = 0.91, p = .34, η²p = .01 (Figure 6A). Controlling for the mean duration, by including this as a covariate in the same repeated-measures design, brought the interaction between group and time closer to significance and increased the effect size, brought the interaction between group and time closer to significance and doubled the effect size; F (1, 74) = 2.6, p = .11, η²p = .03. Finally, replacing the mean MUs with MUs per second in the repeated-measures design, and showed a non-significant effect for group; F (1, 90) = 3.22, p = .08, η²p = .04, a non-significant effect of test F (1, 90) = 2.54, p = .12, η²p = .03, and a non-significant interaction between group and test; F (1, 90) = 0.45, p = .51, η²p = .01 (Figure 6B). Additionally, these analyses were run with mean 3D distance as a covariate in repeated-measures ANCOVAs, however this made no statistically significant difference to the results.
Figure 6. Graph A, the mean MU (n) from all markers as a function of group and test. Graph B, mean MUs (n) per second as a function of group and test. Vertical bars on graphs denote 0.95 confidence intervals.

To identify if there was any difference in these results for participants’ their dominant side only, a new mean variable was calculated from the markers from the dominant side only, and a new 2 x 2 repeated-measures ANOVA was completed. Exclusions were made according to the previous ANOVA. This showed no significant main effect for group; F (1, 74) = 0.72, p = .40, η²_p = .01, a significant effect of test F (1, 74) = 4.92, p < .05, η²_p = .06, and a non-significant interaction between group and test; F (1, 74) = 2.54, p = .12, η²_p = .03. In this case, with the duration controlled for as a covariate in an ANCOVA, the interaction was between group and test became significant and the effect size was increased; F (1, 73) = 5.39, p < .05, η²_p = .07, with the significant difference being between the mean number of MUs between pre- and post-test for the control group; not the SMT group.

Further inspection was done to understand these results. This showed that the number of MUs (mean number of MU from all markers) at pre-test differed significantly between SMT (M = 6.67, SD = 1.13) and control (M = 6.12, SD = 0.63) groups when the length of time was taken into account; t (99) = 3.12, p < .05. This difference may have been seen due to the low percentage of acceptable data points for the SMT group from the pre-test analysis, which was only 37.5% (versus control = 67.7% and post-test SMT = 90.6% versus control = 64.6%), or due the sample size in the experiment. Either way, this difference at pre-test may have masked potential effects of SMT on MU that could have been seen had the two groups been equal at pre-test.

Pearson’s correlations are reported in Table 3 for the relationship mean change in MUs between pre- and post-test with improvements on the IM test and stepping task. It was hypothesised that change in MU for the SMT group would be correlated to improvement in timing and rhythm and performance on the stepping task; yet it was unknown if this would be a negative or positive relationship and thus two-tailed tests were completed for this test. The correlational analysis showed two strong, significant, correlations, for the control group (3D Distance and duration of the stepping task). Although no
correlations reached significance for the SMT group; three were near the level of significance. MU and speed ($r = .69, p = .06$), MU and timing ($r = -.62, p = .1$), and MU and rhythm ($r = -.65, p = .08$). These relationships are illustrated in Figure 7. This negative correlation between improvement on the IM test and changes in MU was not seen in the control group (timing: $r = .02, p = .50$, rhythm: $r = .02, p = .48$). Thus, although the ANOVA analyses for MUs showed no interaction for the SMT group before and after training, these correlational analyses show support for an interaction between SMT and MU in the stepping task; and thus that there is some meaningful relationship between number of MUs and motor timing and rhythmicity. Although interpretation of these correlations must be taken with caution due to the small sample size.

Figure 7. Pre- to post-test change in MUs (n) with A) Improvement in timing on the IM test, B) Improvement on rhythmicity on the IM test, and C) with the length of time taken to complete six taps in the stepping task. Dotted lines represent 90% confidence intervals.

**Cumulative 3D distance**

To identify what effect the SMT had on the cumulative 3D distance, a 2 x 2 repeated-measures ANOVA was completed, cases were excluded on the same basis as for the ANOVA to test movement units. This showed no significant main effect for group; $F (1, 86) = 0.23, p = .63, \eta^2_p = .003$, a significant effect of test $F (1, 86) = 15.81, p < .001, \eta^2_p = .16$ and a significant interaction between group and test; $F (1, 86) = 10.03, p < .05, \eta^2_p = .10$. This interaction is illustrated in Figure 8A. This figure indicates that this significant change between pre- and post-test is seen in the control group and not the SMT group, this is an unexpected result as a preliminary t-test showed that there were no significant differences between the cumulative 3D distance in the SMT group ($M = 2824.27, SD = 261.09$) or control group ($M = 2952.74, SD = 453.23$) at pre-test; $t (115) = -1.8, p = .07$. As with movement units, a second ANOVA was run to test if this result differed when only the dominant side was tested. This showed no significant main effect for group; $F (1, 86) = 0.21, p = .65, \eta^2_p = .002$, a significant effect of test $F (1, 86) = 6.63, p < .05, \eta^2_p = .07$, and a significant interaction between group and test; $F (1, 86) = 7.19, p < .05, \eta^2_p = .08$. Again, this significant result was due to the change seen in the control group across the pre- and post-test sessions, as illustrated in Figure 8B. This difference in the control group between pre- and post-test was seen in all markers (foot, ankle, and knee) and on both the left and right side.
The duration should not be related to the cumulative 3D distance seeing as the number of steps was controlled for before this data was extracted (data from the first six taps only was extracted). However, as earlier analyses using duration as a covariate revealed a difference in the MUs at pre-test between the two groups, these same analyses was run. There was still a significant difference between the control (M = 3041.66 mm, SD = 448.06 mm) and SMT (M = 2851.73 mm, SD = 252.61 mm) at pre-test when controlling for duration; t (96) = -2.55, p < .001, and as reported in the ANOVA, there was also no difference between control (M= 2723.49 mm, SD = 315.76 mm) or SMT (M = 2732.80 mm, SD = 315.72 mm) at post-test either; t (100) = 0.15, p = .99. Thus, these analyses confirmed that there was no difference between the 3D distance for the tests or groups when the length of time was taken into account. This absence of a relationship is also reflected in the Pearson's correlational analyses presented earlier in Table 3; neither performance on the IM test or the stepping task was correlated with change in 3D distance between pre- and post-test for the SMT group. There were however strong, and significant, correlations in the control group on both the change in speed on the stepping task (r = .99, p = < .01) and in the change of number of MUs (r = .95, p < .01).

Figure 8. Graph A, the mean cumulative 3D distance (mm) of all markers as a function of test and group. The slopes indicate that the control group varied between pre- and post-test. Graph B the mean cumulative 3D distance (mm) of all markers on the dominant side as a function of test and group. Vertical bars on graphs denote 0.95 confidence intervals.
Discussion

The results from the present study show the effects seen in a sample of elite- and semi-elite female soccer players after four weeks of SMT with the IM program. Previous research and popular sports teams have both reported that the IM program is effective in improving sport-specific skills (Notre Dame and the Interactive Metronome, 2011; Libkuman, Otani, & Steger, 2002; Massad, n.d.; Sommer, 2014; Sommer & Rönnqvist, 2009). Specifically, Sommer (2014) showed that SMT was effective in improving motor timing and rhythmicity and accuracy in a sport-specific skill in a sample of elite and semi-elite female soccer players. However, to the author’s knowledge, no study of SMT with athletes has addressed the effect of an SMT intervention on the movement dynamics and efficiency of lower-limb kinematics, likewise no study has compared this with a control group. Therefore the present study investigated how effective the SMT intervention delivered by Sommer was at improving movement dynamics and efficiency by using 3D kinematics analysis in this sample of soccer players and even how effective SMT was in improving accuracy and speed in a soccer-related stepping task, using a between-within groups experimental design.

Effects of SMT

Sommer’s (2014) study describes that there was a strong, significant, correlation between improvement on motor timing and rhythmicity (as measured with the IM pre- and post-test) and improved accuracy in a soccer-specific cross-pass. However, the present study did not repeat this effect of SMT with the soccer-related stepping task. Rather, only a small effect of SMT on the performance of a soccer-related stepping task was seen, and when post-hoc tests were run, it was seen that the difference between the two groups at post-test was not significant. This small effect was seen only in improved accuracy on the stepping task; no effect was found for duration of the task (how fast the participant completed it). Further, correlational analyses found no significant relationships between improvements on the stepping task and motor timing / rhythmicity, yet it must be taken into account that the sample sizes used for these analyses were small, and thus statistical power was low. Additionally, the correlational analysis indicated that there was a relationship between change in the duration of the stepping task and improvement in motor timing skill. Motor planning was a key part to the stepping-task used in this study, since it recruited working memory and other executive functions which are vital to good motor planning ability. Therefore, despite the lack of statistical significance, when eye-ball ing the data it is evident that there was an improvement in the stepping task for the SMT group which was not as pronounced in the control group and so understanding these results within the context that SMT improves motor planning through improving motor timing and rhythmicity (Diamond, 2003; Koziol, Budding, & Chidekel, 2012; Mauk & Buonomano, 2004; Rossini & Pauri, 2000; Sommer, 2014; Stemmer, 1996), the present results do provide some support that SMT strengthened the neural pathways within the spatiotemporal network of these soccer players and thereby improved their motor planning ability which ultimately resulted in better accuracy in this stepping task. The results from the present
study do differ with other studies of which showed significantly increased motor performance in sport-specific accuracy after SMT (Libkuman, Otani, & Steger, 2002; Sommer, 2014; Sommer & Rönnqvist, 2009). However, motor planning ability is just as important when it comes to sport performance, especially in a team sport like soccer, where good players must be able to plan movements in response to other’s actions instantaneously.

The results from tests of the kinematic data variables MUs and cumulative 3D distance, that were extracted to describe changes in movement dynamics and efficiency after SMT in comparison with the control group, were harder to interpret. This is because the control group differed between pre- and post-test. This difference was evident across statistical tests run on both MUs and cumulative 3D distance, thus this lead to meaningless between-group analyses. Therefore, correlation analysis was run between both the change in timing and rhythm skills and change in MUs and cumulative 3D distance, with the hypothesis that although differences were seen in the control group, correlations would show any effect of SMT in the SMT group and that there would not be any meaningful correlations seen for the control group because the changes seen between tests were random and not related to improvement in timing and rhythm. Although no significant correlations were found, in the SMT group there were strong negative correlations for improvement in rhythm and timing that were near the level of significance. The negative relationship describes that with larger improvements in timing and rhythm, there were a greater number of MUs.

Thus correlational analysis supported that there is a relationship between MUs and improved timing and rhythm, but not for cumulative 3D distance. Being the first study to compare the effects of SMT to a control group with kinematic analysis, our hypotheses were broad. Specifically, it was unknown exactly how SMT would ‘improve’ motor dynamics in a sample of elite- and semi-elite athletes who have years of experience in training for soccer-specific and related skills. Previous kinematic analysis in children with cerebral palsy have shown that after SMT there are significantly fewer MUs and a shorter cumulative 3D distance as a function of movements improving from segmented and inefficient to becoming smoother and more efficient (Johansson et al., 2012, 2014), however these children’s motor planning and control ability was well below what is seen in typically developed children, and thus in these populations the effect of SMT that is seen is from inefficient to more efficient movement. Whereas, in the present study, with a sample of elite and semi-elite athletes, the change, if any, needed to be seen between already efficient and smooth movement to even more dynamic movement. Thus, even though the present results do not show the same effect of SMT as seen in Johansson et al. (2012, 2014), the increase in the number of MUs can be understood when the soccer context, that these participants train and compete in, is considered alongside Burnstein’s (1967) theory on skill acquisition and especially, the problem of degrees of freedom (DOF) in complex movements. Burnstein said that the mastery of very complex motor skills (in this case, those needed in soccer) is dependent upon increased availability of redundant DOF; this increase in DOF available to the
individual that has mastered a complex movement thereby allows them to become more efficient and have more flexible motor performance. Therefore we interpret the result of increase in number of MUs to reflect the availability of more DOF. Previous research by Verrel, Pologe, Manselle, Lindenberger, and Woollacott (2013) has discussed this increased availability recently in the context of skilled string instrumentalists, who need to make fast and efficient changes of direction, which is a skill necessary in the stepping task that we used.

The DOF theory can be applied to the present study because soccer demands players to have a greater number of available DOF in multi-joint movements in order to outperform their opposing player. For example, the ability to plan and be able to make fast, accurate, and different, changes in direction when dribbling a soccer ball around a defender is a key skill in soccer that will lead to greater success. Likewise, a defender needs to be able to respond in multiple ways to the attacker in order to block their advancement. Subsequently, one way to understand the lack of an effect of SMT on cumulative 3D distance is that the participants already had well-developed control and efficiency in lower-limb movement; and thus a ceiling effect was seen in the performance of our stepping task. This could be tested by assessing cumulative 3D distance in a longer or more complex task; if this hypothesis is true then the longer or more complex a task is then the stronger the effect of SMT will become.

Limitations
In regards to design specifications of the present study it was limited in that only 12 hours of IM training were provided, and that there was no follow up tests at a later date. These are both limitations because it is possible that 12 hours of training, although it succeeded in reducing participant’s error in timing and rhythmicity, may not have been sufficient to cause changes in the motor performance as measured with kinematic analysis of lower-limb movements. Further, a follow up at for example, six months after completing the IM training, would have provided useful data that could have been used to further explain and understand the results collected at pre- and post-test. Especially as it could be used to explain and understand the change seen in the control group at pre- and post-test. In addition, follow up data would provide information on whether the effects of SMT are long lasting, or alternatively could provide information that continual training over a longer period is needed in order to see any improvements in transfer effects. Alternatively, an experimental design where 3D kinematic data were collected from more than one task would have provided further evidence to support / reject our hypotheses.

The results from the present study are limited in that a lot of trial data were unable to be used in analysis. This was likely caused the video cameras not being able to follow each of the ProReflex markers for the entire trial; for example if a marker was hidden from a camera or fell off the knee, ankle, or soccer boot, which can happen when participants make fast and sudden movements. Therefore, the data used in analyses of MUs and cumulative 3D distance were not representative of the whole sample. This may
be responsible for the differences seen in the kinematic data of the control group between pre- and post-test, and / or for no differences being picked up in the SMT group between pre- and post-test. Subsequently, the correlation analyses that were run had such small sample sizes (N = 6 – 12), thus the information from these correlations must be taken with caution. Further, only two variables were extracted from the 3D kinematic data. Those variables, MUs and cumulative 3D distance, were chosen because they were applicable to the stepping task and they provided data that could be used to test our specific hypotheses. They are also more efficient to analyse than other measures which would require processing and a higher level of statistical analysis. However, seeing that no convincing results were found using the present design, it is recommended that future research explore the applicability of other variables to their research. For example, in the context of our stepping task it would be useful to compare peak accelerations and speed of change of direction, to establish any changes in motor dynamics and efficiency after SMT; this was not done in the present study due to limitations of time and expertise.

**Future research**

Future research must recruit larger groups so that future studies have stronger statistical power and thus can make stronger claims about the effects of SMT on sports skills. To the author's knowledge there have been no other studies that have utilised 3D kinematic analysis to assess the effects of SMT in the context of soccer. It is therefore strongly recommended that future research utilise 3D kinematic analysis when studying SMT because it provides so much data about just how SMT causes transfer effects to sport-specific skills. Future research also needs to use 3D kinematic analysis to assess effects of SMT in a real sport context, for example, penalty shots or a run-up and pass task, in soccer, so that any changes in motor planning, dynamics, or efficiency as a result of SMT can be understood to impact sport skills in the context that players most want to improve: on field performance. It is even important that future studies address gender differences in motor dynamics and efficiency; especially in regards to soccer or other sports where lower-limb kinematics are the focus, because of the difference between hip and knee kinematics between the genders (Sakaguchi et al., 2014). Ultimately, the ideal experimental design for a future study would have a follow up session, and four groups: elite athletes who receive SMT, a control group of elite athletes, and a group of novice players who receive SMT, and a final control group of novice players, would provide the most worthwhile combination of data from which to test the effects of SMT. This would provide evidence on the effects of SMT in groups starting at different amounts of experience / training, and therefore provide information on its efficacy in different groups.

**Implications**

Being the first study to utilise 3D kinematic analysis to assess the effects of SMT in the context of soccer the present study provides new and meaningful information about the effects of SMT on motor dynamics and efficiency. Despite the lack of statistically
significant results the present study has described patterns and relationships found in the data, and these patterns and relationships do provide evidence for the theory that SMT is useful in improving motor planning and performance in a soccer-related task, even when this was not trained, through increasing neural connections within the spatiotemporal pathway. The present study also discusses the potential that SMT leads to greater availability of DOF in accordance with Burnstein's (1967) theory of learning complex motor skills.

Conclusions
The present study found no evident findings that supported our hypotheses. However, what has been described is that there were some effects of SMT in improving motor planning in soccer-related stepping task that recruited both the spatiotemporal network and executive functions by creating a state of high cognitive load. Further, 3D kinematic analysis showed that there was some evidence to support that the number of MUs increased with increased timing skill (as assessed by the IM-test). These results provide some support for the existing theory that SMT increases neural connections in the spatiotemporal network as well as in the prefrontal cortex as described with fMRI analysis by Sommer (2014).
References


MATLAB [Software]. Boston, MA: The Mathworks Inc.


Qualisys Track Manager (Version 2.9, Build 1697) [Software]. Sweden: Qualisys Inc. Available from http://www.qualysis.com


Appendix 1

Instructions given to participants for the stepping task

Ta emot FP:

Hej! Välkommen! Vad var ditt FP nummer?

Ta fram schema för aktuellt FP-nummer, och förklara sedan uppgiften:

- I denna övning kommer det att presenteras en siffer-kombination på 6 siffror på skärmen framför dig.
- Din uppgift är att under 20 sekunder trampa/stampa/tappa fotterna i enlighet med siffer-sekvensen som presenteras på datorn framför dig så många gånger som möjligt. Siffrorna kommer visas på skärmen under hela uppgiften, så du kan när som helst hitta upp om du "tappa bort dig"
- Du skall tappningen/stampningen så snabbt som möjligt OCH så precist som möjligt.
- Höger fot för siffror som befinner sig på din höger sida, och vänster fot på siffror som är placerade på din vänstra sida (du får inte "korsa" benen)
- Precision betyder att foten rör vid bollen!

Ta på MoCap byxor och applicera markörer.

- Vi kommer köra 8 olika kombinationer.
- Men första får du två prov-omgångar
- Frågor?
- Då kör vi!
  1. FP startar inne i markerat action-område, med ansiktet mot datorn.
  2. Siffer-kombination dyker upp på skärmen när Crew I trycker på GO.
     - 20 sekunders mätning per FP

Utrustning:

- Laptop med PPT för tappning-uppgiften, samt för registrering av FP # och resultat.
- Laptop Qualisys med extern hårddisk
- El
- Plywoodskiva med tennisbollar
- Extra markörer + MoCap dräkt
- Kameror
- Bord/stolar
- Protokoll