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Original Article

Evaluation of a foot switch system for the maximal instep kick in soccer – results from a single-case study

FERRARO MATTEO[1]; STALDER SEVERIN[2]; BAUR HEINER[3]; RADLINGER LORENZ[4], ROGAN SLAVKO[5]
[1,2,3,4,5] Bern University of Applied Science, Health, Bern, SWITZERLAND
[5]AfiPT, Akademie für integrative Physiotherapie und Trainingslehre, Grenzach-Wyhlen, GERMANY

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Abstract:
Aim of this single-case study was to investigate the feasibility and the validity of the use of Footswitch System (FS) during maximal instep kick (MIK). One participant conducted 25 MIK's simultaneously recorded by both systems. The MIK was divided into three time phases and total phase and were measured in milliseconds. Feasibility outcome was the time schedule. Validity was examined with ICC and the Bland-Altman method. Total measuring time was 3 hours and 10 minutes. 27% of 25 MIK's were usable for evaluation. Systematic biases are determined for all phases. Negative bias for phase 1 (-7.1 ms), phase 3 (- 3.6 ms) and MIK (- 4.9 ms) and positive bias for phase 3 (5.9 ms) are presented. The authors conclude that the actual investigation protocol is not feasible for measuring the MIK and should be modified.
Key words: biomechanics, electrogoniometer, three dimensional movement analysis system

Introduction

Soccer is one of the most popular sports in the world and is played on all continents (Heidt, Sweeterman, Carlonas, Traub, & Tekulve, 2000). The Fédération Internationale de Football Association (FIFA) counts over 265 million registered licensed soccer players in the year 2012 (FIFA, 2012). In relationship to this popularity, scientific research on this sport discipline is quite rare.

The most researched technique in soccer so far is the maximal instep kick (MIK), because it is a central skill of a soccer player (G. Shan & Westerhoff, 2005). It's used by standard situations like goal kick, free kick, corner or during the ball rolls as shot on goal, by playing a long pass or by kicking with maximal force. The preceding is as following for standard situation. The angle to the stationary ball for the run up in direction of kicking is best by an angle of 43° to 45° for a kick with maximal speed. Furthermore, professionals prefer a distance of three to four steps for the run up. At the beginning of the kick step the player performs a trunk rotation, arm extension and abduction to the non-kick side and a hip extension, abduction and inward rotation of the kicking leg, which describes the forming of the Tension Arc (TA). The upper body movement leads to pre lengthening thigh muscles of the kicking side (G. Shan & Westerhoff, 2005). The release of the tension arc is shown by a quick (quasi whip-like) rotation and flexion of the trunk to the kicking side. The arm of the non-kicking side performs a fast flexion and adduction while the kicking leg flexes and adducts. A key point of the MIK is the formation and release of this tension arc (G. Shan & Westerhoff, 2005). After the ball contact the movement ends in an airborne phase. This important biomechanical aspect of the MIK characterizes a professional soccer player, because novice players don't show this characteristic. The novice players have a smaller range of motion of the hip of the kicking side. The tension arc is not that pronounced and they often lack the airborne phase. Also female players don't show this characteristic (G. B. Shan, 2009). Therefore, the following division of the MIK into three time phases, on basis of four distinct time points, refers only to professional male soccer players.

Phase 1: Last foot ground contact (FGC) from kicking leg → turning point from maximal hip extension to flexion (THEF) from kicking leg (tension arc). Phase 2: turning point from maximal hip extension to flexion from kicking leg → ball contact (BC) with the dorsum of the foot from kicking leg (release of the (tension arc). Phase 3: ball contact with the dorsum of the foot → first ground contact (GC) after the airborne phase.

To simplify the evaluation of the MIK, former studies divided the MIK into different time phases (Charnock, Lewis, Garrett, & Queen, 2009; Manolopoulos, Papadopoulos, & Kellis, 2006; Scurr, Abbott, & Ball, 2011). These subdivisions were not based on specific biomechanical aspects of the MIK, but on the aspects researchers wanted to investigate. In this study the phases are related on the above-mentioned biomechanical aspects.

Currently, three-dimensional kinematic motion analysis system (3DMA) is the reference (gold) standard for investigating the MIK. But this measurement method is not practical for daily routine of a coach or

Corresponding Author ROGAN SLAVKO Email: slavko.rogan@bfh.ch

sport therapist in rehabilitation, because it can only be used in a laboratory setting. Besides it is an expensive investment that can hardly be afforded by a coach or even institution. Furthermore the studies on soccer specific techniques which were conducted so far had little influence on the practical training routine in soccer (G. Shan & Zhang, 2011).

For this reason an evaluation procedure of the MIK with a Footswitch System (FS) as an alternative functional analysis system to the 3DMA was adapted for identification of MIK phases. The FS is based on telemetric footswitches and an electrical goniometer to record the three phases of the MIK as described above. This eventually might lead to a more practical application of MIK analysis in daily training, because the athlete would be able to move freely on the field, in his natural environment.

No research has investigated modifying the MIK with a FS as an alternative functional analysis system to the 3DMA. The authors approach to answering the question of whether FS can be used as an alternative functional analysis system for MIK, a preliminary investigation was carried out. For this proposes a single-case research design was used. Single-case research designs provide an insight into interaction of many factors and variables and get an overview of effect and functioning and human behavior, to reconstruct theoretical models and to generate hypotheses (Green & Johnson, 2006). In addition, details about new technical methods that may go unnoticed in group studies may be revealed by single-case design and makes it practical for group studies (Pinfield, 1986). To the best of the author's knowledge, the Footswitch System (FS) was never used for the MIK on field research.

Therefore, the goal of this single-case study was to investigate the feasibility of the use of FS during MIK. Because it was unknown whether the time schedule of the preparation phase would be feasible. This single-case study also evaluated the validity of the FS.

Material & methods

Participants

The participant was 22 years old with a height of 1.78 m and a weight of 74.1 kg. The measurements were executed during the second part of the 2011/2012 seasons on an off-training day. The day before the measurement also contained no training. The participant was fully informed about the aim, the procedure, the possible risks of the study and his insurance coverage. The participant obtained informed consent, which contains the directives from the Medicine & Science in Sports & Exercise. The Review Board of the University of Applied Science of Bern Institute Physiotherapy proved the testing protocol and data management plan.

Table 1. Anthropometric data of the participant in millimetre (mm)

Anthropometric Data	Left	Right
Leg Length (mm)	930	920
Knee Width (mm)	90	88
Ankle Width (mm)	55	58
Shoulder Offset (mm)	46	45
Elbow Width (mm)	61	61
Wrist Width (mm)	43	43
Hand Thickness (mm)	18	17

Measurement tools

This study used a cross sectional design and was executed in a university movement laboratory. It follows the statement of Thabane et al. (2010) and the guideline for case studies (Budgell, 2008). These statements are checklists intended to improve the quality of study reports.

Including criteria were as follow: Soccer experience more than 10 years and active soccer player not lower than the second league (Switzerland). Following excluding criteria were set: Training absence conditional on illness or injury the last two months, trainings absence conditional on illness or injury longer than 4 weeks the last year, younger than age 18 or older than 30 and on the day of investigation any indication of illness or injury.

Feasibility: The criteria of success and questions for the feasibility of the implementation of the new FS were created as recommended by Thabane et al. (2010). The research questions were:

1) Is the time schedule adequate? Time planned for: a) the preparation of the 3DMA with the setting of the markers 40 minutes (min), b) the preparation and fixation of the FS 35 min, c) preparing the measuring setting 15 min, d) checking of the proper running of both systems 20 min, e) warm up of the participant 15 min, f) clearance after measuring 30 min, g) welcoming and discharge of the participant 30 min and h) and duration of the measurement 40 min. In total 3 hours and 45 min were calculated for the measure. For the Processing time 6 hours were calculated.

2) Is the FS a valid device to measure the 3 phases? 90% of the recorded data must be usable for evaluation. Therefore, a concurrent validity of the FS using the 3DMA as reference standard for measurements the time phases of the MIK was carried out.

Procedures

Reference system: A Vicon®-System (VICON MX Giganet, Oxford, UK) with 6 cameras was used for 3DMA with a sampling rate of 240 Hz. Westhoff et al. (2004) showed that the 3DMA had a good test-retest reliability for path-time parameter (r=0.75-0.99) especially for the sagittal plane (r=0.86-0.98), which applies useful for the research on hip extension (McDermott, Bolger, Keating, McEvoy, & Meldrum, 2010). An additional study (2) showed that the measurement accuracy and instrument reliability were high (SEM<1.82⁻, r>0.998). Additionally two 2D video cameras with a sampling rate of 240 Hz were used synchronously with the 3DMA, to record ball contact (Basler type piA640-210gc, Basler AG, Ahrensburg, GER).

Footswitch system: For this study six telemetric footswitches (Type FSR-2, Noraxon ®, Scottsdale, USA) were used. The recording frequency was 1000 Hz. With these sensors three of the above described time points (FGC, BC, GC) were recorded. These sensors showed a high correlation with the ground contact recorded via the force plate (r = 0.999) (Hausdorff, Ladin, & Wei, 1995). Furthermore Mills et al. (2007) showed that the 95% confidence interval for the difference between the force plate and the footswitches for the ground contact was as low as 8.0-2.5 ms and for the foot-off (-)13.1–6.6 ms. Additionally it was shown that the 3DMA a difference of more than 20 ms for the ground contact and foot-off compared with force plate data had.

For evaluation of the turning point from maximal hip extension to flexion a flexible biaxial electrical goniometer (Goniometer Inline SG 150, Biometrics Ltd. Newport, UK) with a recording frequency of 1000 Hz was chosen. Bronner et al. (Bronner, Agraharasamakulam, & Ojofeitimi, 2010) compared electrical goniometers and the 3DMA for extreme motions by dancers and showed that the concurrent validity was high (r>0.949) and the standard measurement error was <6.8⁻ for the hip. The instrument reliability was r>0.983. The absolute value of the hip extension was not of interest because just the turning point from hip extension to hip flexion was used (TA before release (G. Shan & Westerhoff, 2005)).

The Vicon® cameras were set around the recording area and prepared after the standard guidelines from the manufacturer. For the analysis a full body model with 15 segments was used (G. Shan & Westerhoff, 2005). 38 reflecting markers (diameter = 16 mm) were used and the participant was prepared according to the manufacturer's manual. The markers were placed as followed: Head markers: Two markers in front over the left and right temple and two markers on the back of the head. Torso markers: One on the spinosus process of the seventh cervical vertebrae, one on the spinous process of the tenth thoracic vertebrae, one on the jugular notch, where the clavicles meet the sternum, one on the xiphoid process of the sternum and one in the middle of the right scapula, for the auto labeling routine to determine right from left. Arm markers: One marker on the left acromio-clavicular joint, one on the left upper arm between the elbow and shoulder marker, one on the left lateral epicondyle, two markers on a bar pointing to the thumb and pinkie side on the left wrist and one on the left dorsum of the hand just below of the head of the second metacarpal bone (the same for the right side). Lower body Pelvis: One placed directly over the left and right anterior superior iliac spine and one placed on the skin midway between the posterior superior iliac spines. Leg: one placed on the lateral epicondyle of the left knee, one placed over the lower lateral 1/3 surface of the left thigh, just below of the swing of the hand, one placed on the left lateral malleolus along an imaginary line that passes through the transmalleolar axis and one on the left shank on the lower 1/3 of the surface to determine the alignment of the ankle flexion axis (same for the right side). Foot: one placed over the left second metatarsal head, on the mid-foot side of the equines break between fore-foot and mid-foot and one on the left calcaneous at the same height above the plantar surface of the foot as the toe marker (same for the right side). Before placing the markers, the referring anatomical points were marked with a pen, so that lost markers could be replaced on the same position. Anthropometric data (Table 1) were measured with scales, goniometer, measuring tape and a vernier caliper. This data were transferred into the 3DMA-Software (Vicon® Nexus, Vers. 1.7.1, Oxford, UK). The software package is created for 3 dimensional video reconstructions and analysis. Synchronous analog data from force plate, EMG, accelerometer could be obtained. This was a prerequisite for this case study, for testing the question 1.

The six footswitches were placed as follow: Central on the heel of the kicking and supporting leg, on the dorsum of the kicking foot (basis of the first metatarsal bone and two fingerbreadths further distal) and on the head of the first metatarsal bone on the plantar side of the foot of the kicking and supporting leg.

The goniometer was fixed with adhesive tape on to the participants kicking leg (hip). The proximal side was fixed on the iliac crest in a line with the trochanter major and the lateral epicondyle of the femur. The distal side was fixed on the same line, so that the turning center of the flexible part was one fingerbreadth cranial from the trochanter major. The goniometer arms were additionally fixed with classic tape (3M Center, Minnesota, St. Paul, USA). The zero-point was defined in supine position (leg straight).

A wireless transmitter (TeleMyo 2400 G2, Noraxon, Scottsdale, USA) was used, to transfer data from the measurement tools (foot switches and goniometers) to the recording PC and allowed the participant to move freely without any constriction. The sender was fixed to the participant´s back. The cables of the above described footswitches and goniometer were connected to the sender and fixed to the participant so that no tractive forces influenced the cables during the MIK.

In the current study the aforementioned phases were optimized, based on the biomechanical description of the MIK by Lees et al. (2010) and Shan and Westerhoff (2005).

The phases were retrieved from the time points described above, captured by both systems. Phase one is calculated from turning point from maximal hip extension to flexion with the kicking leg minus last foot ground contact with kicking leg. Phase two is calculated from ball contact with kicking leg minus turning point from maximal hip flexion with kicking leg. Phase three is calculated from first ground contact after airborne phase minus ball contact with the kicking leg and the whole MIK from ground contact after the airborne phase minus foot ground contact with kicking leg. As a result following variables from both systems were used: the duration (ms) of phase one, two and three and the duration of the whole MIK.

An artificial turf (1.5m x 4m from WALO Bertschinger AG, Schlieren, CH) was placed in the motion capture volume to provide a more realistic soccer environment. The turf was placed to allow the participant a run up with an angle of 45° to the ball in the kicking direction. The length of the run up could be chosen freely by the participant but had not to exceed more than 4 steps. An original soccer ball (size 5 from Adidas Type: F-50 X-ite, Bern, CH) was fixed with a ball net and a cord on a concrete plug, to avoid damage to the laboratory equipment.

The warm-up consisted of aerobic steps. The intensity was about 60-70% of VO_2max (Rogan, 2008). The participant was familiarized to the measurement situation with five augmenting kicks from light kicks up to a MIK.

The Participant was instructed as follows: “Please kick the ball as hard as possible. You will have 1 min break between the kicks and will be given a signal when to start for the next trial.”

The participant wore the electrical goniometer, the footswitches, the markers, the Data-Logger, the cables, shorts and socks as described in the equipment section. The socks were to make the MIK more endurable. Lees et al. (2010) showed that kicking barefoot is even faster than with shoes. During the warm up the participant had time to practice following criteria, which had to be met for a MIK: 1. The run up had not to exceed 4 steps. 2. The angle from the run up way to the shooting direction had to be 45°. 3. The kicking technique had to be an MIK. If a try didn’t consist one of the three above described criteria’s, it did not enter data analysis. Before starting, signals from all measurement methods were checked visually on the PC monitor for simultaneous recording. During the experiment, signals were rechecked after each MIK to detect if any equipment didn’t run round to assess the following trial.

Statistical Analysis

For evaluation of the concurrent validity the agreement between the two measurement tools was evaluated as follows. Normal distribution of the differences of the phases measured by the two measurement systems was tested with the Shapiro-Wilk test. Interpretation of limits of agreement (LoA) is a clinical question, not a statistical one. It requires a professional scientific estimation whether the range of the limits of agreement is clinically significant or not. This current study, with mean bias of ± 4 ms as the maximum, homogeneous bias and homoscedasticity were established a priori parameters that would indicate acceptable agreement between the FS and 3DMA. The level of agreement between the two devices was expressed as intraclass correlation coefficients (ICCs, 2,1), associated 95% confidence intervals (CI) and limits of agreement (LoA). LoA was calculated according to the method by Bland and Altman (1986). The LoA (mean difference ± 1.96 SD) represent the range of values in which agreement between methods will lie for approximately 95% of the sample (Grouven, Bender, Ziegler, & Lange, 2007). Bland-Altmans plot of the phases were constructed to represent FS agreement with the 3DMA. Standard measurement error (SEM) was calculated out of the error Variance ($\sqrt{\sigma 2error}$). For statistical analysis the Microsoft Office Excel 2007® (Microsoft Inc., Redmond, Washington, USA) and SPSS 20 (SPSS Inc., Chicago, Illinois, USA) for Windows were used.

Results

Feasibility

The time needed for: a) the preparation of the 3DMA with the setting of the markers took 40 min, b) the preparation and fixation of the FS took 35 min, c) preparing the measuring setting took 10 min, d) the checking of the proper running of both systems and the warm up of the participant were made parallel and took 15 min, e) the clearance after measuring took 20 min, g) the welcoming and discharge of the participant took 30 min, h) and the duration of the measurement took 40 min. The whole measuring took in total 3 hours and 10 minutes. The investigators needed 8 hours (for the 3DMA 6 hours, for the FS 2 hours), to retrieve the data from the measurement systems.

100% of the 25 MIK’s were usable for evaluation from the 3DMA and 27% of 25 MIK’s were usable for the evaluation from the FS (the percentage of missing data for MIK was 63%). During the preparing of the measurement set-up investigators found out that the wearing soccer boots was not possible in the presented protocol.

Validity

The data was normally distributed and shows homoscedasticity (Fig. 1). Table 2 presented data of the two devices over all phases. The level of agreement was excellent for phase 1,3 and MIK and moderate for phase 2. Systematic bias is shown (Fig. 2) for all phases and for MIK. Negative bias for phase 1 (-7.1 ms), phase 3 (-3.6 ms) and MIK (- 4.9 ms) and positive bias for phase 3 (5.9 ms) are presented. The ranges of different points (LoA 95%) are located for phase 1,3 and MIK at negative and for phase 2 at positive site.

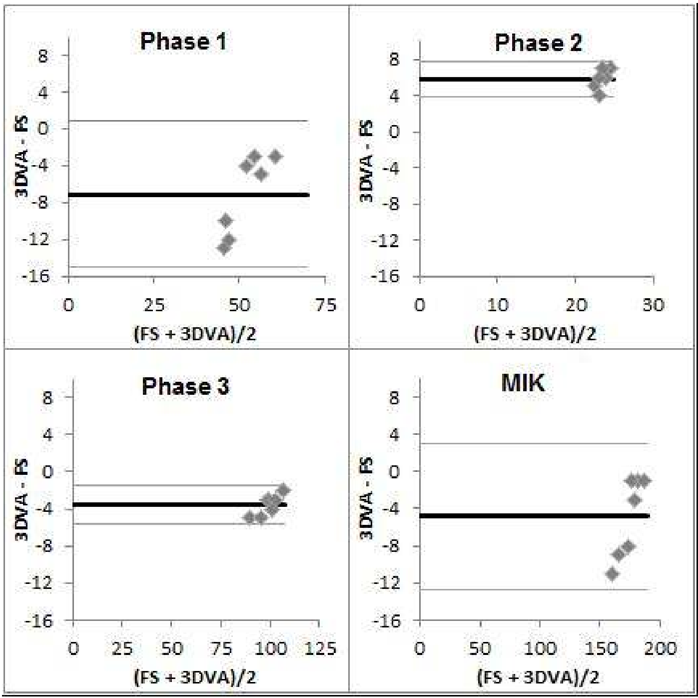

Fig. 1 Bland-Altman-plots of Phase 1 to Phase 3 and MIK. Dot's presents differences, thin lines present upper and lower line of agreement (95%) and thick line presents mean of the differences.

Table 2. Descriptive Statistics

	3MDS (ms) (Mean ± SD)	FS (ms) (mean ± SD)	ICC (95%)	LoA 95%	SEM (ms) ($\sqrt{\sigma^2_{error}}$)
Phase 1	48.1 (± 7.8)	55.3 (± 4.0)	0.86 (0.17 – 0.98)	-7.1 (-15.1 to 0.08)	7.58
Phase 2	26.4 (± 1.1)	20.6 (± 0.5)	0.43 (-2.33 – 0.90)	5.9 (3.9 to 7.8)	1.85
Phase 3	97.3 (± 6.0)	100.9 (± 5.0)	0.99 (0.94 – 1.00)	-3.6 (- 5.6 to – 1.5)	1.96
MIK	171.9(± 11.3)	176.7 (± 7.4)	0.95 (0.68 – 0.99)	-4.9 (- 12.7 to 3.0)	7.51

3MDS: three-dimensional kinematic motion analysis system, FS: footswitch system, ICC; intraclass correlation coefficient; LoA: limits of agreement; SEM: standard measurement error: ms: milliseconds, $\sqrt{\sigma^2_{error}}$: error of variance; MIK: maximal instep kick

Discussion

The aim of this single-case study was to investigate the feasibility and the concurrent validity of the use of FS during MIK. This single-case study provides useful information concerning the feasibility and the validity of a foot switch system derived phase definition of the MIK. The description in this single-case study may help sport sciences and sports therapists for a future clinical study for the evaluation of parameters of the MIK with the FS.

Feasibility

Answer to question 1. The time schedule can be adjusted as followed: The participant`s preparation for movement analysis with attachment of the retro reflective markers took 5 min longer than the preparation of the sensors of the foot switch system, as planned above. The preparing of the measurement set-up took 10 min. The checking of the systems and the warm-up can be made in parallel and took 15 min. The clearance after the measurement lasted 20 min. The welcoming and discharge of the participant took 30 min as planned and the duration took 40 min also as planned. So a total of 3 hours and 10 minutes has to be calculated for this type of measurement.

The processing time for the movement analysis data took 4 hours longer compared to the foot switch system data. The data of the movement analysis system needed several time-consuming steps. This elongated the time substantially, compared to foot switch system data.

The timetable has to be adjusted as described above. The strength of the FS system is that the athlete can move freely around the area but it is too fragile. It needs some improvements so that it withstands the high forces and it can be also worn with soccer boots. Furthermore a sensor barrier should be included, this would allow the control of the player`s fatigue and to calculate correlations between ball speed and the parameters of the MIK, because Kellis and Katis (Kellis & Katis, 2007) showed, that speed of the ball is a major biomechanical indicator of kicking success. Additionally the reflecting markers need to be fixed with a stronger tape. Also the recording frequency of both systems should be equal for better comparison. Furthermore, the study should be conducted with more participants to increase the external validity and power. This study was performed before a planned diagnostic study, which represents the validation phase and processing steps of the test procedure and establishes the validity of the FS of the basis of the 3DMA during the maximal instep kick (MIK).

Validity

No direct comparison with other studies could be made on the research of the MIK because so far there is no study which uses the same time phases, based on biomechanical aspects, as were used in this study. That's why this study was conducted to gain quantitative data for further studies and to gain reference points for future study designs. The main findings of this single-case study indicate this current study is not feasible to measure the three time phases of the MIK. The reasons are now described and explain their modifications.

In this current study the FS records not equal than the 3DMA. This is not surprising, when considering the recording frequencies of both systems. The MIK is a very fast movement and the sampling rate of the movement analysis system (240 Hz) might be inadequate to capture such a fast movement (Windolf, Gotzen, & Morlock, 2008). The foot switch system samples with 1000 Hz. This results for the movement analysis system that the time interval between two measurement frames is close to 4.2 ms, whereas the foot switch system records one frame per millisecond. This discrepancy leads automatically to a higher data variation during phase 1, 2, 3 and MIK by the movement analysis system and therefore a systematic bias of +/- 4.2 ms was expected as aforementioned (Windolf et al., 2008).

The Bland-Altman-Plots show that phase 3 and MIK are within this systematic bias and also the ICC values show high agreement for phase 1,3 and MIK between the measurement tools. But phase 1 and two show greater systematic bias than 4.2 ms and additionally the ICC value is only moderate for phase two. The low ICC value of phase 2 can be explained, because the phase two was measured quite consistent (low SD) which leads to a homogeneous data basis for the calculation of this ICC end therefore to a low value. This phase contains the release of the tension arc and is therefore essential for the acceleration of the ball (G. Shan & Westerhoff, 2005). Furthermore Lees et al. (2010), showed that the range of hip extension (the greater the range, the faster the ball) is a predictor for ball velocity and therefore might serve as an indirect parameter for the quality of the MIK. Moreover, Shan and Zhang (2011) reports that professional soccer players have a significantly higher range of motion in the kicking hip than male novice players. But this is just a hypothesis and has to be investigated with the measurement of the hip range of motion with the goniometer and the measurement of the ball speed.

Additionally phase 2 and 3 show acceptable SEM < 2ms. The high LoA of phase 1 and two and the high SEM of phase 1 and 4 cannot be ignored. They show an uncontrolled bias, which is too high for the evaluation of the MIK. Therefore the FS is not rated as a valid instrument for the evaluation of the time phases of the MIK in this study. Higher trial numbers and equal recording frequencies are recommended to avoid systematic errors.

Limitation

The foot switch system is not a fully adequate tool to measure the MIK. The data show that only 27% of the recorded data from the foot switch system could be evaluated. This tool failed to record sufficient usable data. Two sensors of a foot switch are matched together with one cable. On this account, it is not possible to know whether the heel or toe is first placed on the ground or even one sensor doesn't send any signal. This point led to the problem that only 27% of the MIK (7 MIK from 25) could be analyzed. The investigators didn't detect when the cable tore out of one of the foot switches one the palm of the foot immediately, because of the problem mentioned above. Furthermore this study showed that the foot switches implemented in this research are too fragile for such a movement. Two-foot switches broke during the recording but could be replaced.

Conclusions

The foot switch system is not able to measure adequately the time phases of the MIK compared to the initially chosen reference standard (movement analysis system). The initial reference standard was chosen because of the possibility to evaluate the MIK in its complete 3D-motion. This allowed the definition of the MIK-phases and the phases extracted from the foot switch system could be compared with the 3D motion data. The FS needs to be adjusted as mentioned above to become a feasible tool

Conflicts of interest

No conflicts of interest exist

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