FAIL MODE AND EFFECTS ANALYSIS (FMEA) APPLIED TO BIOFOOT/IBV2001® EQUIPMENT ADAPTATION FOR LONG JUMP

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Increasingly, techniques and instruments coming from different fields of science are being used in sports research. This study proposes the application of an engineering methodology, the FMEA, for the adaptation of a plantar pressure measurement device to its safe and reliable use in the long jump analysis. This project's aim is to analyse the possible failures of the measurement equipment when used for long jump study, propose and validate changes in the measure equipment and in the research protocol. The FMEA methodology allowed to identify and to give priority to ninety four possible failures and their effects. Sixty four of them were solved, the remaining were of very low importance. In any case, further improvements were envised to eliminate all those possible failures. A new plantar pressure measuring equipment and a modified study protocol were obtained as a result.

KEY WORDS: track and field, FMEA, biomechanics, long jump, plantar pressures.

INTRODUCTION: A great number of instrumental techniques are used in Sports biomechanics research. One of the more recently incorporated is the instrumented insoles equipment for plantar pressures registering. This technique was developed in order to study human gait (Hoyos, J.V. *et al.* 1984) and since then its use has been widely extended to orthopaedics and others. Its applications in sports have mainly focussed in running (Ferrandis, R. 1989) and soccer (Brizuela, G. *et al.* 1998) with little reported use in other sports disciplines. We found several problems to use this technique for registering plantar pressures during long jump take-off. Only a work was found in literature (Perttunen and cols 2000). Commercially available systems (BIOFOOT/IBV 2001®, EMED-PEDAR and TEKSCAN) show a similar configuration and were considered as potentially dangerous for the athlete, as well as to disturb and even modify the gesture. Thus, adaptation of instrumented insoles to long jump was deemed necessary as the previous step to biomechanical analysis of the take-off. Therefore, the objective of this study was to adapt an existing and already available plantar pressures measurement equipment (BIOFOOT/IBV 2001®), to the study of long jump when increasing the athlete's safety and reducing the modification of the gesture. A clearly established procedure called Failure Mode and Effects Analysis (FMEA) was used. This method has been widely used in many fields of engineering to improve processes, equipment and machinery (Passey, R. 1999, Willis, G. 1992).

METHODS: The equipment to be adapted consisted of a commercial system, BIOFOOT/IBV 2001® (Figure 1). It consists of 64 piezo-electrical ceramics sensors 0.7 mm thick, distributed into a flexible insole. The insole is placed into the shoe of then athlete and the plugged into an amplifier fixed at the athlete's tibia by an elastic band. The amplifier is connected to a telemetry equipment to transmit the data to a portable PC, so that the user can move freely around the test area. The work carried out consisted of first applying the FMEA method to identify and rate possible equipment failures; second, developing a new equipment to avoid those failures, and finally, validating the new equipment. *FMEA* is an engineering qualitative methodology that follows an established procedure to compute a coefficient called Risk Priority Number (RPN) that is used to arrange in order of increasing importance the possible failures allowing to identify the need and urgency of modifications. The procedure consists of the following steps: 1. Identification of equipment elements. 2. Identify potential failures of each element and their effects on the athlete and the experimental procedure. This was done by experts' analysis of filming from different long jumps with two athletes wearing the instrumented insoles equipment. 3. Establish possible causes for the failures and their effects by experts. 4. Compute the Risk Priority Number as. RPN = severity x occurrence x detection probability, which are given a number between 1 and 10 as a function of estimating the severity of failures' effect, the frequency with which it could occur and the possibility of detecting the failure. The greater the RPN the more important the failure. Experts in biomechanics, sports and instrumentation proposed the different solutions for most important failures (higher RPN) and quoted their feasibility. The solutions were implemented in the development of a new equipment and tested on a prototype. Validation was done by experts' observation on long jump filming from 2 athletes wearing the new equipment. They evaluated that risks had been eliminated and that no new ones appeared.

RESULTS AND DISCUSSION: Sensors, amplifier, cable, transmitter, insole and others were the elements (figure 1) of the equipment considered for the FMEA study. This analysis allowed to identify ninety-four possible failures that could affect both the athlete and the investigation during the long jump. Most relevant failures were those that could result in athlete´s injury, as for example amplifier or transmitter damage during landing by impacting the athlete or skin abrasion in the flight phase due to cable interference that could also modify the gesture performance. Also, potential failures were identified as being able to affect the experimental procedure as far as sensors could fail the sand or break by very high pressures at take off that would distort the measures or cause information loss. In this sense, design modifications were proposed for higher RPN failures. As a result, a new equipment was developed (Figure 1) as well as an improved experimental procedure. The most relevant failures, their RPN, proposed modifications and feasibility are showed in table 1 as an example.

Table 1. Example of the FMEA procedure showing the elements, potential failure their effects and causes as well as the RPN, solutions proposed and their feasibility.

Element	Potential failure	Potential effects	Potential causes	RPN	Solutions	Feasibility
Amplifier	damage	Hurt athlete	Knock	270	Shock absorber	easy
Transmitter	damage	Hurt athlete	Knock	270	Shock absorber	easy
Cable	High abrasion	Burn	Finishing	210	Protection	easy
insoles	damage	Equipment damaged	Crease	180	Inspection and correct desing	easy
Amplifier	Wrong location	Hurt athlete	Inadequacy to gesture	180	Polyvalen ce	difficult
Cable	Rough	Hurt athlete	Finishing	180	Protection	easy
Fixation harness	Get loose	Hurt athlete	Velcro no ok	180	velcro® OK	easy
Fixation harness	Tension no ok	Hurt athlete	Material no ok	162	Elastic	easy
Cable	Tear	Athlete fall	Inadequate length	162	Elastic cable	easy
Cable	Tear	Hurt athlete	Inadequate length	162	Elastic cable	easy
Sensors	Damage	Equipment damaged	Overloading	150	Set up	easy

The changes that were proposed focussed on the relocation of some elements of the equipment and the adaptation of the instrumented insole to such changes. The transmitter was placed on the chest, supported by a fixation harness, placed on the thorax and fixed on the back. The amplifier was moved to the medium section of the tibia, in the plane zone (internal part of the leg). The cable, which connects the amplifier with the transmitter, was a spiral cable with a smooth finishing. Design modifications were applied to the insole in its connection band, due to the new location of the amplifier. These consisted of a new design of the connection band with a sinuous form (Figure 2). Concerning the experimental protocol, checking points were included to assess sensors function and to verify that all the elements of the equipment were functioning correctly and that neither sand nor the strong impact caused breakdowns, which would distort the measures.

Figure 2. New design of connection band with a sinuous form (blue) and the insole form (violet).

The validation work showed that most of the identified risks of failure have been eliminated with the new equipment and FMEA showed only low RPN risks. Only NN out of 94 possible failures remained with the new equipment. In this sense, further improvements of the equipment were proposed.

Table 2. Possible further improvements for the BIOFOOT/IBV 2001®.

Element	Improvement
Insoles	Modify the curve of the connecting band
	Divide the connecting band in two
Amplifier	Avoid that the fixation band velcrum gets in touch with subject's skin
	Protect the amplifier against sand entering
	Fixation band with breathable material
Transmitter	Place a cushioning material between the emitter and the subjects chest
Cable	Fix the cable to the athlete by an elastic band
	Dispose an spiral at knee level for the cable
Fixation harness	Improve harness comfort
	Use velcro® back fixation

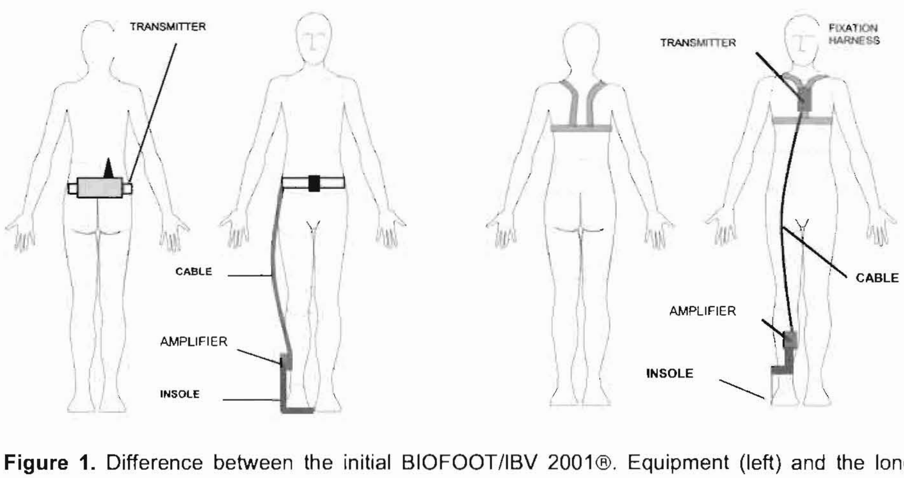

Figure 1. Difference between the initial BIOFOOT/IBV 2001®. Equipment (left) and the long jump adapted prototype of BIOFOOT/IBV 2001® equipment (right).

After the last phase of the process, the main modifications proposed were: the location of the transmitter, which for design reasons of the equipment would be better placed horizontal; the protection of the amplifier through neoprene and elastic fabrics; and the design of the connection band of the insole, caused by its modified curvature in order to fit better the amplifier. This article introduces the fail mode and effects analysis (FMEA) method as an ordered, and established qualitative procedure for adapting existing biomechanical instrumentation to be used in sports where current devices could either damage the athlete or negatively influence the technical performance of the gesture. It has been successfully used to adapt a plantar pressure registering device for the study of long jump take-off, assuring the physical integrity of the athlete and the quality of the sports study. In the future, more improvements focussed on electronics could be studied, which would improve the performance of the equipment as they would reduce the size of both, the amplifier and the transmitter.

CONCLUSIONS: The use of FMEA has allowed the development of an equipment for plantar pressure analysis during long jump take-off reducing athlete damage risk and improving the reliability of experimental protocol.

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