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A NEW METHOD FOR THE MEASUREMENT OF GROUND REACTION FORCES DURING ICE HOCKEY SKATING

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SUMMARY

The measurement of ground reaction forces (GRF) is considered as a standard complement of kinematic analysis of most movements (Jelen 2006). In sport is measured in many disciplines such as athletics or volleyball (Meldrum, Hilton et al., 2004; Klenerman 2006). Less frequent and technically more difficult is to measure interaction forces during the ice hockey (Pearsall, Turcotte et al., 2000; Dewan 2004; Tyler J. Stidwill 2010). In the laboratory of extreme loading (BEZ) was developed a special measuring device "a measuring skates" to measure the GRF during the ice hockey skating (Šťastný, Kubový et al., 2010). The measuring skate measure separately two components of interaction forces (GRF as reducible) and it can be synchronized with other measuring devices. This new measuring device created in BEZ laboratory has been synchronized with technology Footscan Insole®. There have been done several pilot measurements, which examined the interpretability of survey outputs from "measurement skates" together with the 2D kinematic record and Footscan Insole® technology.

The result of synchronization a "measuring skate" with other measuring technology is the ability to record interaction forces on the skate boot with the distribution of plantar pressures. It is thus allowed to research the interaction of forces in the foot-skate-surface interactiv system, or causes a discomfort arising from the use of skates. The 2D skating record can be evaluated together with changes in local dynamic plantar pressures and size of the loading forces on the skate's blade.

Key words: dynamometrics, measuring skates, Footscan Insole®, ice-hockey

INTRODUCTION

The measurement of GRF is considered as a standard complement of kinematic analysis of most human movements. In a sport is GRF measured in many disciplines such as athletics or volleyball (Meldrum, Hilton et al., 2004; Klenerman 2006). Less frequent and technically more difficult is to measure interaction forces during the ice hockey (Pearsall, Turcotte et al., 2000; Dewan, 2004; Tyler J. Stidwill, 2010), which is due to technical difficulties. The GRF on the ice surface is not measured by force plates located beneath the ice surface. The solution however is to measure these forces on the beam of the skate's blade. Moreover, if it was ever done extensive measurements of interaction forces in the skates, the results retain to manufacturers of skates.

The aim of this work is to show a possibility of enriching the kinematic record of ice hockey skating by record of plantar pressures distribution and interaction forces on skates. In this study is presented a sample measurement with it's qualitative analysis of a slide with push off during forward skating.

In the BEZ laboratory has been newly designed and validated measuring device that is capable of measurement the loading force component F_t, bending force component F_o with an acceptable error of measurement (Šťastný, Kubový et al., 2010). An important aspect was to synchronize this measuring device with standard technology Footscan Insole®. This would allow the measurement of local plantar pressures on the sole of the foot inside the skate, while are measured the interaction forces F_t and F_o acting in system skates-surface. These measured components F_t and F_o representing the GRF, if the slide of skates toward the surface is known. In previously published studies of skating has always been used in only one detection technology (Yuki, Norihisa et al., 1996; Dewan 2004; Stidwill, Turcotte et al., 2009). For research of the interaction forces during skating, it is require more detection technologies, which significantly refines the interpretation of relevant outputs. The following example is a case study of one sample measurement of interaction forces during skating forward, the two technologies were used for qualitative analysis of the loading of the foot in skates together with 2D kinematic record.

METHODS

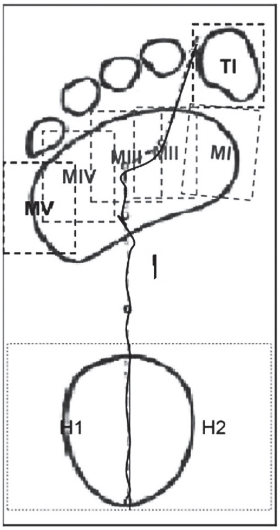
The 2D record of forward skating was evaluated together with dynamics of loading of the foot. Loading forces were measured by two different detection methods with different measurement error. As a record of plantar pressures was used the outputs from a standardized measuring device Footscan Insole®, which is determined by measurement error under 5% (Low, Dixon et al., 2010) (for the distribution of plantar pressure). On the other side the outputs from measuring skates have a measuring error for $F_t \pm 8.6\%$, for $F_o \pm 8.4\%$ and for point of action of the force $\boldsymbol{x} \pm 0.6\%$. The differences in measurement errors were resolved by evaluating the movement phase (expression of an ongoing phenomenon in time), which has been used such as Chang (Chang, Turcotte et al., 2002). Thus we observed the phenomena which occur in certain time, rather than absolute values of measured interactive forces.

In a pilot study using a time signal were synchronized the Footscan Insole® technology with the "measuring skate's technology". Synchronization ran through a light signal from 2D kinematic record. Performed movement was a skating forward, when was evaluated the slide with push off. As a beginning of slide was meant the finish of the lay down the blade of left skating boot to the ice during skating step (see Fig. 3, time 10.00 s). As a finish of the push off was mend the time when the left skating boot loose the contact with the ice (see Fig. 3 time, 10.50 s). During the measurements was evaluated a slide with push off of the left foot when skating by stable cyclic motion.

Player had booted a "measuring skate" on the left leg, which was supplemented by measuring insert Footscan Insole®. The same pair of skates was booted on the right leg, which was the same weight and shape. Camera was carried out recording the ongoing movement. Synchronization of measurement techniques was performed using the timeline in the videotape, where the light signal started both measuring techniques. Player instructions were:

After the start, using forward skating executes a several aggressive push offs. Evaluated movement was the slide with the push off. To demonstrate the possibility of measuring devices was not necessary to perform repeated measurements of which would be a representative sample their average.

For measurement by Footscan Insole© are the outputs a "plantar pressure" in kPa . These plantar pressures are result of F_t acting at the surface area of the soles of the foot. Plantar pressures are therefore divided according to area of action. For the purposes of this study were used eight areas of plantar pressures action. The results are then the relative timing of the distribution of plantar pressures in the choose places. Areas selected for plantar pressures measurement and their descriptions are shows schematically in Figure 1. While selected areas are geometric unit from measuring insert, in which is presumed the contact with desired part of sole of the foot (Low, Dixon et al., 2010). The size of these areas are optional for measurement. Heel areas H1 and H2 were geometrically divided into two equal halves, as the plane passes through the center of the skate blade



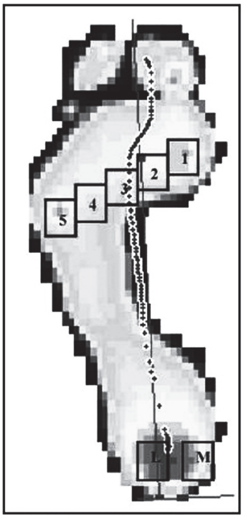


Figure 1. Detected areas the sole of the foot

Legend:
On the left: Schematic pics, T1 – area under big toe, MI – area under the first methatarzal head, MII – area under the second methatarzal head, MIII – area under the third methatarzal head, MIV – area under the fourth methatarzal head, MV – area under the fifth methatarzal head, H1 – outer side of heel, H2 – inner part of heel.
On the right: Original differentiation of geometric areas in Footscan Insole® software.

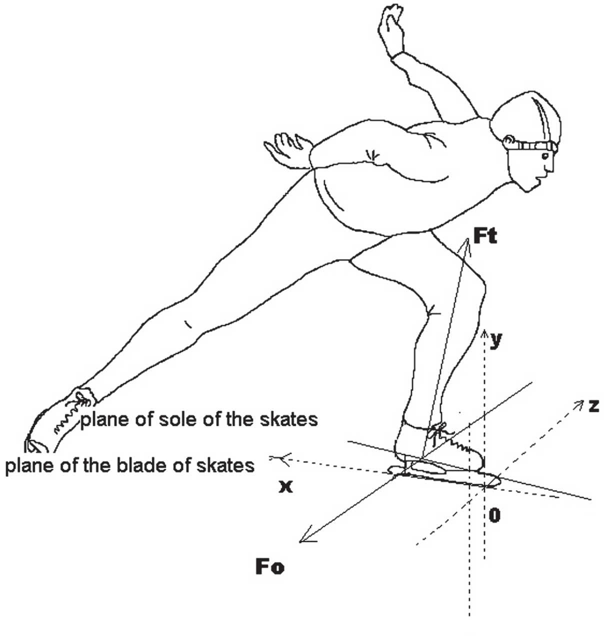


Figure 2. Coordinate system for description of the force components of the experimental device

Legend:
F_t = pressure force component, F_o = bending force component, reference point **0** is on the skates blade bellow the front top of the skates, the shift point of action of the force from point 0 towards the heel skates has a positive value, *x*, *y*, *z* are spatial coordinates of point 0. Origin of picture before repaint: http://www.lucylearns.com/.

(detected rectangle was then size of 30 × 70 × mm). In metatarsal and big toe areas was the original geometric field (the original software size was 15 × 15 mm) increased by 10 mm on each side, in order for their diffusion. It was used as method of "sliding average" for the determination of the ratio of loaded area between them.

With the newly designed measuring skates could be measured a two components of the interactive forces acting on the skates blade and it's beam that are possible to associate with GRF. So it is possible to measure the loading force component F_t, bending force component F_o and counted the point of action of the force on the skates blade.

As the **loading force F_t** (Fig. 2) was defined the force component which is perpendicular to sole of the skate boots. Sole of the skates is choosing as reference because during skating the skates are changing the slope of the blade from "edge to edge" towards the ice.

As a **bending force F_o** is defined a force component acting in the medio-lateral direction towards the sole of skates, which corresponds to the force that acts perpendicular to the F_t. (see Fig. 2).

The point of action of the force '*x*' was defined as the point on the spatial coordinate x, which is in contact with the ground between points 0 and the rear end of skate's blade. The thickness of the blade due to its size (3 mm) was neglected.

RESULTS

As a result of measurement is presented the qualitative analysis of individual player activity measured during slide with the push off. During the slide with push off was made a motion kinogram which is documenting the key phases of movement in the exact time.

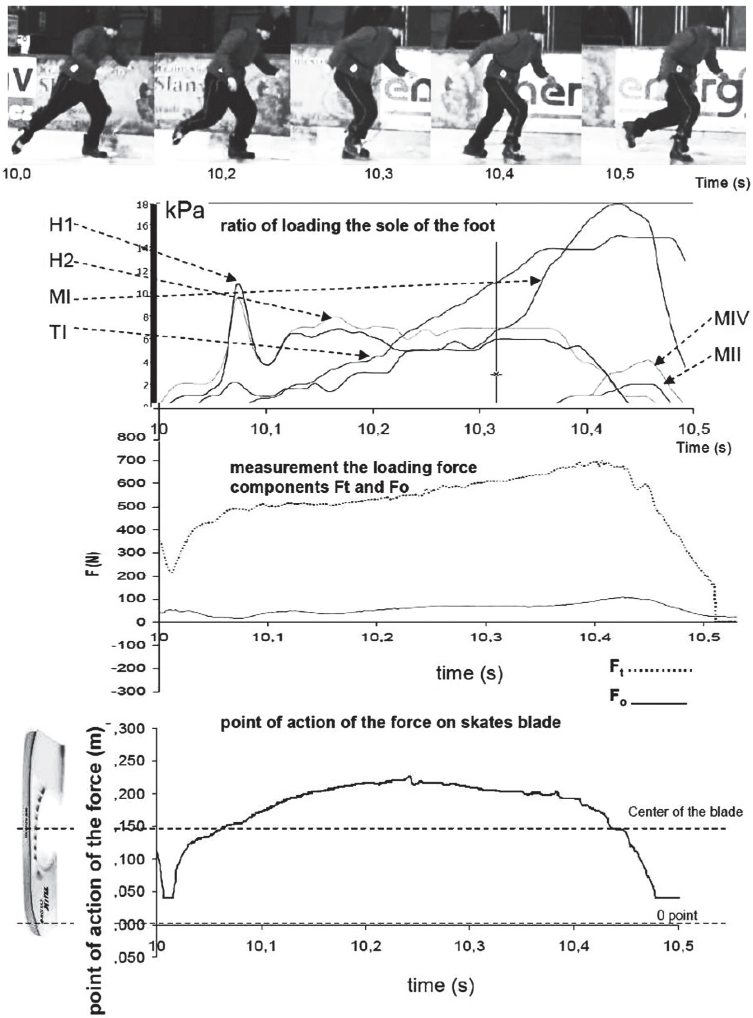


Figure 3.

Legend:
Record of measured player, top is the kinogram and timeline (T). The first graph showing the local plantar pressures detected Footscan Insole®. Other graphs becomes from measuring skates. F_t means loading force, F_o means bending force, Schematic pics, T1 – area under big toe, MI – area under the first metatarsal head, MII – area under the second metatarsal head, MIII – area under the third metatarsal head, MIV – area under the fourth metatarsal head, H1 – outer side of heel, H2 – inner part of heel.

The timeline shows the curve of relative loading of detected areas of the soles of the foot (Footscan Insole®), the time curve of F_t together with the bending force F_o and the timeline the point of action of the force – x. Bending force F_o becomes in that case only in positive values. That means it is always a bend in the outside (medio-lateral) direction.

The record shows the ratio of loaded areas of the sole of the foot (Fig. 3), where is possible see a gradual transfer of bearing the H1 and H2 location in the area of the first metatarsal (MTI) and thumb (T1). The even bearing is the intersection of these curves. The bearing the H1 and H2 areas then continues in a relatively significant degree until the final phase of push off (in time from 10.30 to 10.38 is ratio of both parts of the heel to the MI and TI greater than 1/3).

In the final stage of push off is possible to see the involvement of the dominant areas of MTI and TI, while being recorded significant involvement MIII and MV. Slide with the push off itself lasted 0.5s and peak load was achieved in time 10.4 (dominantly beard areas MTI and TI), when the F_t reached 700N together with the lateral-medial component of force F_o = 100 N.

Record of forces detected by "measuring skates" shows the size of the F_t, F_o and point of action of the force on the skate's blade (Fig. 3). The F_t culminates during the push off, while F_o is also the highest during the completion of push off. The transfer of skates follows after the push off. The lateral-medial (bend in inner direction) component of force was not measured during the slide with the push off.

The location of point of action of the force was under the front part of skate at the beginning and end of the slide with push off. In middle of slide during a full skate flip on the inner edge is point of action of the force far below the rear of skates, which is the moment when the loading ratio between heel and MTI-TI is most even (Fig. 1).

During the MTI and TI dominance has been the point of action of the force close to the centre of skate's blade. It can be said that the player foot was loaded most in the metatarsal area MI and big toe area TI. In the loading of the heel is recognized an effect, when heel is beard also in moment when point of action of the force is at the front of skates blade.

The dynamic course of interaction forces F_t and F_o is similar to each other, both components of force graduated during the slide with push off. The F_t to F_o ratio is approximately 1 : 7, indicating a relatively smoothly executed slide with push off (when move without correct technique, the ratio would be proportionally higher at F_o).

DISCUSSION

As a result of synchronization the two detection devices, which evaluate the interaction forces, is a qualitative analysis. But it is not yet possible to determine the correct method of loading for the ice hockey player foot. Nowadays are missing any standards for loading the foot in ice hockey skate. By used the methodologies could be the standard in skate shoes determine in the following quantitative research.

The presented example of the interaction forces has some common links to forces find out during running. Even in skating were shown that the loading force culminates under the banner of MTI and big toe (Dickinson, Cook et al., 1985). However, our example can only be applied to one case in particular. To generalize those outputs would be possible after a quantitative study with the possibility of counting average from several measurements as recommended by the Stergiou (Stergiou 2004). Our aim was, however, demonstrations of potential of outputs after synchronization of two different measurement technologies and interpretation of survey findings. To consider these needs is the aim done.

Distribution of pressure on the sole of the foot describes the relative effect of loading forces and it may be related to functional properties of the foot (Jelen, 2007). In particular, detection of pressure through thin inserts can determine the relative loading of individual parts of the foot (Owings, Woerner et al., 2008). The GRF is different to the determination of the plantar pressure distribution in that it's taken into account with the vertical component of force and the exact area to which this force operates. In case of ice hockey skating can not be interaction force described as vertical, but pure bearing force to the sole of the foot. Slide with the push off is carried out in the medio-lateral tilt of skates. On the contrary, by knowing the F_o and F_t can be calculated the GRF if slope of skates is known. The synchronization a technology Footscan Insole® and measuring skates allows a detailed description of the interaction forces in the system of foot-skate-surface.

CONCLUSSION

Qualitative evaluation of the synchronized outputs from measuring skates and Footscan Insole® is, in our opinion, very useful for research on the interaction forces in ice-hockey. We managed to successfully synchronize and interpret outputs from those two measuring devices. The newly designed experimental device – "measuring skates". is possible to use for further qualitative or quantitative research.

LIST OF ABBREVIATIONS

2D	two dimensions
BEZ	laboratory of Biomechanic of extreme loading
F_t	pressure force component
F_o	bending force component
GRF	ground reaction forces
H1	space under medial part of heel
H2	space under lateral part of heel
MI	space under head of first metatars
MII	space under head of second metatars
MIII	space under head of third metatars
MIV	space under head of fourth metatars
MV	space under head of fifth metatars
T	time
TI	Toe 1, space under the big toe
z	space component of force "z"

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NOVÁ METODA MĚŘENÍ REAKČNÍCH SIL PODLOŽKY BĚHEM BRUSLENÍ V LEDNÍM HOKEJI

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SOUHRN

Měření reakčních sil podložky (GRF) je považováno za standardní doplněk kinematické analýzy u většiny pohybů. Ve sportu je měřeno v mnoha disciplínách jako je atletika nebo volejbal (Meldrum, Hilton et al., 2004; Klenerman, 2006). Méně časté a technicky obtížnější je měření interakčních sil během ledního hokeje (Pearsall, Turcotte et al., 2000; Dewan, 2004; Tyler J. Stidwill, 2010). Pro měření GRF u pohybů na ledové ploše v ledním

hokeji byla v laboratoři Biomechaniky extrémní zátěže (BEZ) vyvinuta speciální měřící brusle (Šťastný, Kubový et al., 2010), která měří samostatně dvě složky interakčních sil (přepočitatelné jako GRF) a je možné ji synchronizovat s dalším měřícím zařízením. V laboratoři BEZ, bylo toto nově konstruované měřící zařízení synchronizováno s technologií Footscan Insole®. Poté bylo provedeno několik pilotních měření, které prověřili interpretovatelnost zjišťovaných dat z „měřící brusle“ současně s 2D kinematickým záznamem a technologií Footscan Insole®. Výsledkem synchronizací „měřící brusle“ s další měřící technikou je možnost záznamu reakčních sil na botě brusle společně s rozložením plantárních tlaků. Je tak umožněn výzkum interakce sil v systému noha-brusle-podloží, či příčin diskomfortu vznikajícím při používání bruslařských bot. Kinogram bruslení tak může být doplněn o záznam dynamických změn lokálních plantárních tlaků a velikosti zátěžových sil na noži brusle.

Klíčová slova: dynamometrie, měřící brusle, Footscan Insole®, lední hokej

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