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Crowd Biomechanics and Ground Reaction Force

Juan CarlosMUÑOZ,GustavoREPRESAS,Ana P.TOSCANO, Osvaldo GARCÍA PICCININI, Belén MIYANO

PhD, Professor, Department of Computer Engineering, UNTREF, Buenos Aires, Argentina

PhD, Professor, Instituto de Ciencias de la Rehabilitación y el Movimiento, UNSAM, Buenos Aires, Argentina

Laboratory of Biomechanics, UNSAM, Buenos Aires, Argentina

Laboratory of Biomechanics, UNSAM, Buenos Aires, Argentina

Assistant Professor, Instituto de Ciencias de la Rehabilitación y el Movimiento, UNSAM, Buenos Aires, Argentina

ABSTRACT: This article introduces a new field of application of Biomechanics, which we have called Biomechanics of Crowds or Crowd Biomechanics. Taking advantage of the space and equipment of a Biomechanics laboratory, we have analyzed the behavior of the Ground Reaction Force (GRF) on a multitude of people crossing an artificial door that consisted of a free space between two bulkheads. Being a preliminary study, the results are not generalizable, but they have been useful to know some limitations and establish more rigorous experimental conditions to carry out future measurements.

KEYWORDS*:* Biomechanics of crowds, evacuation, vertical ground reaction force.

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I.INTRODUCTION

The Physics of Crowds is the branch of Physics whose objective is to describe, explain and predict the mechanical behavior of crowds in specific situations, such as a crowd of people passing through a gate during the evacuation of a football stadium or during an emergency. This discipline considers each person as a "human particle" and makes models that take advantage of statistical analysis, just as kinetic theory establishes models of gases from molecular motion. From another perspective, Biomechanics deals with the analysis of kinematics, kinetics and energetics of human movement, considering each subject as a system. In this paper, however, a Biomechanics of Crowds is proposed, with the aim of extending the biomechanical analysis to a multitude of people. For this purpose, we have carried out a preliminary study in the Biomechanics Laboratory at San Martín University, simulating a real evacuation through an open door, which has allowed us to obtain graphs of ground reaction forces.

II. RELATED WORKS

In Biomechanics, the Ground Reaction Force (GRF), exerted on a single person in his displacement on the ground, is represented by a vector in three-dimensional space, whose components indicate the values of the force in the vertical, anteroposterior and mediolateral directions, and can be measured experimentally by using a platform of forces (Figure 1). During normal gait, the vertical component of the GRF vector is the one that reaches the highest intensity, presenting a curve similar to an inverted letter W [1].

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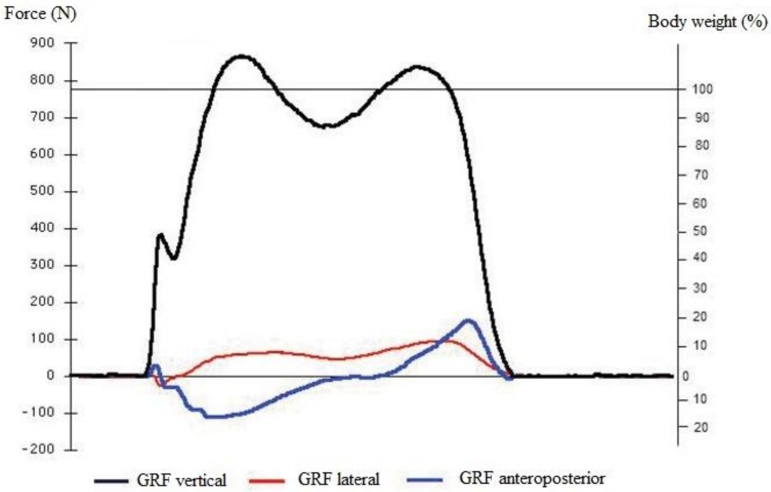

Figure 1: Components of Ground Reaction Force in Normal Human Gait

Going back to the past, the application of Physics for the research of social phenomena should be sought, at least, until the 19th century [2]. Currently, the Physics of Crowds aims to study the movement, forces, pressures, interpersonal distances, which occur during the movement of small groups or large number of people, such us in stampedes of terrified crowds [3]. Predictability seems impossible when panic strikes a crowd, however, irrational behavior does not mean unpredictable. In this regard, Philip Ball (2005) asked when referring to the crowds: “Does physics simply help us to explain and understand, or can we use it to anticipate and thereby to avoid problems?” [4]. For several decades, many investigations have shown that both scientific activities are possible and necessary: passenger flow in subways [5], pedestrian traffic [6], movement of pedestrians on footways in shopping streets [7], multi-agent approach to pedestrian and crowd dynamics, quantified by video tracking [8], the role of panic in the room evacuation process [9], are just some examples. In continuity with this type of studies, and understanding the value of its interdisciplinary approach [10] [11], we have proposed to analyze the vertical component of the ground reaction force when a crowd moves through a door simulated between two bulkheads.

III. MATERIAL AND METHODS

This is a preliminary study carried out in the Biomechanics Laboratory of the National University of San Martín. Two bulkheads separated by 90 cm were placed simulating the space of a wide door, which was crossed by the group of members of the sample. Two force platforms were located at ground level in the open space between the bulkheads, just where the people passed. These platforms are identified as A and B, right and left respectively, following the traffic direction of the crowd.
The laboratory is 9 meters long and 5 meters wide. The force platform is installed at ground level, in the center of the laboratory. There are 10 cameras located below the ceiling at 2.30 meters high, which have allowed us to follow the trajectory of the subjects of the sample who carried markers.

The selected sample consisted of a total of 40 Physical Education teachers, currently studying the Bachelor's Degree in Physical Education of the UNSAM. The average weight of the sample is 678.23 N ± 148.57 N. Maximum weight of 934.57 N and Minimum weight of 452.09 N.
A reflective marker was placed on the forehead of 6 members of the sample, in order to be able to follow their individual trajectories throughout the movement. The teachers with markers were distributed in different areas of the initial mass of people, trying to respect a certain homogeneous distribution, so that there were not two markers very close to each other.
All the teachers, homogenously distributed, were placed against one of the walls of the laboratory in front of the door. At the signal, all of them went towards the "open door" delimited by the bulkheads. The experiment consisted of going through the door as quickly as possible, while recording the motion kinematics (triplanar trajectories, velocities and

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accelerations) of the people with markers, as well as the kinetics of the whole sample, expressed in the Ground Reaction Force.

IV. RESULTS

The values of the GRF were graphically represented. Below are the graphs of the vertical component of the force as a function of time (GRFz vs. t), from the moment in which the first contact with the platform is made until the last person stops making contact. The graphs on each of the platforms are shown. The absence of force during the first two seconds is due to the time elapsed between the signal to start the movement and the moment in which the first person makes contact with the platform, after traversing the distance between his initial position (against the wall) and the platform.

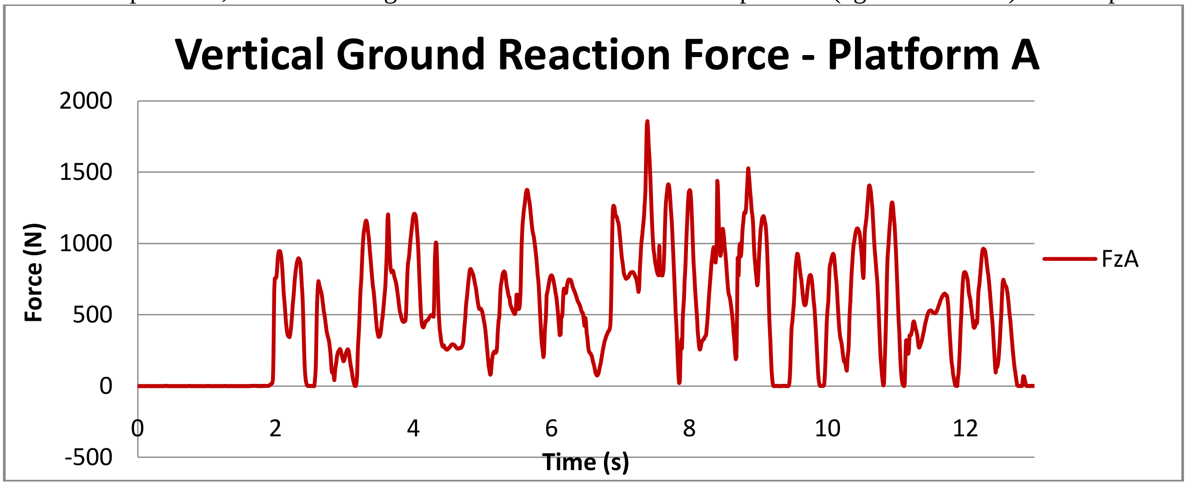

Figure 2: Vertical Ground Reaction Force on platform A.

Average GRFz (FzAa) = 496.29 N
Average GRFz without null intervals ($FzAa\text{-}_0$) = 575.01 N
MaximunGRFz (FzAmax) = 1858.58 N (7.39 s)

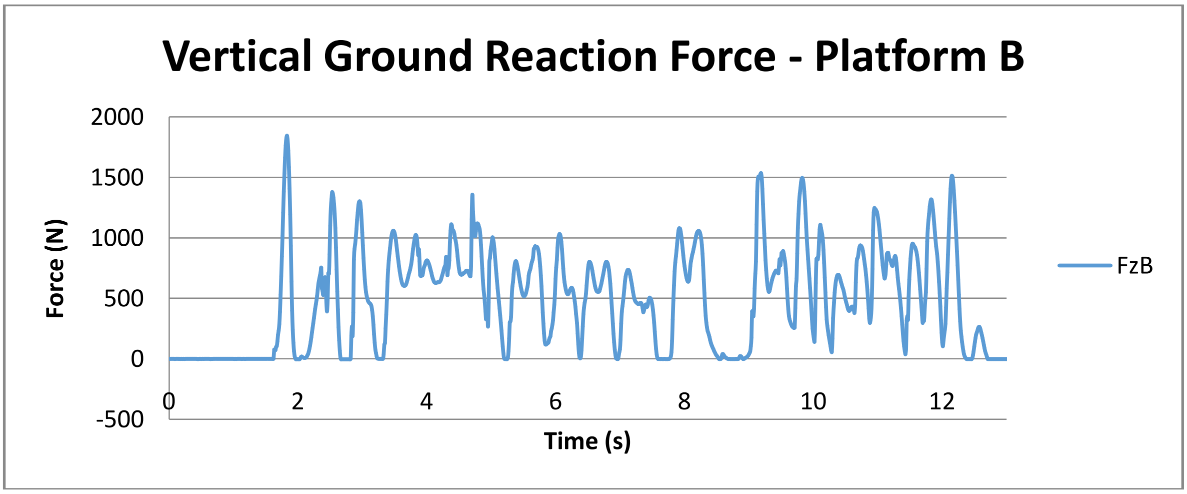

Figure 3: Vertical Ground Reaction Force on platform B.

Average GRFz (FzBa) = 481.04 N
Average GRFz without null intervals ($FzBa\text{-}_0$) = 543.67 N
MaximunGRFz (FzBmax) = 1844.56 N (1.83 s)

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V. DISCUSSION

The relative maxima of FRTz reached on each platform are significantly higher than those obtained in normal human gait. However, they are slightly higher than those obtained when two people walk simultaneously on the same platform. This result could indicate that the door was not crossed by people running, in which case peaks higher than 1500 N and even 2000 N would be expected, depending on the speed.
The absolute maximum values of force on each platform occur at different times.
Platform B (figure 3): an initial maximum peak is observed. This peak indicates that the first person to reach this platform did it very quickly. This is in accordance with its short duration (0.3 s), and also with the fact of being the first person to cross "the door", as it is deduced from the first contact produced a few hundredths of a second earlier than in platform A. These inferences are consistent with what is seen in the video of the simulated evacuation.
Platform A (figure 2): at the beginning (1.96 s) the curve corresponding to the ground reaction force on a person in fast gait is observed (0,5 s). The impact peak, the minimum peak and the active peak can be clearly distinguished. The impact and active peak values, 945.66 N (2.06 s) and 895.57 N (2.33 s) respectively, are consistent with fast gait values (speed walk values), and are in accordance with what is observed in the video.

An overlap of treads is observed a second and a half after the first contact, common pattern in both platforms, which is indicating a first crowding of people at the door.
Individual treads are observed on platform B (blue line), in the middle region of the graph, between 5 and 9 seconds approximately. This would be indicating a less crowding of people on this platform in this time interval. On the other hand, on platform A (red line), a greater concentration of simultaneous treads is observed, with a certain degree of individualisation towards the end of the circulation of people through the door.
We highlight the particular form of individual GRFz curves in which one of the peaks is clearly diminished with respect to the other. We have found that, in many cases, they are caused by incomplete tread on the platform. A graph similar to the normal gait, in which the first peak is clearly visible and the second is markedly diminished (almost non-existent) may be due to a tread of a person in gait, making the contact of the heel inside the platform but with the forefoot out of it. Contrarily, in the case of people who contact with the heel outside the platform and the forefoot inside it, a result similar to the normal one but with the impact peak notoriously diminished with respect to the impulse peak is obtained. This has been verified by video analysis and other subsequent measurements.

A) Limitations of the present study

- The reduced dimensions of our laboratory to perform the test and the consequent difficulties to work with large crowds.
- The small sample, and its relation to the width of the "door" is insufficient to achieve a crowding of people that slows down the pace sufficiently.
- The number of subjects with markers was insufficient.
- Lack of video cameras at ground level in the door space.
- The "door" delimited by two bulkheads is not rigid enough to withstand strong blows or shocks against it, as would be two walls in a real case. This could be altering the behavior of people when approaching the bulkheads.
- Unrealistic emergency evacuation. The teachers moved tidily and carefully to avoid throwing the bulkheads.

The study in the laboratory is an intrinsic limitation of this type of research, being the physical space one of the most important limitations. We consider that the realization of similar studies in wider spaces (gymnasiums, sheds, covered stadiums) will allow obtaining more reliable results. For this purpose, the installation and use of specific Biomechanics equipment (force platforms, baropodometers, digital goniometers, joint markers, myoelectric sensors, etc.) will be essential outside the laboratory, including on train platforms, subways, streets and busy corners , open stadiums, etc.

B) Future considerations

At this moment we are analyzing the results of the kinematics, speeds and individual accelerations, and its relations with de GRF. At the same time, we are improving the experimental conditions that will allow us to carry out more precise studies.
The result achieved meets the expectations proposed as a preliminary study. The purpose of this preliminary paper should not be understood as much from the results obtained, which are limited, but rather to a new possibility that opens up in the field of Biomechanics, in its relation to the Physics of Crowds and other sciences involved in the analysis of this type of phenomena. The Biomechanics of Crowds can also be applied to the behavior of animal masses,

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such as herd stampedes. The proposal is open to other researchers in Biomechanics who are interested in venturing into phenomena involving crowds, in large and small groups.

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