BIOMECHANICAL PROPERTIES OF INFANTRY COMBAT BOOT DEVELOPMENT

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INTRODUCTION

Military requirements demand a boot that is comfortable, durable, and enhances the locomotor capabilities of the soldier (1). At Marine Corps Recruit Depot (MCRD), San Diego, **40%** of all recruits going through "boot camp" report to sports medicine or podiatry with musculoskeletal complaints (2). These conditions have a significant impact, resulting in 53,000 lost training days and a cost of $16 million per year **(3).** Since the anatomical sites of most of these training-related complaints are below the knee, a further look into the role of footwear in the development of musculoskeletal injuries was warranted. The objective of this research was to evaluate the biomechanical properties of current commercially available boots and to provide a recommendation for a combat boot with optimal biomechanical properties.

MATERIALS AND METHODS

The 'evaluation included objective physical tests of the cushioning and material characteristics of military and commercial footwear, and biomechanical tests to evaluate the human subjective biomechanical performance of the footwear. At the conclusion of the biomechanical tests, a brief survey addressing comfort parameters was administered to each subject.

Physical Tests:

Materials. The commercially available boots tested were the Rocky **RB7774,** Red Wings **04473-2,** Timberland Iditarod, Hi-Tec Magnum, Browning Climber **400,** Danner Acadia, Bates Lite **924,** and Northlake N9013. Standard-issue jungle boots and leather combat boots **(3)** were also tested. All boots were prepared for testing by separating the sole from the rest of the boot and removing the insoles. Equipment. A computerized, gravity-driven impact tester, the *Exeter Impact System,* was used to provide force deformation data on the footwear materials. This device drops an 8.5-kg shaft a 50-cm onto the surface of the shoe. The total impact force with no resistance is 42.5 peak *g.* The shaft was instrumented to provide a recording of displacement and force. Data collection. Data were gathered while each boot was impacted 10 times separately on the heel and forefoot. Variables measured included material thickness, peak ***g,*** time to peak ***g,*** peak force, percentage penetration, and percentage energy return. **Peak g** describes the ability of the item tested to sense the shock that is applied

to it **Peak force is** the maximum amount of force that a material senses during impact. The higher peak force during activity means the body will sense more shock. The material tests selected were based on American Society of Testing and Materials (ASTM) standards.

Subject Performance Tests

Subjects. Ten healthy male **U.S.** Marine Corps volunteers served as subjects. **Materials.** All subjects were tested using 9 different footwear designs as follows: a standard military combat boot, a military hot-weather (jungle) boot, the Danner Acadia boot, the Bates Lite 924 boot, the Asolo 540 hiking boot, the Northlake N903**13** boot. Two prototype boots with jungle boot uppers, /inch polyurethane insoles and polyurethane midsoles were developed using the information from the boot impact tests. Subjects were also tested wearing Asics Gel 125 high performance running shoe while running, and while running barefoot. **Equipment.** The ground reaction force was measured with a piezoelectric force plate housed in a commercially manufactured treadmill. Rearfoot angles were measured by attaching a flexible goniometer to the rearfoot of each subject. A spring-mass biomechanical model was created to analyze the ground reaction force data. The model calculated the peak impulse loading and power absorption of the subject while wearing each of the test footwear and while barefoot. **Data collection.** Ground reaction force data and rearfoot motion were collected while the subjects ran at 8 mph and 0% grade **on** a motor-driven treadmill. Variables measured included peak impulse loading, peak power, rearfoot motion, pronation time, and pronation velocity. Peak impulse loading is an indication of the shock absorbency characteristics of the footwear in relation **to** the human foot and lower leg. A lower value indicates better shock absorbency. **Questionnaire.** After each subject's biomechanical test, a brief survey addressing comfort parameters was administered immediately after testing. Comfort level was rated **on** a scale from 1 (extremely uncomfortable) to **5** (extremely comfortable).

RESULTS AND DISCUSSION

Data derived from the boot impact tests revealed that all of the commercially available boots tested superior to the standard-issue jungle and leather combat boots. According to the subject performance tests, the greatest shock absorption and lowest power requirements were obtained with the Asolo **540** boot, the Bates Lite 924 boot, and the polyurethane prototype boot. The greatest stability was achieved with the Danner Acadia boot, the leather combat boot, and the Bates Lite boot. The jungle boot improved markedly in each of the subject test parameters with the addition of the polyurethane sole (polyurethane prototype boot).

Physical Tests

Impact tests that measured peak g at the heel of the footwear revealed that the Bates Lite and Northlake boots had values that were approximately half those of the military boots (see Figure 1). These results suggest that the Bates Lite boot is

best suited to absorb the shock applied to the heels in comparison with the other footwear tested. Conversely, the combat boot and jungle boot transfer more shock to the body during activity when compared with the other footwear tested.

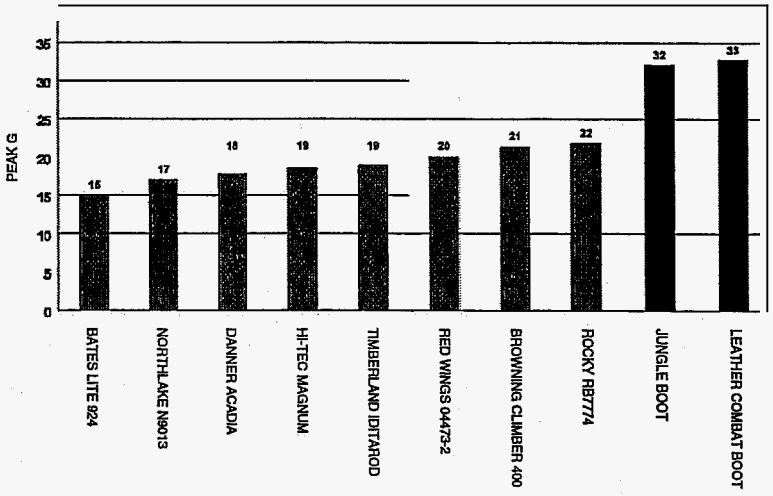

Figure 1. Heel peak g scores.

Figure 2 shows heel peak force. The Bates Lite boot absorbed the lowest amount of force at the heel (1247 N) compared with the leather combat boot, which absorbed the highest amount of force at the heel (2722 N). Theoretically, the boot that absorbs a greater magnitude of this force will transfer more shock **to** the body.

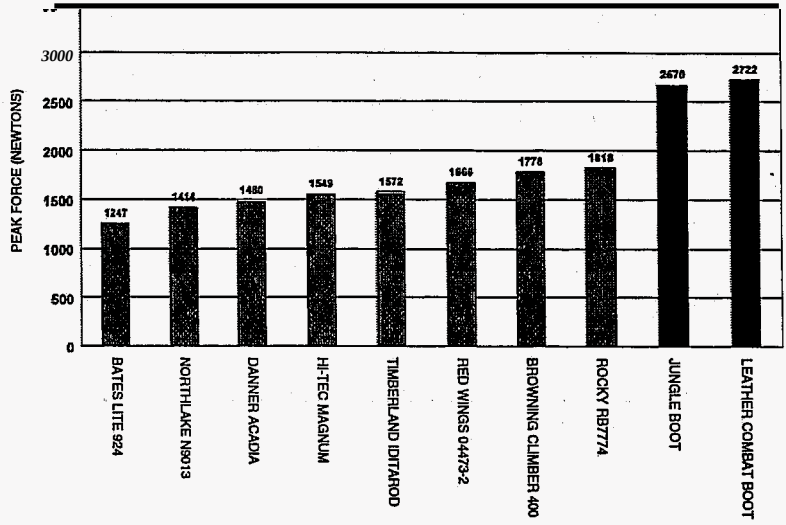

Figure 2. Heel peak force.

Subject Performance Tests

Peak impulse-loading scores for each boot are presented in Figure 3. The Asolo boot scored the lowest value (55.5 Ns) indicating the greatest shock absorbency of all the boots tested, with the Bates Lite boot having the next lowest value (56.5 Ns).

The boot with the optimal combination of shock absorption and stability was the Bates Lite boot. This boot also scored the highest comfort level subjective rating, followed by the Asics running shoe and the polyurethane prototype boot.

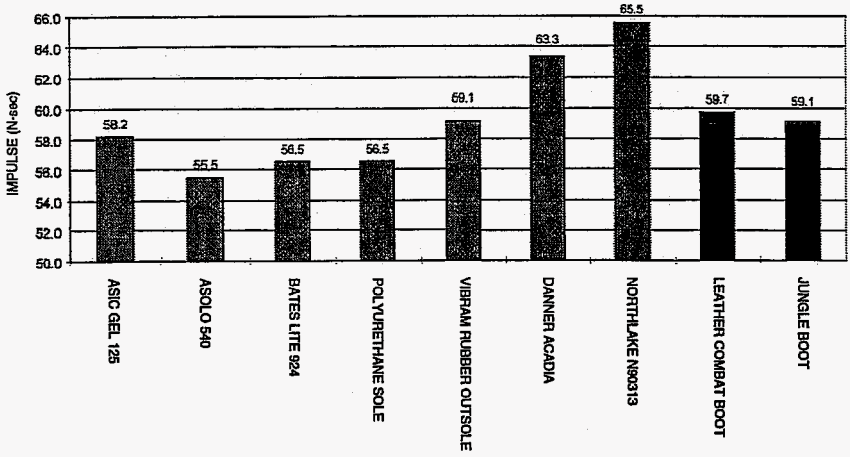

Figure 3. Peak impulse loading (10-subject average).

CONCLUSIONS

Data derived from the boot impact tests revealed that all of the commercially available boots tested superior to the standard-issue jungle and leather combat boots. Our findings suggest that currently available boots offer superior features over the standard-issue military boots. This study illustrates that several optimal characteristics from various commercially available boots can be combined to create a military prototype boot which surpasses that which is currently in use.

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