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Definition and Perception of Nervousness, Feel and Control in Tennis Rackets

•Feel •Control •Vibration •Nervousness

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The feel and control a tennis racket provides is of major importance to tennis players, with the racket acting as an extension of their bodies. However, feel and control are highly subjective performance parameters, making them difficult to associate with specific design criteria. As a result, literature covering tennis racket characteristics is limited in its discussion of the human-racket interaction. This project investigated feel in tennis, baseball, golf, and virtual sports to add to the discussion of how the racket interacts with the hand, and how players perceive feel during and post-impact. The parameters of feel in tennis rackets were identified to be shock, plow-through, and soundwave properties. We also defined a new parameter, nervousness, which relates to the lingering vibrations in the racket. These feel components can be further manipulated in racket construction through stiffness, mass distribution, and damping. The criteria associated with the desired feel of maximizing the feeling of hitting at the sweet spot were found to be low shock, low nervousness, and high plow-through.

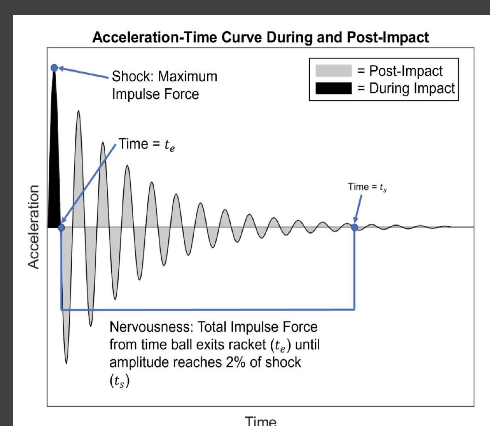

Fig. 1: Labeled acceleration curve, perpendicular to racket face, displaying shock and nervousness.

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PROJECT OVERVIEW

The objective of the project was to publish a review paper identifying tennis racket design that optimizes feel and control for a tennis player, making the racket a further extension of the hand. In this paper we define nervousness, a new parameter explicitly describing the lingering vibrations felt in the hand after impact. Published work in sports engineering concerning feel in sports equipment have discussed tactile and auditory responses in golf clubs, quietness in skis, and the stinging feeling in baseball bats. However, literature discussing feel and control in tennis lacks discussion of how racket characteristics affect the human-racket interaction, specifically relating to human perception of feel. Since Fall 2022, the team has been conducting a literature review identifying the parameters that contribute to feel for tennis, and how they are affected by a racket's physical properties: stiffness, weight distribution, and damping. This work included understanding the tennis racket response to be modeled as a 2nd-order mechanical system and how different properties affect the system response. In the paper, findings made in other similar sports and from the replication of feel in virtual sports were drawn upon to properly define the components of feel in tennis and the factors that contribute to them. The contributions of racket materials and string configurations to feel were also explored. This review paper is set to be published this year, supporting the experimental works moving forward in optimizing feel and control in tennis rackets.

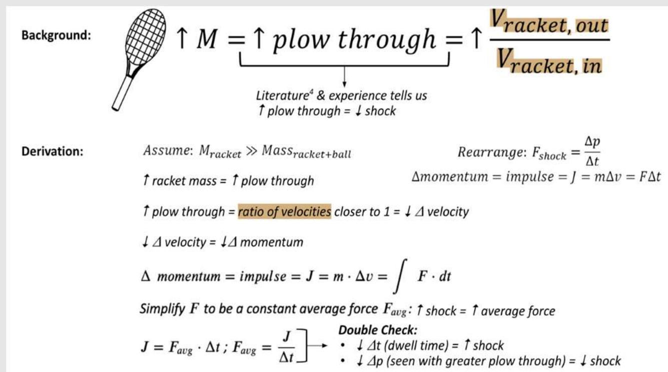

Fig. 2: Shock derivation

PROJECT METHOD AND RESULTS

The team reviewed research papers involving tennis racket design, vibrations, and injuries to better understand its contribution to feel in tennis. Papers on other sports involving vibrations and auditory feedback, as well as papers on the human body's response to vibrations were reviewed to gain insight into racket-hand interactions. From these papers, the team categorized feel into four parameters: shock, nervousness, plow-through, and soundwave properties. These parameters are related to physical racket quantities of stiffness, weight distribution, and damping, helping identify how a racket could be designed prioritizing feel. Shock is defined as the force felt at the hand due to racket-ball impact and is seen on an acceleration signal response graph as the maximum impulse force (see Figures 1 and 3) [1].

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PROJECT METHODS AND RESULTS CONT.

From literature, it was found that increasing racket mass or increasing the swingweight (the moment of inertia of a racquet) by shifting mass distribution towards the racket tip decreased shock. Although there were conflicting findings on whether high stiffness or low stiffness was desired concerning shock, from the team's definition of shock (see Figure 2) and experience, low stiffness was found to be desired. Damping, when designing for low shock, was found to have no effect. Nervousness, the new parameter drafted by the team, is defined as the total impulse from the time the ball exits the racket until the impulse amplitude reaches 2% of shock (see Figures 1 and 3). These prolonged vibrations can cause an uncomfortable and forceful quivering feeling in the player's hands which results from the ball contacting the strings outside of the sweet spot. Low nervousness was found to correspond to high damping, increased swingweight, and stiffness [2]. Plow-through is a measure of the racket's stability through impact and is quantitatively defined as the percentage of racket velocity at the impact location remaining the instant after impact (see Figures 1 and 3). Increased plow-through was identified for feel as it gives the player stability during impact with literature indicating that increasing the swingweight and stiffness would cause an increase in plow-through [3]. The summarized findings for feel parameters can be seen in Figure 3.

Legend: ↑ = higher ↓ = lower N/A = does not affect output	**Goal**	**Stiffness**	**Weight**	**Damping**
Shock $F_{shock} = m * \lvert a_{max} \rvert$	**Decrease** the initial peak in acceleration signal and minimize the initial force (shock) felt at the hand	↓	↑	N/A
Nervousness $N = \int_{t_e}^{t_s} m \lvert a(t) \rvert dt$	**Decrease** the settling time of the vibration response signal	↑	↑	↑
Plow-through $P = \frac{v_{racket, out}}{v_{racket, in}}$	**Increase** by minimize speed lost after racket-ball collision	↑	↑	N/A

Fig. 3: Summarized findings for feel parameters.

CONCLUSIONS AND FUTURE WORK

- Nervousness, shock, plow-through, and soundwave properties are crucial aspects of feel and control.
- Team publishing a review paper with findings.
- Team plans to move into a design and testing phase of the project, with hopes of integrating enhanced feel into a racket with modern-day performance.

REFERENCES

[1] R. Cross, "Factors affecting the vibration of tennis racquets," Sports Engineering, vol. 18, no. 3, 2015, doi: 10.1007/s12283-015-0173-7.

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[3] C. Lindsey, "Tennis Racquet Weighting and Customization — The Effect of Tennis Racquet Weight Customization on Swing Speed and Ball Speed"," Tennis Warehouse, Sep. 02, 2014. https://twu.tenniswarehouse.com/learning_center/racquet weighting.php (accessed Nov. 03, 2022).

ABOUT RESEC

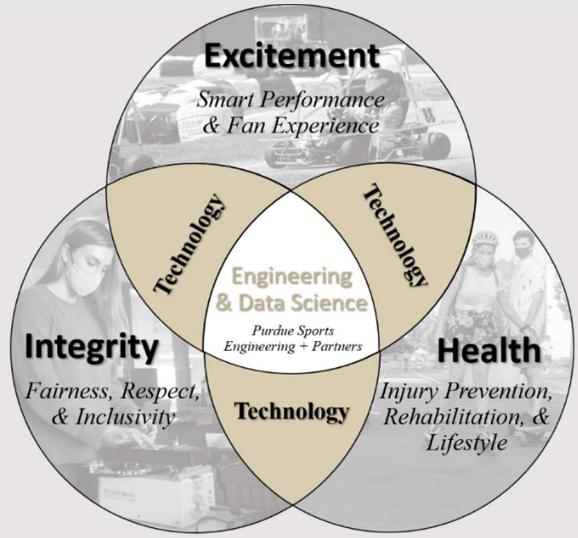
The Ray Ewry Sports Engineering Center (RESEC) was launched as a joint collaboration between Purdue College of Engineering and Purdue Intercollegiate Athletics, highlighting Purdue's reputation as the Cradle of Quarterbacks and Astronauts.

Sports have the power to unite, to teach, to challenge, and to initiate change, and those are our goals for RESEC. We are driven by our passion for sport and a deep understanding of the influence it has in shaping society. As technology continues to advance, there is enormous room for opportunity to rethink how athletes train, coaches coach, fans engage, and event organizers plan events. We collaborate closely with partners in athletics, industry, academia, and more to create the solutions that will help bring sports into the future, specifically in the three key research areas highlighted below.

Smart Performance & Fan Experience

Injury Reduction & Rehabilitation

Sports Integrity, Fairness, & Societal Integration



WHAT IS SPORTS ENGINEERING?

Sports engineering is a global, fast-paced, and multidisciplinary industry that brings people from different backgrounds, cultures, and experiences together. It is an industry that is heavily influenced by advances in other sectors as well as societal pressures and shifts, making working as a sports engineer very exciting. However, it also means being keenly aware of how these innovations and discoveries can be integrated and applied, especially as digitalization expands and what people – the athletes, fans, coaches, governing bodies – expect from sport evolves.

Engineering and data science are at the center of excitement, health and safety, and the integrity of sport, and by bringing a data-driven, human-centered approach to this industry, we can address the growing need and desire to increase participation and engagement of athletes and fans.

WHO IS RAY EWRY?

A Boilermaker track and field athlete, Ewry (1873-1937) won eight gold medals in three Olympic Games from 1900 to 1908. But his story is relatively unknown: at the age of five he became an orphan, and at seven he contracted polio and was confined to a wheelchair. Doctors had little hope he would be able to walk. Later nicknamed "The Human Frog," Ewry won gold in the standing long and high jumps and standing triple jump. By the end of the 1908 Games, Ewry had set a medal count record that lasted more than 100 years.

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