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Review of Parameters that Contribute to the Feel and Control of Tennis Rackets

• Tennis Racket • Feel • Control • Vibration

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Feel and control for a tennis racket are incredibly important to a tennis player as the racket acts as an extension of the player's hand. While important, feel and control are largely subjective performance parameters making design criteria difficult to satisfy. Existing literature has tested the components of feel in other sports such as sensation in the hands and auditory responses in golf clubs. Literature discussing tennis racket characteristics are limited in their discussion of the human-racket interaction. Therefore, this project investigates feel in tennis to add to the discussion of how the racket interacts with the hand, and how players perceive feel post-impact. Feel was parameterized based on reviewed literature and player experience, identifying the parameters of feel to be shock, nervousness, and plow-through.

These feel components can be further manipulated in racket construction through damping, stiffness, and mass distribution. The criteria associated with desired feel were found to be low shock, low nervousness, and high plow-through.

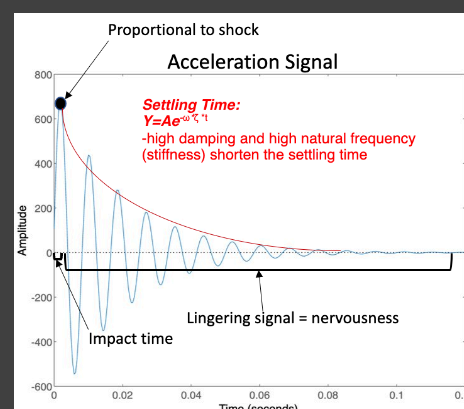

Fig. 1 Labeled example of acceleration response signal for the handle of a tennis racket from impact time till racket vibrations reach rest

PROJECT OVERVIEW

The objective of the project is to understand and identify tennis racket design that optimizes feel and control for a tennis player making the racket a futher extension of the hand. 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 both consistent discussion of feel components and connection to the developing technologies from tennis racket manufacturers. 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 includes understanding the tennis racket response to be modeled as a 2nd-order mechanical system and how different properties can affect the system response. The paper additionally discusses the evolution of materials in tennis racket construction and the classification of perfomance rackets into power rackets (stiffer), control rackets (more flexible). The classification of the performance rackets are decomposed into discussing how their mechanical responses systems are modeled as a 2nd-order system. The results will be shared in a review paper, supporting the experimental works moving forward in optimizing feel and control in tennis rackets.

Background:

$$\uparrow M = \uparrow \text{plow through} = \uparrow \frac{V_{racket,\,out}}{V_{racket,\,in}}$$

Literature[4] & experience tells us
↑ plow through = ↓ shock

Derivation:

$Assume: Mass_{racket} \gg Mass_{racket+ball}$

↑ racket mass = ↑ plow through

↑ plow through = ratio of velocities closer to 1 = ↓ Δ velocity

↓ Δ velocity = ↓Δ momentum

$\Delta momentum = impulse = J = m\Delta v = F\Delta t$

$Rearrange: F_{shock} = \frac{\Delta p}{\Delta t}$ → **Double Check:**

- *↓ Δt (dwell time) = ↑ shock*
- *↓ Δp (seen with greater plow through) = ↓ shock*

Fig. 2 Shock derivation composed by team

PROJECT METHOD AND RESULTS

The team reviewed research papers involving tennis racket design, vibrations, and injuries to better understand the contribution to feel in tennis. Papers on other sports involving feel and vibrations, 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 three parameters: shock, nervousness, and plow-through. These parameters are related to physical racket quantities of stiffness, weight distribution, and damping to 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 initial peak as shock is proportional to acceleration in accordance to Newton's second law (see Figure 1) [5]. From literature, it was found that increasing racket mass or increasing the

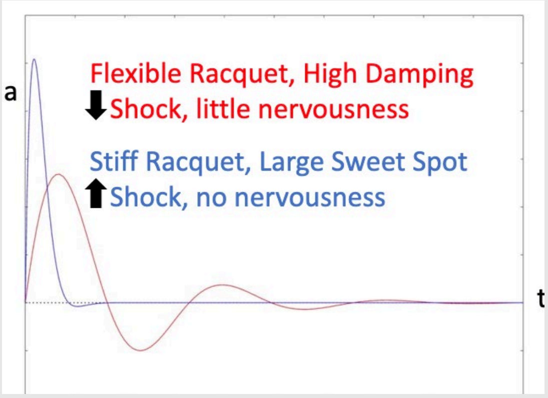

Fig. 3 Acceleration response signals for a stiff and a flexble racket that maximizes feel

PROJECT METHODS AND RESULTS CONT.

moment of inertia of a racquet) by shifting mass distribution towards the racket tip decreased shock [1,2]. Although there were conflicting findings on whether high stiffness or low stiffness was desired concerning shock, from the team's derivation 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 is the lingering vibrational signal after racket-ball impact with large nervousness corresponding to low damping. Low nervousness was found to correspond to high damping, increased swingweight, and stiffness [3].

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. 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 [4].

Performance tennis rackets sold today mainly fall into two categories: stiff rackets for power and flexible rackets for control. Seeing this market trend, the team created two racket design suggestions with feel prioritized and plotted their acceleration response signals (see Figure 3). The relative values for stiffness, weight, and damping were determined using the findings of the team's literature review, summarized in Figure 4.

PROJECT METHODS AND RESULTS CONT.

Legend: ↑ = higher ↓ = lower N/A = doesn't affect output	**Goal**	**Stiffness**	**Weight**	**Damping**
Shock	Decrease the initial peak in acceleration signal and minimize the initial force (shock) felt at the hand	↓	↑	N/A
Nervousness	Decrease the settling time of the vibration response signal	↑	↑	↑
Plow Through	Minimize speed lost after racket-ball collision	↑	↑	N/A

Fig. 4 Table summarizing findings for feel paramameters

CONCLUSIONS AND FUTURE WORK

- Decreased shock corresponds to decreased stiffnes and increaed mass. Damping is unrelated to shock.
- Decreased nervousness corresponds to increased mass/swingweight, stiffness, and damping
- Increased plow through corresponds to increased mass, swingweight, and stiffness. Damping is unrelated to plowthrough
- Team looking to publish a review paper with findings

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ABOUT RESEC

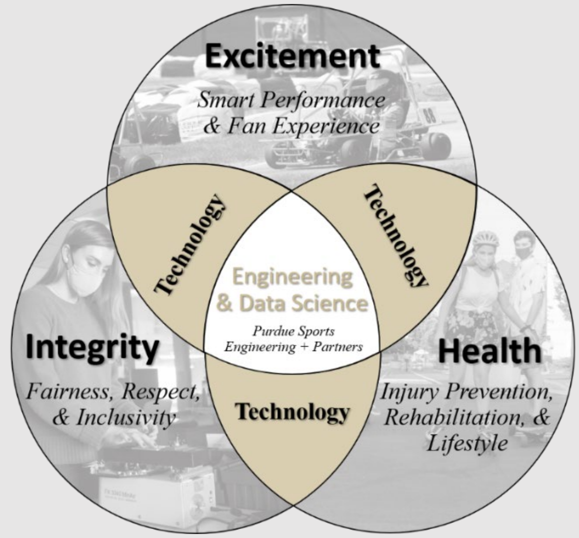
The Ray Ewry Sports Engineering Center (RESEC) was launched as a joint collaboration between Purdue College of Engineering and Purdue Intercollegiate Athletics, highlighting Purdue's reputation as the Cradle of Quarterbacks and Astronauts.

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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