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# VIBRATORY BEHAVIOUR AND TENNIS RACKETS CLASSIFICATION USING EXPERIMENTAL MODAL ANALYSIS

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## Introduction

Vibratory behaviour analysis of tennis racket is not a new topic as from 1976, Hatze became interested in the grip tightness effect on post-impact vibrations [1]. The transmission of these vibrations to the upper limb remains a main issue for both racket manufacturers and tennis players. Stroede indicated that these vibrations induce discomfort for the player [2]. Li et al. thought that vibrations under 200 Hz might contribute to increase injury risk [3], these low frequency values corresponding to the first resonance mode of graphite frames (from 120 to 200 Hz [4]).

Even though the scientific community seeks to study the dynamic behaviour of tennis racket, in real conditions of use, it turns out that designing repeatable protocols and comparing different equipment remain delicate. Objectifying the outcomes is what should allow experimental modal analysis (EMA).

The purpose of this study is twofold. When conducting EMA on tennis rackets, it comes first to determine if the impact point chosen have an effect on the vibration response. From this, is there a way to differentiate and classify different rackets models?

## Methods

Two rackets (R1 and R2) with different characteristics have been used to carry out the EMA tests. Data acquisition was conducted by the use of one uniaxial accelerometer (Dytran 3035B1G), an impact hammer (Dytran model series 5800B3) mounted with a semi-hard cap, both linked to a PowerLab 26T (ADInstruments) and LabChart 7 for Windows.

On both rackets, eight impact points were spotted on the frame (from P1 to P8) and also one measurement point where the accelerometer was positioned (at the handle-neck junction). Rackets were mounted in "free-free" condition [5] as proposed by Kotze et al. [6] who presented this condition as providing the best representation of actual vibratory response. The accelerometer was positioned to record the signal perpendicular to the plane of the strings. Indeed, even if significant vibrational responses were observed on the three dimensions of the racket, most of the total energy of the vibration signal was recorded on the plane perpendicular to the strings [7]. Three shocks were conducted on each impact point.

The acquisition of the impact (hammer) and response (accelerometer) was performed at 4000 Hz. Temporal input signals and responses of the structure were cut and turned into the frequency domain (Fast Fourier Transform (FFT), Matlab R2013a). For each shock, the frequency response function (FRF) corresponding to

the ratio between output and input FFT was calculated. For each FRF, natural frequencies and damping rates were determined using the EasyMod toolbox [8]. Two methods were jointly used: the least-square complex exponential method to determine all the modes, and the line-fit method to refine the detection of the first (bending) and second resonance modes (bending and torsion [9]).

## Results

Mode	Frequency (Hz)			Damping ( $\xi$ , %)		
	1 <sup>st</sup>	2 <sup>nd</sup>	3 <sup>rd</sup>	1 <sup>st</sup>	2 <sup>nd</sup>	3 <sup>rd</sup>
R1	164.0	419.4	524.8	0.2	0.5	-
	$\pm 0.2$	$\pm 0.6$	$\pm 1.1$	$\pm 0.3$	$\pm 0.4$	-
R2	165.3	397.7	524.2	2.8	4.5	0.5
	$\pm 3.7$	-	$\pm 1.2$	$\pm 2.6$	-	$\pm 0.3$

Table 1: Frequencies and damping rates (mean  $\pm$  sd) of the first three modes.

## Discussion

The analysis of all shocks made on the eight impact points of the racket indicates that the location of the impact point does not influence the vibration response of the structure for the first three modes. Thereafter, we choose to study only the impact shocks made at the apex of the racket head (P6).

The analysis of frequency of the first three modes of the two rackets presents similarities between them (Table 1). However, it appears that R2 presents higher damping for these modes. A preliminary study on R1 and R2 rackets had led to highlight their characteristics related to the perception of the high level players who tested them: R1 was considered as "very vibrant" and R2 as "not much vibrant".

In conclusion, EMA seems to be a useful tool for objectifying the vibratory behaviour of a tennis racket in use: a racket with high damping rate may be defined as not much vibrant. To conduct such analysis one should hit the frame of the racket regardless of the localisation of the impact.

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