Model-Aided Design of a Rear-Vehicle Impact Testing System for *in-vivo* Investigations

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Introduction

Low velocity, rear impact collisions are a frequent source of claimed whiplash associated disorders (WAD) [1–7]. Human volunteer research studies have been conducted at various collision severities (ranging from 4 km/h to 15 km/h) to determine the mechanical responses and thresholds for symptom reporting associated with such collisions [1–7]. However, to ensure the responses of human volunteers are representative of real-world collisions, it is imperative that the testing device used mimics the impact parameters of a low velocity impact. Therefore, the purpose of this investigation was to design a repeatable testing device to simulate rear-end impacts, on human volunteers, using inputted impact parameters obtained from vehicle to vehicle rear-end collisions [9].

Methods

The test device consists of a rear-facing cart mounted on an inclined plane (Fig 1). The cart accelerates under gravity until it collides with the springs and dashpots at the base. Altering the mechanical parameters of the device—the mass of the sled, spring stiffness, damper viscosity, length and angle of the ramp—allows the investigator to tune the impact parameters—the duration of impact, peak acceleration and collision severity (delta-V). The optimal mechanical parameters are determined by minimizing the squared difference between impact parameters obtained from a simple model (Eq 1, [8]) of the impact and the desired impact parameters [9].

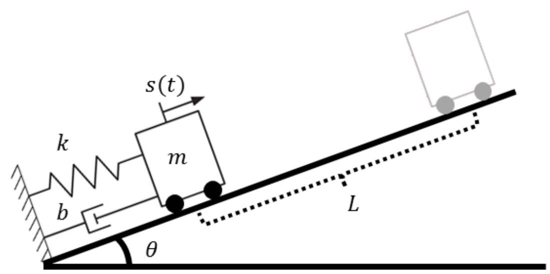

Figure 1: Simple 1-D Sled Model. The sled starts from the greyed position at zero velocity, and accelerates under gravity. It strikes the springs and dashpots, whose mechanical parameters are selected to yield the desired impact parameters.

$$m\ddot{s} + b\dot{s} + ks = -mg\sin\theta\,, \qquad s(0) = 0, \dot{s}(0) = -\sqrt{2Lg(\sin\theta - \mu\cos\theta)} \tag{1}$$

Where $s(t)$ is the deflection of the springs, m is the mass of the sled (350 lbs), k is the stiffness of the spring, b is the viscosity of the damper, L and θ are the length and angle of the ramp, respectively, and μ is the coefficient of friction for the sled (measured to 0.02). Optimization was done in the Python (version 3.5.1) programming language, using the minimize function in the 'Scipy' package. Springs were custom ordered (Omnicoil, Ayr, Ontario, Canada) such that four in parallel would supply the estimated required stiffness. Impact parameters for physical trials were recorded from a 3 degree-of-freedom accelerometer, which was processed in accordance with SAE standards (Society of Automotive Engineers, 1995).

Results

The method provided mechanical parameters (Table 1) which replicated the desired impact parameters (Table 2).

Table 1: Mechanical parameters determined by the optimization routine.

Parameter	Stiffness	Damping	Ramp Length	Angle
Value	31991 N/m	593.78 Ns/m	1.12 m	5.8^o

Table 2: Comparison of desired values for impact parameters against those estimated by the model and those measured from the sled.

Variable	**Desired Value**	**Estimated Value**	**Measured Value**
Duration	135 ms	123.5 ms	107 ms
Coefficient of Restitution	0.60	0.599	0.511
Max Acceleration	3.5 g	3.3 g	3.99 g
Delta-V	7 km/h	7.99 km/h	7.26 km/h

Discussion and Conclusions

The proposed method was successful in providing mechanical parameters which approximated the desired impact parameters. Currently, this testing device is in operational use to simulate 8 km/hr collision severities on human volunteers to evaluate the effectiveness of lumbar support in protecting the spine in such collisions.

References

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