Research
Report Summary

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Regenerative Braking

The goal of this research was to determine whether regenerative braking (RB) provided a negative acceleration advantage over traditional service braking (SB) that allowed drivers to better avoid collisions in safety-critical events.

In order to explore the research question, an experiment was run on the NADS-1 large motion driving simulator. Three conditions were tested; baseline (SB), RB low, and RB high. A between-subjects study design called for 30 participants, resulting in 10 participants per condition.

Every participant drove the same scenario. The study drive was 8.3 miles of rural two-lane highway with a speed limit of 55 mph. The drive had three braking events. Two of these events were mild and one was severe. The lead vehicle did not come to a complete stop in the mild events, while it braked to zero speed for the severe event.

Participants were instructed to follow the speed limit as closely as possible. A dial graphic with moving needle and colored speed regions was provided on the center console to aid them in tracking the target speed (figure right center). The participant was instructed to keep the needle in the green zone, a speed band that covered about six mph.

Throughout the drive, participants engaged in a number recall secondary task. A monitor was placed in the center console (right center figure). Approximately every minute, and right before each of the two mild events, a chime would sound, indicating to the driver that a number recall task was about to begin. About a second after the chime, five random single-digit numbers were presented one at a time on the center console, approximately a half second apart. After all five numbers were presented, the participants had to recall all of the numbers out loud in the correct order.

This study used measures to explore all possible advantages and disadvantages that RB might have when compared to SB. The measures included: crash or no crash, time to collision (TTC), time for the participant to begin the braking process, distance traveled during the braking event, maximum brake pedal force, brake time, average negative acceleration of the vehicle, and average negative

Experimental Setup

NADS-1 Simulator

Center Console Screen. Speed Dial (left), Number Recall (right).

Condition	Negative Acceleration Rate in g
SB Baseline	.01 to .04
RB Low	.02 to .05
RB High	.15 to .2

Conditions and Negative Acceleration Rates (initial speed of 55 mph) accelerator to the time the driver presses the brake.

The Kruskal Wallis test was used to compare means between the three braking conditions. When testing all three events individually, the only measure that showed significant differences between braking levels was the average negative acceleration of the vehicle from the time the driver removes their foot from the accelerator to the time the driver presses the brake. This measure showed the expected influence of RB during the period when no pedals were pressed. When events 1 and 2 were combined into one analysis, the maximum brake force was found to be significantly less than in the baseline.

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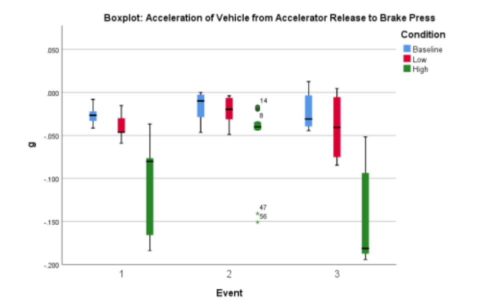
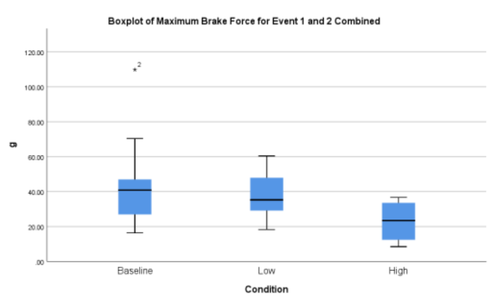
Despite significance in these two measures, other measures, such as average acceleration and TTC were not found to differ significantly. We hypothesize that drivers use perceptual cues such as looming and TTC to gauge when and how much to slow down, as well as how much space to leave between vehicles. In our events, it appeared to be the case that RB did give them an initial advantage in early braking. However, drivers were then able to brake less in order to achieve their desired minimum TTC and minimum distance.

Future research with RB should include more severe events in which collisions would be observed in the baseline condition. More severe events may highlight the negative acceleration advantage of RB better than the more mild events considered here. We plan to further decompose driver responses in electric vehicles with RB. More advanced techniques that use dynamic RB may provide additional contextual benefits. Dynamic RB could alter how quickly RB slows the vehicle depending on the environment around the vehicle.

Significant Results of the Kruskal Wallis Test

Event / Measure	Value	1	2	3	1 and 2 combined
Average acceleration of vehicle in the time interval the driver releases the accelerator and presses the brake	Kruskal-Wallis H	16.175	8.932	15.283	11.097
	DF	2	2	2	2
	Asym. Sig.	0.000	0.011	0.000	0.004
Maximum brake force during braking event	Kruskal-Wallis H	-	-	-	7.177
	DF	-	-	-	2
	Asym. Sig	-	-	-	0.028





References

1. Brown, T. (2014). Crash Warning Interface Metrics: Protocol Completion.
2. McGehee, D. V., Lee, J. D., Rizzo, M., Dawson, J., & Bateman, K. (2004). Quantitative analysis of steering adaptation on a high performance fixed-base driving simulator. *Transportation Research Part F: Traffic Psychology and Behaviour*, *7*(3), 181–196.
3. Xu, G., Li, W., Xu, K., & Song, Z. (2011). An intelligent regenerative braking strategy for electric vehicles. *Energies*, *4*(9), 1461–1477.

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