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Summary
Visually-Guided Braking: The Optical Variables, Control Strategies and the Effect of Vehicle Dynamics

Didem Kadıhasanoğlu[1]

TOBB University of Economics & Technology

This work aims to investigate the effect of a non-linear braking function on the optical variables control strategies used in visually-guided braking in the context of a driving-like braking task, i.e., the task of slowing down from high speed to stop before reaching an obstacle in the path of motion. Given such a task, humans exhibit two different braking behaviors: impulsive braking and continuously regulated braking (Yilmaz and Warren, 1995). In impulsive braking, the brake is used in an on-or-off fashion. In continuously regulated braking, the brake is applied continuously. It can be increased or decreased but once it is applied it is never released completely. In this work two experiments were designed to investigate the effect of braking function on the optical variables and control strategies used in impulsive braking and continuously regulated braking.

The relative motion between an observer and his/her environment creates an optical motion at the eye of the observer, which is called the optic flow (Gibson, 1979/1986). The optic flow provides a rich and continuous source of information about the three dimensional structure of the environment, the motion of the observer in the environment, and also, the motion of the objects in the environment. As the observer moves in the environment, the optic flow changes. However, there are some patterns in the optic flow that are preserved in an otherwise changing optic flow. These patterns are called optical variables.

In the case of a driving-like braking task used in this study, there are three optical variables that could in principle used to control braking. The first optical variable is tau, which specifies time-to contact with the objects in the environment (Lee, 1976). Bingham (1995) suggests that to stop successfully at an object, the observer should move so as to keep tau constant a value, magnitude of which depends on the initial conditions and maximum brake capacity. This strategy is called the strict constant tau strategy. There is also a weak version of the constant tau strategy, in which the optical variable tau is used to initiate braking. in other words, the brake is initiated whenever tau reaches a critical value, magnitude of which again depends on the initial conditions and the maximum brake capacity. The strict version of this strategy results in continuously regulated braking whereas the weak version gives rise to impulsive braking.

The second optical variable that could be used to control braking is tau-dot, which is the first time derivative of tau (Lee, 1976). Tau-dot provides information about whether the current deceleration is enough to stop safely at the object. The constant tau-dot strategy proposed by Lee (1976) suggests that the observer should move so as to keep tau-dot at –0.5 stop at the object.

The third optical variable that could be used in visually-guided braking is proportional rate, which is mathematically equals to tau divided by tau-dot (Anderson and Bingham, 2010). Anderson and Bingham (2010, 2011) suggest that visually-guided braking is achieved by using proportional rate control. Unlike the optical variable tau, which only offers a single value of –0.5 for successful braking, the optical variable proportional rate a range of values that could be kept constant for successful braking. There are two versions of the proportional rate control. The strict version suggests that to stop successfully at the object, the observer should move so as to keep the proportional rate constant at a certain value within this range. The weak version suggests that as long as the proportional rate values stay within this range, the proportional rate does not have to be kept constant.

Kadıhasanoğlu (2012) suggests that when the braking function is linear the impulsive braking is achieved by using the weak version if the constant tau strategy. In other words, humans use the optical variable tau to initiate braking. They observed two critical tau values the first braking was initiated when tau reaches about 3.5 s. After that, the brake is initiated whenever tau reaches 2 s.

Address for Correspondence: [1]Didem Kadıhasanoğlu, TOBB University of Economics & Technology, School of Science and Literature, Department of Psychology, Sogutozu Street No: 43, 06560 Sogutozu / Ankara
E-mail: dkadi@etu.edu.tr

Kadıhasanoğlu (2012) also suggests that when the braking function is linear, the continuously regulated braking is achieved by using the proportional rate control. They observed two groups of participants. The participants in the first group used the strict proportional rate control: they kept proportional rate constant at a certain value. The participants in the second group did not keep proportional rate constant at a certain value but they kept it with in a range, boundaries of which were determined by the initial conditions and the maximum brake capacity.

In the light of these findings, the aim of the present study is to investigate how a nonlinear braking function affects the optical variables and the control strategies used in impulsive braking and continuously regulated braking.

Experiment 1: Impulsive Braking

The aim of Experiment 1 was to investigate the effect of a nonlinear braking function on the optical variables and control strategies used in impulsive braking.

Methods

Participants

10 university students (six female and four male) participated in the experiment. The mean age was 19.80 with a standard deviation of 1.23.

Sessions

Each participant completed three training sessions and one test session. The aim of the training sessions was to familiarize the participants to the experimental set-up and the brake used in the experiment.

Stimulus and Procedure

On a computer screen, participants saw a simulated three-dimensional environment, which had three target objects that were placed next to each other at a distance. The target objects were similar to traffic signs. Each trial started with a constant velocity approach to the targets. The task of the participants was to stop as close as possible to the targets using a joystick attached to the computer as a brake. Then output of the joystick was converted to deceleration using the nonlinear function given in Formula 1. Five initial time-to-contact values (8.0 s, 9.0 s, 10.0 s, 11.0 s ve 12.0 s) were crossed with five initial distances (96.0 birim, 106.0 birim, 116.0 birim, 126.0 birim ve 136.0 birim) to get 25 different initial conditions. Each initial condition was presented four times, giving rise to 100 trials, which were presented randomly.

Data Analysis

For each trial, the raw data collected in the experiment consisted of the times series of the distance values to the targets during that trial. The time series of the velocity, deceleration, tau, tau-dot and proportional rate were calculated by using numerical differentiation and the formulas given in Formula 2 and Formula 3. To test whether the optical variables were kept constant, the split-half analysis were used.

Results

The results of Experiment 1 showed that participants used the weak version of contant tau strategy in impulsive braking. The critical tau values used were found to be 3.7 s and 2.0 s. There values are very close to the values observed in Kadihasanoglu (2012). Based on these findins, Experiment 1 suggests that a nonlinear braking function does not an effect on effect (or change) the impulsive braking behavior.

Experiment 2: Continuously Regulated Braking

The aim of Experiment 2 was to investigate the effect of a nonlinear braking function on the optical variables and control strategies used in continuously regulated braking.

Participants

The same university students who participated in Experiment 1 also participated in Experiment 2.

Sessions

Each participant completed five training sessions and one test session. The aim of the training sessions was to familiarize the participants to the experimental set-up and the brake used in the experiment.

Stimulus and Procedure

The stimulus and the procedure used in Experiment 2 was the same as those used in Experiment 1, with one exception. To discourage impulsive braking behavior, In Experiment 2 , the computer screen went black for one second when the participant used the brake impulsively, i.e., when the change in joystick position in two successive frames was greater than a certain threshold value.

Data Analysis

The analysis methods used in Experiment 2 were the same as those used in Experiment 1.

Results

The results of Experiment 2 showed that when a nonlinear braking function was used participants used predominantly impulsive braking. In other words, a nonlinear braking function inhibits continuously regulated braking and reinforces impulsive braking. Impulsive braking behavior was achieved by using the weak version of the constant tau strategy. The critical tau values used in Experiment 2 were 3.0 s and 1.5 s.

General Discussion

The aim of this study was to investigate the effects of the braking function on the optical variables and control strategies used in visually-guided braking, using a driving-like braking task. Given such a task, humans exhibit two different braking behaviors: impulsive braking and continuously regulated braking. Two experiments were conducted to investigate how a nonlinear braking function affects the optical variables and control strategies used in impulsive braking and continuously regulated braking, respectively. In both experiments, the braking function was modeled with an exponential growth function.

The results of Experiment 1 revealed that, when braking function was nonlinear, the weak version of constant tau strategy was used to control braking in impulsive braking. The results of Experiment 2 indicated that when braking function was nonlinear it was not possible to inhibit impulsive braking behavior. Even thought the aim of Experiment 2 was to investigate continuously regulated braking behavior, the participants exhibited predominantly impulsive braking in Experiment 2. They used the weak version of the constant tau strategy.

Taken together the results of the present study indicate that a nonlinear braking function does not effect and/or change the impulsive braking behavior. However, it inhibits continuously regulated braking and reinforces impulsive braking. When braking function is nonlinear, people tend to use the optical variable tau and the weak constant tau strategy to control deceleration.

The reason why a nonlinear braking function suppresses the continuous braking behavior can be explained as follows. When the braking function is nonlinear, the deceleration obtained will be very low if brake is applied lightly. In order for deceleration to reach half of the maximum deceleration, it is necessary to apply almost full brake. This makes it difficult to control the brake continuously, thereby reinforcing impulsive braking behavior.