Pedal Misapplication: Interruption Effects and Age-Related Differences

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Objective: This study aimed to investigate whether pedal misapplication occurs more frequently when a pedal task is interrupted for a longer period of time.

Background: Misapplication of a vehicle's brake and accelerator pedals can cause severe traffic accidents, especially for older drivers. The present study provides empirical support for the hypothesis that pedal misapplication occurs more frequently when drivers are interrupted for longer periods of time and is demonstrated more prominently in older drivers.

Methods: Forty younger participants and 40 older participants were asked to perform a pedal choice response task (stepping on either a brake or accelerator pedal) that had been preceded by an interruption task (i.e., touch number task).

Results: Pedal misapplications occurred more frequently when the pedal choice response task was preceded by the touch number task for a longer interval (about 120 s) than for a shorter interval (about 30 s). Furthermore, the time-related increase in pedal misapplications was greater for older participants.

Conclusion: Pedal misapplication increases when the pedal task is interrupted for a longer time period, especially for older adults.

Application: The findings contribute to our understanding of when and where pedal misapplications tend to occur.

Keywords: accidents, human error, age, driver behavior, distraction, risk assessment

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PEDAL MISAPPLICATION: INTERRUPTION EFFECTS AND AGE-RELATED DIFFERENCES

Misapplication of a vehicle's brake or accelerator pedal can cause severe traffic accidents. Recently, the dangers of pedal misapplication have received more attention, as reports of serious accidents caused by pedal misapplications have been sensationally covered in countries such as Japan (Japan Broadcasting Corporation, 2016; Schreiber, 2019), the United States (Lococo et al., 2012; National Highway Traffic Safety Administration, 2011, 2015), and the United Kingdom (British Broadcasting Corporation, 2017, 2018a, 2018b). One of the major characteristics of pedal misapplication accidents is that many are caused by older drivers (National Police Agency, 2017; Lococo et al., 2012). According to a national census of licensed drivers in Japan, there were over 17 million drivers over 65 years old in 2016 (National Police Agency, 2017), accounting for approximately 21.5% of all licensed drivers. Thus, the prevention of pedal misapplications, especially among older drivers has become an urgent issue in Japan, as well as other countries with aging populations.

To prevent pedal misapplications, it is important to understand the situations where they tend to occur, and a key finding of the research is that most occur when drivers are unhurried (Schmidt et al., 1997). In an analysis of traffic accidents, a study found that 68% of these accidents occurred in unhurried situations. When unhurried, drivers can be easily distracted by nondriving-related events (e.g., wandering thoughts; Smallwood & Schooler, 2015) or nondriving-related tasks (e.g., smartphone use). In light of these factors, it seems possible that pedal misapplication accidents

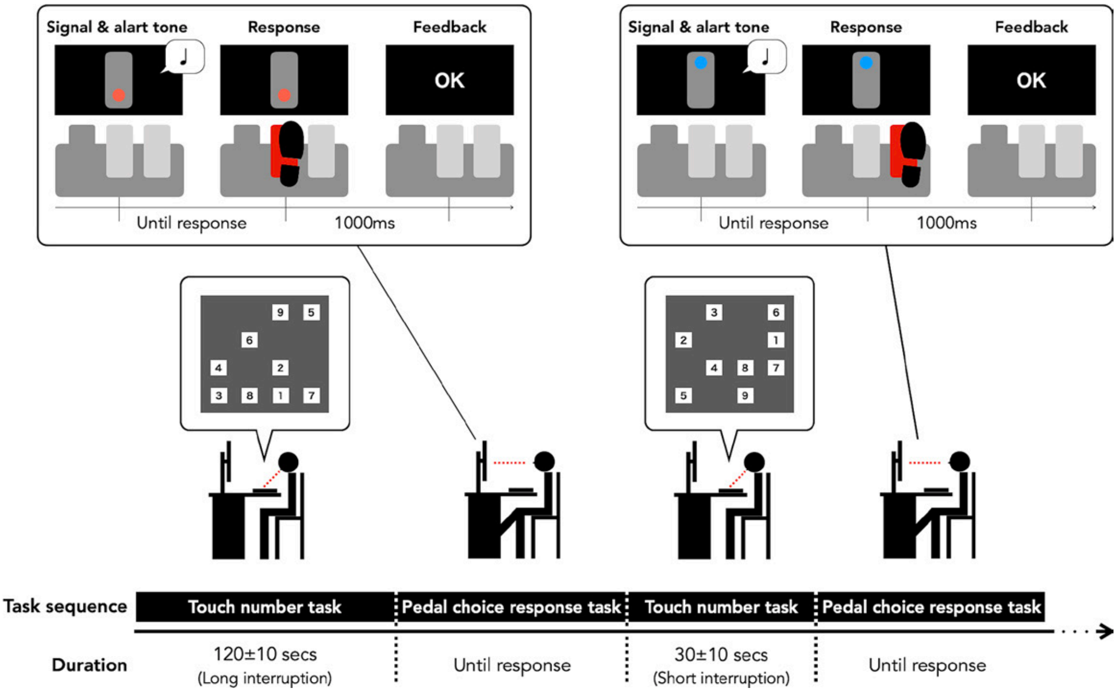

Figure 1. Schematic illustration of the pedal choice response task.

may occur more frequently when drivers step on a pedal after a longer interruption than a shorter one from driving. This seems plausible from a theoretical viewpoint. That is, the interruption effect can be explained by the Memory for Goal Model (Altmann & Trafton, 2002), which posits that a longer interruption period decreases the participant's activation of their memory for task completion (i.e., goal), when one task is interrupted by an alternative task and resumed after the interruption. Thus, the memory activation for pedal manipulation (i.e., the goal of the primary task) could have been reduced by a nondriving-related event.

Although the interruption effect may be responsible for the occurrence of pedal misapplication, previous empirical studies have not examined this possibility. Instead, they have primarily addressed pedal misapplications in situations in which participants were engaged in driving only (Freund et al., 2008; Rogers & Wierwille, 1988; Tomerlin & Vernoy, 1990; Wu et al., 2014, 2015). In these situations, only a small number of pedal misapplications were detected. For example, Rogers and Wierwille (1988) observed serious errors in only 0.2% of all pedal applications.

Here, we tested the hypothesis that pedal misapplication may occur more frequently when drivers are required to step on a pedal after being interrupted from driving for a longer period of time and developed a paradigm in which participants performed a pedal choice response task which was preceded by an interruption task (i.e., a touch number task; see Figure 1). Participants were required to engage in the touch number task until a signal requiring pedal action was presented. When the signal was presented, they had to step on either a brake or accelerator pedal as quickly and accurately as possible. Based on the hypothesis that the occurrence of pedal misapplication is related to the interruption period, the length of the touch number task was manipulated to simulate interruption from driving for shorter and longer periods of time (i.e., short and long interruption conditions). In the short interruption condition, the pedal choice response task was preceded

TABLE 1: Neuropsychological Test Results

	Younger (n = 40)		Older (n = 40)	
Neuropsychological Test	*M*	*SD*	*M*	*SD*
Mini-Mental State Examination	29.82	0.38	29.30	1.09
Clock Drawing Test	10.00	—	10.00	—

Note. All participants received full marks in the Clock Drawing Test.

by the touch number task for a relatively short interval (approximately 30 s). In contrast, in the long interruption condition, the pedal choice response task was preceded by the touch number task for a relatively long interval (approximately 120 s). According to the Memory for Goal Model, pedal misapplication occurs more frequently after a driver has been interrupted for a longer period of time than in the shorter interruption condition.

The study also investigated whether there is an age-related effect on the frequency of pedal misapplication. As mentioned above, many serious pedal misapplication accidents are caused by older drivers (Lococo et al., 2012; National Police Agency, 2017). In addition, although not a study of pedal misapplication, Arnau et al. (2019) demonstrated that the interruption effect could be larger in older adults than in younger adults, suggesting that the Memory for Goal Model has age-related differences. Therefore, it is plausible that a possible increase in the frequency of pedal misapplications as a function of the interruption period would be more prominent in older adults as compared to younger adults. To test this hypothesis, the present study recruited both older adults and younger adults as participants. If pedal misapplications increase as a function of interruption time more prominently in older drivers, then an increase in the frequency of pedal misapplications in the longer interruption condition should be greater in older adults than younger adults.

METHODS

Ethics Statement

This research complied with the American Psychological Association Code of Ethics and was approved by the Institutional Review Board at the National Institute of Advanced Industrial Science and Technology (AIST). Informed consent was obtained from all participants.

Participants

Forty younger adults (20 females and 20 males, mean age = 21.73 years old, age range = 18–32 years) and 40 older adults (20 females and 20 males, mean age = 71.35 years, age range = 67–81 years) were the participants. All participants had normal or corrected-to-normal vision and were not aware of the purpose of the experiment. All participants had a valid driver's license and had driven more than 3 days a week in the previous 6 months. The participants underwent two neuropsychological tests before the experiment: The Mini-Mental State Examination (Folstein et al., 1975) and the Clock Drawing Test (Shulman, 2000). The results of the Mini-Mental State Examination and the Clock Drawing Test are shown in Table 1. The study required that participants who scored less than 24 points on the Mini-Mental State Examination would be excluded from the data analyses; however, all participants scored over 24 points and received full marks in the Clock Drawing Test. This suggested that both younger and older participants were comparable and had no signs of dementia. Therefore, data from all participants were used for the analyses.

Apparatus

The pedal choice response task was controlled by a laptop computer (Apple, MacBook Pro) with MATLAB R2017a (Math Works) and Psychophysics Toolbox 3 (Brainard, 1997; Kleiner et al., 2007; Pelli, 1997). Visual stimuli were presented on a liquid crystal display screen in front of the participants (BenQ, XL2410T). The viewing distance was approximately 100 cm. Sound stimuli were presented using a headset (Sony, MDR-XD150). Pedal choice responses were measured using a pedal box from a racing game controller (Logitech, Driving Force G29).

The touch number task was controlled by a tablet computer (Microsoft, Surface Pro 4) with Python 2.7 (https://www.python.org) and PsychoPy 2 (Peirce, 2007, 2008). The tablet computer was placed flat on a desk in front of the participants with a viewing distance of approximately 30 cm. The depression vertical angle from the front screen to the screen of the tablet computer was approximately 40–50°.

Stimuli and Procedure

In each trial, participants performed the pedal choice response task preceded by the touch number task. Figure 1 shows a schematic illustration of the trials. The touch number task started with the presentation of a yellow traffic signal on the front screen. While the yellow traffic signal was presented, participants were required to perform the touch number task. Nine small white squares (approximately 2 by 2° of visual angles) containing numbers (1–9) were presented in a 4 by 4 array (within a range of approximately 11 by 11° of visual angle) at the center of the tablet screen placed flat on the desk. The positions of the nine squares were randomized for each trial. Participants were asked to touch the numbers in ascending order (i.e., from 1 to 9) as quickly and accurately as possible. When the task was finished, the array was renewed, and the task continued. During the touch number task, participants were asked not to look at the front screen until the alert tone was presented and not to put their foot on either pedal. An experimenter observed the participants' behavior to confirm that they did not move their head toward the front screen, and they did not move their foot from the standard position (approximately 20–30 cm from the pedal box). Following a predefined time period, an alert tone (frequency = 1000 Hz, duration = 1 s) and a traffic signal (red or green) were presented simultaneously. In the short interruption condition, the interval was 30 s on average (randomized between 20 and 40 s), and in the long interruption condition, the interval was 120 s on average (randomized between 110 and 130 s). The interruption time lengths were decided by a pilot study performed by the authors and colleagues. When the alert tone was presented, participants were asked to give priority to the pedal choice response task, look at the front screen, and step on either the center (brake) pedal for the red traffic signal or the right (accelerator) pedal for the green traffic signal, as quickly and accurately as possible. This meant that they had to stop the touch number task immediately after the onset of the alert tone. One second after the pedal choice response was detected, the message "OK" was presented at the center of the front screen, and the next touch number task was started. After the experiment, we also measured subjective factors using several questionnaires for exploratory investigations. However, the results of these questionnaires would be a diversion from the main purpose of the present study, so they are not reported here.

The present experiment consisted of 80 trials: 40 trials (20 trials for the red signal and 20 trials for the green signal) for the short interruption condition and 40 trials (20 trials for the red signal and 20 trials for the green signal) for the long interruption condition. The 80 trials were divided into 10 blocks of 8 trials, and the order was randomly determined. Participants could rest during the intervals between the blocks.

Statistical Analyses

We used R 3.6.1 (https://www.r-project.org) for all statistical analyses in the present study. The mean percentages of pedal misapplications and the response times in the pedal choice response task were analyzed by a two-way ANOVA with factors of age group (younger and older, between-subject factor) and interruption period (short and long, within-subject factor). In the analysis of the response times, outliers were detected by the modified-recursive outlier removal procedure with moving criterion according to Van Selst and Jolicoeur (1994) and were excluded (3.66% of data in short interruption condition and 3.31%

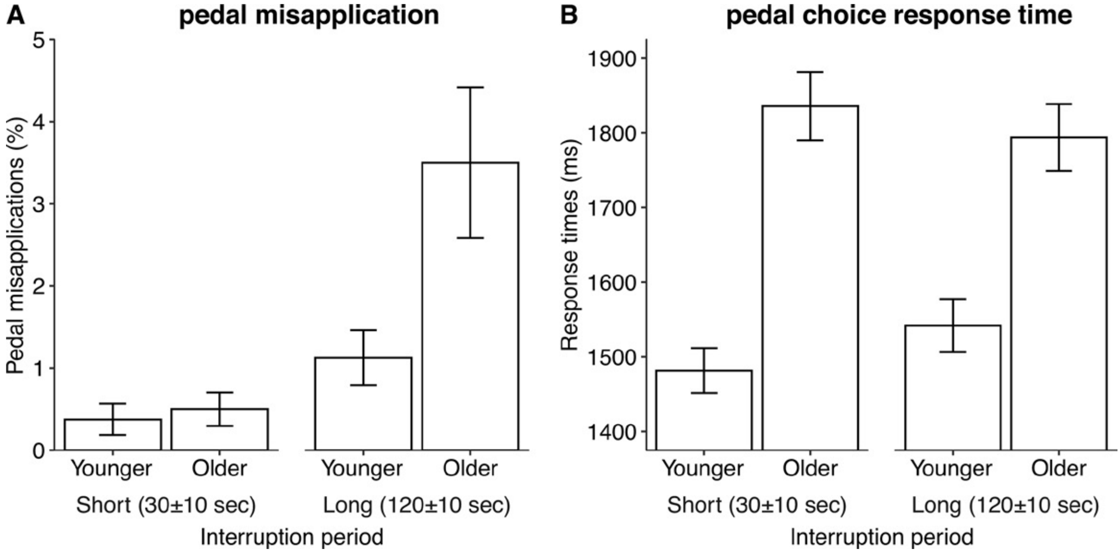

Figure 2. The results of the pedal choice response task: (A) mean percentages of pedal misapplications; (B) mean response times for pedal choice. Error bars indicate 1 standard error of the mean.

of data in long interruption condition). The outlier exclusion was conducted using the "prepdat" package (Allon & Luria, 2016) with R. As the post hoc analysis, the effect of the interruption period in each age group was directly compared by a paired sample *t*-test. The effect of the age group in each interruption period condition was directly compared by an independent sample *t*-test. The *p*-values were adjusted with Holm's correction. Furthermore, to address the possibility of the general slowing of older adults' response times, statistical analyses using the standardized data were performed according to Faust et al. (1999). The mean response times of the touch number task (i.e., the required time for touching from 1 to 9) were analyzed by an independent sample *t*-test with a factor of age group.

RESULTS

Pedal Misapplication Rates in Pedal Choice Response Task

The percentages of pedal misapplications in the pedal choice response task are shown in Figure 2A. These values were analyzed using a two-way ANOVA with factors of age group and interruption period. The main effect of age group was significant, $F(1, 78) = 5.84$, $p = .018$, $\omega^2 = .06$. The main effect of interruption period was significant, $F(1, 78) = 14.22$, $p < .001$, $\omega^2 = .07$. The interaction between age group and interruption period was significant, $F(1, 78) = 5.12$, $p = .026$, $\omega^2 = .02$. The direct comparisons using an independent sample *t*-test indicated that pedal misapplication rates in the long interruption condition were higher for older adults than younger adults, $p = .017$, Cohen's $d = .54$; however, there was no such tendency in the short interruption condition, $p = .656$, Cohen's $d = .10$. Further, a paired sample *t*-test indicated that pedal misapplication rates were higher in the long interruption condition compared to the short interruption condition for older adults, $p = .002$, Cohen's $d = .52$, but did not reach significance for younger adults, $p = .076$, Cohen's $d = .29$.

Response Times in the Pedal Choice Response Task

For pedal response times, trials in which pedal misapplications occurred and the subsequent trials were excluded from analysis. Mean response times are shown in Figure 2B. These values were analyzed by a two-way ANOVA with factors of age group and interruption period. The main

TABLE 2: The Mean and Standard Deviation of Median Standardized Scores of the Pedal Choice Response Times for Each Participant

	Short Interruption		Long Interruption	
	M	*SD*	*M*	*SD*
Younger	−0.30	0.18	−0.02	0.19
Older	−0.23	0.15	−0.21	0.22

effect of age group was significant, $F(1, 78) = 30.52$, $p < .001$, $\omega^2 = .27$; the main effect of interruption period was not significant, $F(1, 78) = 0.73$, $p = .397$, $\omega^2 < .01$; and the interaction between age group and interruption period was significant, $F(1, 78) = 16.867$, $p < .001$, $\omega^2 = .01$. The direct comparisons using an independent sample *t*-test indicated that pedal response times were longer for older adults than younger adults in both the short interruption condition, $p < .001$, Cohen's $d = 1.45$ and long interruption condition, $p < .001$, Cohen's $d = .98$. Furthermore, a paired sample *t*-test indicated that pedal response times in younger adults were longer in the long interruption condition compared to the short interruption condition, $p < .001$, Cohen's $d = .87$. On the other hand, for older adults, the difference in pedal response times between the short and long interruption conditions did not reach significance, $p = .076$, Cohen's $d = −.29$.

Furthermore, to address the general slowing of older adults, an additional analysis was conducted using standardized scores (Faust et al., 1999). The means and *SD*s of median standardized scores are shown in Table 2. These values were analyzed by a two-way ANOVA with factors of age group and interruption period. The main effect of age group was significant, $F(1, 78) = 8.39$, $p = .005$, $\omega^2 = .09$; the main effect of interruption period was significant, $F(1, 78) = 17.30$, $p < .001$, $\omega^2 = .13$; and the interaction between age group and interruption period was significant, $F(1, 78) = 14.18$, $p < .001$, $\omega^2 = .11$. The direct comparisons using an independent sample *t*-test indicated that the standardized scores were larger for older adults than younger adults in the short interruption condition, $p = .045$, Cohen's $d = −.46$. On the other hand, the standardized scores were smaller for older adults than younger adults in the long interruption condition, $p < .001$, Cohen's $d = .95$. Furthermore, a paired sample *t*-test indicated that the standardized scores for younger adults were larger in the long interruption condition compared to the short interruption condition, $p < .001$, Cohen's $d = .97$; however, there was no such tendency in older adults, $p = .799$, Cohen's $d = .04$.

Touch Number Task Response Times

The mean response times for nine items were calculated as scores for the touch number task. Analysis was performed using an independent sample *t*-test with a factor of age group. The results showed that response times in the touch number task were shorter for younger adults (mean = 6.48 s, $SD = 1.41$) than older adults (mean = 9.78 s, $SD = 2.30$); $t(78) = 7.72$, $p < .001$, $d = 1.73$. It should be noted that the response times and accuracies in the touch number task were not reliable enough to perform further detailed analysis, because participants' inputs sometimes failed to be detected by the touch screen.

DISCUSSION

The present study examined the hypothesis that pedal misapplication may occur more frequently when drivers are interrupted for longer periods, with this tendency being more prominent in older adults. For this purpose, we conducted an experiment in which younger and older adults performed a pedal choice response task preceded by a touch number task for shorter and longer intervals (i.e., the short and long interruption conditions). Pedal misapplication rates and response times in the short and long interruption conditions were calculated for younger and older adults.

The pedal misapplication rate was higher in the long interruption condition compared to the short interruption condition in older adults (about 3.8% vs. 0.5%). Although not statistically significant, the same tendency (but weak) was also observed in younger adults (about 1.0% vs. 0.4%). This indicated that pedal misapplication occurred more frequently when participants were required to step on a pedal after they had been interrupted in the pedal choice response task for a longer period of time.

Importantly, the present study also showed that the pedal misapplication rate in the longer interruption condition was clearly higher for older adults as compared to younger adults (about 3.8% vs. 1.0%), while in the short interruption condition there was no significant difference between older and younger adults (about 0.5% vs. 0.4%). This implies that the increase of pedal misapplication rates in the longer interruption condition was greater for older adults compared to younger adults. Furthermore, in younger adults, both performances of speed (i.e., response time) and accuracy (i.e., pedal misapplication rate) worsened in the longer interruption condition compared to the shorter interruption condition. On the other hand, in older adults, accuracy worsened more in the longer interruption condition compared to the shorter interruption condition, whereas this was not the case for speed. Moreover, the performance of speed in older adults was worse compared to younger adults regardless of the length of the interruption period. These findings suggest that older adults may sacrifice accuracy to avoid further response delay in the longer interruption condition. This age-related difference in the interruption effect is also consistent with the Memory for Goal Model (Altmann & Trafton, 2002). A recent study showed that the interruption effect could be larger for older than for younger adults (Arnau et al., 2019). Based on this finding and that of the present study, it can be suggested that pedal misapplication tends to be influenced by a decrease in memory activation for goals, caused by a longer interruption period, especially among older adults.

From the theoretical viewpoint, the present study results can be explained by the interruption effect of the Memory for Goal Model (Altmann & Trafton, 2002). As stated in the Introduction, this model posits that a longer interruption period decreases the participant's activation of their memory for task completion (i.e., goal), when one task is interrupted by an alternative task and resumed after the interruption. Based on this model, it is considered that the pedal choice task was interrupted by the touch number task in the present study. Thus, the memory activation for the pedal choice reaction task completion (i.e., the goal of the primary task) could have been more reduced in the longer interval condition than the shorter interval condition, resulting in lower performance of the pedal choice reaction. Moreover, the present study also demonstrated an age-related difference in the interruption effect. The age-related difference is also consistent with the Memory for Goal Model (Altmann & Trafton, 2002), and a recent study proposes that the interruption effect could be larger in older than younger adults (Arnau et al., 2019). According to this notion, the present study results can be interpreted such that pedal misapplication tends to be induced by a decrease in memory for goals caused by the longer interruption time, especially in older adults.

One important aspect of these findings is that the age-related factor of pedal misapplication was observed even in older adults with no signs of dementia. All the older adults attained very high scores on the Mini-Mental State Examination (Folstein et al., 1975) and Clock Drawing Test (Shulman, 2000), which are well-known neuropsychological tests for the detection of dementia. A pioneering study on the effects of age on pedal misapplication showed that the frequency of pedal misapplication was associated with low scores on the Clock Drawing Test (Freund et al., 2008). Given that the Clock Drawing Test may not be a sensitive assessment for screening in the early stages of dementia (Nishiwaki et al., 2004), this association is thought to be significant only in older adults in the relatively later stages of dementia. The present study extends this previous finding and suggests that the age-related increase in pedal misapplication can be observed even in older adults with no signs of dementia.

The present study clearly demonstrated that the pedal misapplication rate could increase in the longer interruption condition; however, it is still unclear whether the execution of the alternative task (i.e., the touch number task) was critical or the longer inter-trial interval was critical for the increase of pedal misapplication. According to the time-based resource-sharing model (Barrouillet & Camos, 2007), it is considered that the performance of memory trace gets worse over time regardless of the complexity or simplicity of the interruption task (Lépine et al., 2005). If so, the inter-trial interval rather than the execution of the touch number task may be critical for the increase in pedal misapplication. In addition, the present study shows that few pedal misapplications occurred in the shorter interruption condition (<0.5%), indicating that the execution of the touch number task did not have a big impact on the occurrence of pedal misapplication. Since the present study did not include a condition in which participants were asked to "do nothing" during the inter-trial interval, it is difficult to conclusively ascertain the influence of the alternative task. Nevertheless, although speculative, it is plausible that the length of the inter-trial interval can be a critical factor in the increase of pedal misapplication.

From the viewpoint of accident prevention, the experimental paradigm used in the present study may be useful for the assessment of the risk of pedal misapplications in older adults with no signs of dementia. The paradigm can be performed by using readily accessible apparatus (a standard PC, an LCD monitor, and a steering game controller) in a small space. Moreover, this paradigm may also be useful as a training tool to reduce accidents caused by pedal misapplication. It should be noted that, however, this paradigm remains untested as to whether it can be effective as an assessment/training tool that reduces pedal misapplication accidents in the real world. Although the present study developed a pedal choice response task to simulate pedal application in real traffic situations, the task may be too simple to simulate real traffic situations. Basically, the lab-based experiment has the benefit that researchers can control factors with comparative ease, but there is also a concern about ecological validity. Further studies including the examinations of more complex situations and follow-up surveys of participants are needed to clarify this issue.

The limitations of the present study and future directions for research on the prevention of pedal misapplication accidents are identified here. First, further research should be performed on the critical factors that determine the occurrence of pedal misapplications in unhurried situations. The present study examined a hypothesis based on previous reports that many pedal misapplication accidents occur in unhurried situations (Schmidt et al., 1997). Thus, the findings of the present study support the view that the length of time a driver is distracted could be a critical factor in explaining the occurrence of pedal misapplications in unhurried situations. However, it should be noted that driver distraction may be just one critical factor. More detailed analyses of traffic accidents caused by pedal misapplications and empirical studies that reveal other critical factors are required for the further prevention of pedal misapplication accidents.

Second, more detailed assessment of cognitive abilities in older drivers should be taken into consideration in future studies. The present study demonstrated that pedal misapplication rates increased in older adults as compared to younger adults, after a longer interruption period; however, there was not a statistically significant difference between older and younger adults after a shorter interruption period. This may indicate that, even in older drivers, pedal misapplications rarely occur under a short interruption situation; however, this notion should be treated with caution. The present study recruited only older adults with no signs of dementia. Furthermore, as mentioned above, a previous study on the effects of aging on pedal misapplication showed that pedal misapplication rates were associated with Clock Drawing Test scores (Freund et al., 2008). Thus, the null results in the present study between older and younger adults under the shorter interruption situation would be applicable only for older adults with no signs of dementia. Additional experiments using several types of older adults (e.g., healthy, mild cognitive impairment, early stages of dementia, and late stages of dementia) would be helpful in clarifying the effects of interruption length on pedal misapplication.

CONCLUSION

The present study demonstrated that pedal misapplication occurred more frequently after the pedal application was interrupted for a longer period of time, especially in older adults. Thus, the length of interruption period may be a critical factor in determining the occurrence of pedal misapplications in real traffic situations.

KEY POINTS

- Forty younger adults and 40 older adults participated in a pedal choice response task that was preceded by an interruption task (i.e., a touch number task).

- Pedal misapplications occurred more frequently when the duration of the interruption task was longer (about 120 s) compared to shorter (about 30 s).
- The interruption effect on pedal misapplication was larger in older adults than younger adults.

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