**Variability of Mental Workload across Different Levels of Feedback and Age**

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**Abstract**

A growing line of evidence suggests mental workload plays a key role in car crashes which have become the leading cause of death on the road, particularly in young and older drivers. These age groups were found to exhibit different levels of mental workload, therefore, this study investigated the role of different levels of Parasuraman's four-stage model feedback in lowering the mental workload in young and older car drivers. A two-factorial simulator study was conducted at the University of Groningen in which 17 young and 11 older drivers, drove through a simulation several times with different feedback conditions. A two-way Repeated Measures ANOVA analysis revealed no statistically significant main or interactions effects of feedback conditions and age on mental workload of participants. Nevertheless, the study raises important considerations regarding the effects of age and experience and proposes several useful implications to ensure lower mental workload and higher safety on roads in the future.

*Keywords:* driving, mental workload, feedback, automatization, age

**Variability of Mental Workload across Different Levels of Feedback and Age**

Car crashes are the leading cause of death of 1.3 million people annually (World Health Organization, 2022). Among those, young novice drivers tend to be more often responsible for causing the crashes, compared to an older, more experienced population (Mayhew et al., 2003). According to Wilde (2013), those under the age of 25 account for up to twice as many accidents as other age groups but the number reduces with each year of additional driving. The young drivers, however, are not the only ones posing an elevated risk on roadway. Due to a globally aging population, the numbers of older drivers on the road are increasing and the involvement of a group over the age of 65 in a car crash dramatically rises (Rahman et al., 2020). It is estimated that age-related frailness will be the leading cause of death in car crashes by 2025 (Haghzare et al., 2021). Therefore, possible incentives for drivers to understand and lower these rates should be primarily directed at young novice and older drivers in order to improve overall road safety.

According to Rahman et al. (2020) and Muller et al. (2021), more than 90% of accidents are due to human error and most often a consequence of an excessive mental workload (Michaels et al., 2017). Mental workload is defined as the amount of mental capacity needed to execute or perform a set of given tasks and can range from low (i.e., underload) to high (i.e., overload) (Da Silva, 2014). Both scenarios are suboptimal during driving since the former results in boredom and inattentiveness to the surroundings of the driver, while the latter presents too big of a challenge, both eventually preventing the driver from taking the suitable course of action at an appropriate time to avoid potential accidents. One of the most sensitive measures of subjective mental workload assessment is the Rating Scale Mental Effort (RSME) questionnaire which has been a common measure in traffic-related scenarios (Da Silva, 2014).

During driving, different age groups have been found to exhibit differing levels of mental workload. In a study by Cantin et al. (2009), although an increase in mental workload in progressively more complex contexts was observed for all the participants, higher mental workload was recorded in older drivers for all situations. Getzmann et al. (2018) proposed that elevated mental workload is a compensation technique for their declining neurocognitive and motor functions, while in younger people it might be a consequence of susceptibility to distractions and attending to irrelevant stimuli.

**The Role of Feedback in Lowering Driver's Mental Workload**

Several recommendations have been proposed and are already in use to lower the driver's mental workload and amount of information needed to process for a successful ride. One of such is the use of feedback during the ride in the vehicle. This helps in eliminating the unnecessary time spent by the driver on searching for information and instead aids in efficient utilization of it (Parasuraman et al., 2000). In addition, highlighting and integrating of important data into a straightforward visual display further eases the information processing (Parasuraman et al., 2000). One plausible design is a four-stage model proposed by Parasuraman et al. (2000) where feedback is presented in terms of automation, and it describes levels of human-machine interactions, which are interpreted for a car driving scenario in this case. The first stage refers to Information acquisition, where the vehicle aids the human in acquiring relevant information from the environment (e.g., speed, lane placement, distance from the car in front). The next stage of Information analysis refers to vehicle's help in cognition by applying algorithms that consider several provided pieces of information. The third stage, namely Decision selection, goes a step further by providing the driver with several possible option, but the final decision on which course of action to take is still operated by the human. And finally, in the Action implementation stage, the vehicle completely excludes human input and makes appropriate decisions for the driver as well as implements them. This can also be commonly referred to as fully automated or “driverless” cars (Wadud, 2017).

The benefits of such automatization, in form of feedback, on a person’s mental workload have been considered in several studies. Parasuraman et al. (2000) argues that well-designed systems can lower the mental workload to a level appropriate for effective task completion. Particular vehicle automation devices such as automatic steering have also been found to reduce the mental workload (Young & Stanton, 2007). In addition, Walker et al. (2001) found that vehicles providing more feedback, lowered the subjective perception of mental workload in drivers of several ages. Consistent and personalized feedback while driving has also been found to exhibit immediate positive changes in driver’s behaviour, particularly with compliance to regulations (Feng & Donmez, 2017). This could be especially effective for younger drivers, who tend to overestimate their ability and have trouble recognizing the risks on the road (Wilde, 2013).

Receiving feedback while driving has thus been found to have positive effects in reducing the driver’s mental workload, which in turn improved performance (Young & Stanton, 2007). This has, however, not been specifically investigated in young novice as well as older drivers, who pose a higher risk on roads. Thus, the current study aims to investigate the difference in effect of increasing levels of feedback (on speed and distance from the front car) on mental workload in young and older car drivers. In order to answer this main research question, the following three sub research questions will be investigated: 1) effect of feedback condition on mental workload; 2) effect of age on mental workload; 3) interaction effect of feedback and age on mental workload of participants. Based on previous studies, a young driver will be defined as someone below the age 25, while an older driver will be considered somebody of 50 years or older (Wilde, 2013; Rahman et al., 2020).

Greater amounts of feedback have been found to lower mental workload (Walker et al., 2001), therefore the first hypothesis predicting lower mental workload in higher level feedback conditions will be tested. In several previous studies, older drivers exhibited lower mental workload than younger drivers (Schwarze et al., 2014; Getzmann et al., 2018; Cantin et al., 2009), thus, the second hypothesis predicting higher mental workload in older drivers will be examined as well. And last, since elevated mental workload in older drivers seems to be a strategy to counteract their age-related neurocognitive decline, while in younger people it is due to processing task-irrelevant stimuli and distractions that do not aid in anticipatory behaviour, feedback providing relevant information would be more useful in directing attention to important details than in counterweighing the decrease in cognitive abilities (Getzmann et al., 2018; He et al., 2021). Therefore, the third hypothesis stating higher levels of feedback will result in greater decrease in mental workload in younger drivers, when compared to older drivers, will be tested.

# Methods

## Participants

In total, the sample included 29 participants, which were recruited from SONA participant pools and by word of mouth. The inclusion criteria were language proficiency in English or Dutch, being 18 years or older, and having a valid driver's licence. After data collection, one participant from the total sample ($N = 29$), who was 30 years-old, had to be excluded from further analysis, due to being an outlier, which fit neither of the two predefined age groups. Thus, the final sample consisted of 28 participants. Of these, 13 identified as men and 15 identified as women.

The 17 participants' ages in the 'young' group ranged from 18 to 22 years ($M = 19.71$, $SD = 1.16$). On average they drove 2030 kilometres per year ($SD = 240$) and obtained their driving licence at 17.82 years of age ($SD = 0.81$). The 11 participants who were part of the 'old' group had ages ranging from 50 to 62 years ($M = 55.27$, $SD = 4.08$), drove 18640 kilometres per year ($SD = 5223$) and obtained their driver's licence at the age of 20.73 years ($SD = 3.07$).

## Procedure

The experimental study was conducted in a driving stimulator in the facilities of University of Groningen. Upon arrival, the participants were informed about the goal and the procedure of the experiment and were required to sign a consent form before filling in a Qualtrics questionnaire. The questionnaire asked the participants about their demographics, driving experience as well as subjective perception of their driving ability. Then, participants were asked about their affinity with technology and attitudes towards automation in driving and advanced driver assistance systems. The questionnaire, which took around 7 minutes, was available in both English and Dutch language.

After filling in the questionnaire, participants were introduced to the driving simulator where they first drove a short test drive of 10 minutes to get familiar with both the setting and the simulator. The route consisted of a road passing through a village, driving on a narrow street, and finally a highway segment after which they were asked to exit and park the car on the side. The participants went on to complete a 10-minute-long route 5 times, in a randomized order, while receiving automated feedback on speed and headway distance of different levels. In the control condition, no such information was provided aside from the usual speedometer. The different levels of feedback were operationalized in the following manner: in the “Information Acquisition” condition, the exact speed and distance were provided in km/h and meters on the screen of the simulator next to the road. In the “Information Analysis” or “Assessment” condition, instead of the exact speed and distance visual images (thumbs) were provided that communicated whether or not the speed and distance were appropriate. In the “Decision” condition, instead of the visual thumbs, written suggestions were presented to the driver to either maintain speed or slow down, depending on the road situation. For distance they were advised to either maintain or increase it. The mentioned feedbacks were chosen based on the results of a small pilot study where opinions on different feedback options were collected. The participants drove an additional short ride with a condition irrelevant for this study.

To avoid carryover effects, the order of the conditions was randomized for each participant. After each drive, they were asked to fill in a RSME questionnaire to assess their subjective mental workload. The participants were also asked to rate their mental workload for all the feedback conditions at the very end. The procedure of the experiment lasted on average 90 minutes and upon completion they were entered into a raffle to win a 25€ voucher while SONA students were awarded credits as well.

**Measures**

The study used a two-factorial design in which feedback conditions and age comprised the independent variables, while the dependent variable was mental workload. Leaving out the last level of Parasuraman's model (2000), the feedback conditions consisted of Control, Information, Assessment and Decision conditions. The participants were also divided into two age groups: one consisting of young drivers, below the age of 25, and the other including older car drivers over the age of 50.

Several dependent variable measures were used throughout the experiment (e.g., SART, ATI) to assess different variables, but the most relevant for this study's research question is the measure of the mental workload. It can be assessed either subjectively, by individual's own assessment of cognitive effort exerted during a task, or objectively by measuring physiological indicators (e.g., ECG, EEG, heart rate) which are thought to correlate well with unconscious and subjective ratings of mental workload (Paxion et al., 2014; Da Silva, 2014; Marchand et al., 2021; Foy & Chapman, 2018). Therefore, in order to assess the invested effort, the one-dimensional Rating Scale Mental Effort (RSME) was used on which a 0–150-point scale ranging from "absolutely no effort" to "extreme effort" was presented and participants were asked to type in the number corresponding to the points of mental workload out of 150, which they felt during the driving task.

**Analysis**

The obtained data was first analysed with JASP software for descriptive statistics and assumption checks were performed. Because of the two-factorial design of this study, in which feedback level was a within-subject while age group was a between-subject variable, a Two-way Repeated Measures Analysis of Variance (ANOVA) was performed. Firstly, to investigate the main effects of the feedback condition and age on the dependent variable (mental workload), and secondly, to assess their interaction effect.

# Results

## Descriptive Statistics

The reported mental workload ranged from 10.0 to 95.0 with an average of 45.84 (*SD* = 25.41) in the control condition. In the Information condition, the mean mental workload was 45.41 (*SD* = 24.24) with a minimum of 10.0 and a maximum of 85.0. The mental workload in the Assessment condition ranged between 10.0 and 90.0 with a mean of 46.48 (*SD* = 24.72), while in the Decision feedback the average was 46.56 (*SD* = 23.98) ranging between 10.0 and 95.0.

When analysing the effect of age on mental workload ratings, the group of younger drivers reported mental workloads ranging from 10.0 to 95.0 with a mean of 51.48 (*SD* = 25.51), while the drivers in the elder group had an average mental workload of 38.17 (*SD* = 20.59) ranging between 10.0 and 90.0.

Taking into account both feedback conditions and age of participants, the mental workload in the control condition was reported as 50.47 on average (*SD* = 25.93) for young drivers, while older participants reported a mean of 38.69 (*SD* = 23.96). In the Information feedback condition, the younger group assessed their mental workload on average at 51.77 (*SD* = 26.04), while the older drivers did so with a mean 35.60 (*SD* = 18.08). In the Assessment feedback condition, the younger participants rated themselves as having on average the mental workload of 50.0 (*SD* = 27.16), while the elder rated it on average at 38.96 (*SD* = 17.15). At last, in the Decision feedback condition, the young drivers reported mental workload with a mean of 51.18 (*SD* = 22.95), while the older drivers reported an average of 39.42 (*SD* = 24.85). The descriptives per feedback and age condition with additional information on range of the data can be found in the Table 1 below.

**Table 1**

*Descriptive Statistics of Mental Workload in Different Feedback Conditions and Age Groups*

| Feedback | Control | | Information | | Assessment | | Decision | |
|---|---|---|---|---|---|---|---|---|
| Age | 18 –22 | 50 – 62 | 18 – 22 | 50 –62 | 18 – 22 | 50 –62 | 18 –22 | 50 – 62 |
| n | 17 | 11 | 17 | 11 | 17 | 11 | 17 | 11 |
| Mean MW | 50.47 | 38.69 | 51.77 | 35.60 | 50.0 | 38.96 | 51.18 | 39.42 |
| SD MW | 25.93 | 23.96 | 26.04 | 18.08 | 27.16 | 17.15 | 22.95 | 24.85 |
| Minimum | 10.0 | 12.0 | 10.0 | 10.0 | 10.0 | 10.0 | 20.0 | 10.0 |
| Maximum | 95.0 | 90.0 | 85.0 | 65.0 | 90.0 | 70.0 | 95.0 | 85.0 |

*Note*: $N = 28$

**Two-way Repeated Measures ANOVA**

In order to assess the effect of age and feedback conditions on mental workload a Repeated Measures ANOVA was performed. To investigate the interaction effect of feedback and age on mental workload, a Mixed design RM ANOVA was conducted.

Mauchly's test of sphericity indicated no significance ($\chi^2$ (5) = 10.84, $p$ = .06) meaning the sphericity assumption was met. Levene's test for equality of variances, however, showed statistically significant differences in variances for the Information ($F(1,26) = 5.33$, $p$ = .03) as well as the Assessment feedback conditions ($F(1,26) = 7.21$, $p$ = .01). Because the assumptions were violated in the two feedback conditions and there is no specific non-parametric test for Two-way Repeated Measures ANOVA, their results were interpreted with caution and are further discussed in the Discussion section.

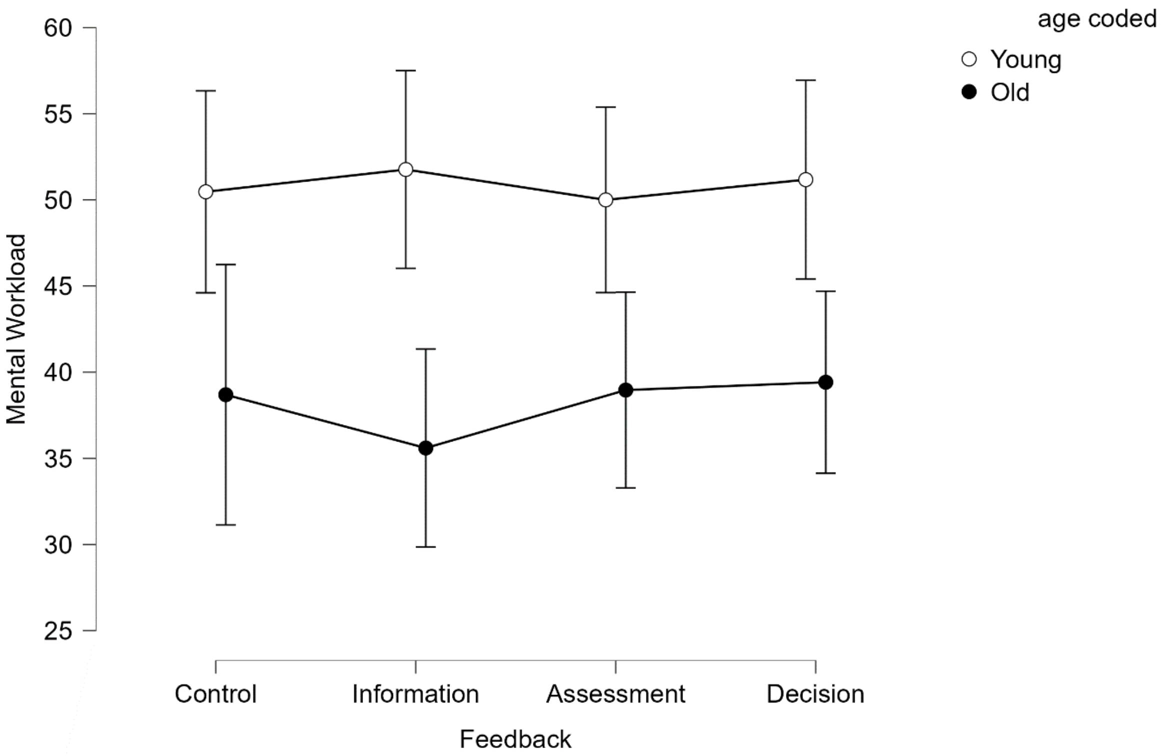
Firstly, the analysis revealed no statistically significant main effect of feedback condition on mental workload ($F(3, 78) = 0.11$, $p$ = .96), with a very small effect size ($\eta_p^2$ = 0.001).

In addition, no statistically significant effect was found for the effect of age on mental workload ($F(3,26) = 2.17$, $p = .15$), with a medium effect size ($\eta_p^2 = 0.067$).

Lastly, the interaction effect of feedback conditions and age on mental workload was investigated. The analysis revealed no statistically significant interaction between the effects of both factors ($F(3, 78) = 0.34$, $p = .80$). A descriptive plot summarizing these findings is presented in Figure 1, where the error bars represent the 95% CI.

**Figure 1**

*Descriptive Plot of Repeated Measures ANOVA Analysis for Mental Workload*




In addition to mental workload values assessed immediately after each ride, the mental workload values reported at the end of all the rides were analysed as the dependent variable. The results were similar to the ones for immediately assessed mental workload, in that they also showed no statistically significant main and interaction effects.

# Discussion

The aim of the current study was to investigate the effect of increasing levels of feedback on mental workload in younger and older car drivers. The proposed hypotheses stated higher levels of feedback will result in lower mental workload, older participants will exhibit higher mental workload, and higher levels of feedback will induce a greater decrease in mental workload for younger compared to older drivers.

Results showed no statistically significant effect of different feedback conditions on mental workload of participants, thus finding no support for the first hypothesis. This is in fact, in line with several other studies which have been conducted due to conflicting evidence on feedback and mental workload in drivers. Fairclough et al. (1997) found no significant effect of headway feedback on driver's mental workload. Similarly, Singh et al. (2010) also found no reduction in mental workload of drivers when provided with feedback in a multi-task condition, which confirmed previous findings by Singh et al. (1999).

Results also showed no statistically significant effect of age on the mental workload of drivers, therefore failing to support the second hypothesis. Interestingly, however, older car drivers reported on average lower mental workload then younger drivers. This is contrary to proposed hypothesis as well as several other studies which have all found a greater mental workload exhibited by older when compared to younger participants (Schwarze et al., 2014; Getzmann et al., 2018; Cantin et al., 2009). A plausible explanation could lie in the fact that the mentioned studies made use of objective measures of mental workload, such as reaction time, EEG and heart rate's inter-beat-interval (IBI). These might have resulted in a more accurate measure of their mental workloads. A study by Schwarze et al. (2014), which implemented both objective and subjective measurements, observed a discrepancy between the results in which older drivers reported very low mental workload while IBI contradicted such findings. The authors proposed the possibility of reporting bias among the older drivers who have been stigmatized by media as being dangerous on the road and are therefore counteracting such expectations by underreporting their actual mental workload on the driving tasks at hand. Therefore, this might have been the case in the current study as well.

At last, there was no statistically significant interaction effects found of different feedback conditions across the same age on the mental workload of participants. Since the assumption analysis revealed a violation of homogeneity for Information and Assessment mental workload results, the F statistic obtained from them was biased and there was a chance of falsely rejecting the null hypothesis. Since the p-value was larger than the significance threshold of 0.05, the null hypothesis was not rejected in the first place. The violation thus did not affect the conclusion drawn from the results, namely that there was no statistically significant effect found. The finding was further supported by the final mental workload analysis which also showed no statistical significance across all feedback conditions and ages. Thus, our third hypothesis could not be supported, since higher levels of feedback did not result in any kind of significant mental workload decrease in younger or older drivers.

Despite the insignificance, the graph in Figure 1 showed some noteworthy details. There was a general tendency of older drivers reporting lower mental workload across all the feedback conditions. Possible explanations could be connected to differences in information processing of participants. With regards to the Information feedback, which incorporated numbers, Norris et al. (2015) found that aging had a positive effect on numerical processing, since elder participants outperformed younger ones in mathematical ability and symbolic comparison. They suggested that their lifelong exposure to numbers may lead to their better numerical skills.

The reason why their mental workload was not further lowered in higher feedback level conditions could lie in crowding and reading speed. A study by Liu et al. (2017) investigated the inability of recognizing objects in a clutter, called crowding, and reading speed in younger as well as older people. Older participants, whose ages ranged from 50 to 73 years of age, showed a significant decrease in reading speed, connected to higher inability of object recognition in a cluttered zone. The increased crowding might be an explanation as to why the feedback in Assessment, in which a symbol had to be inferred, did not result in lowered mental workload, as well as why the same absence of difference was observed in Decision feedback where reading took place. Although a pilot study was conducted before the experiment to infer opinions on clarity of the several options of presented feedback images, it could have perhaps focused more specifically on elder people's opinions, to avoid crowding during the experiment.

Limitations of the study include a single subjective measure used to infer the mental workload of participants. The inability to correctly assess the demands of the tasks on the road are one of the main reasons for poor driving performance, particularly when automated driving is involved (Stanton, 1995; Young & Stanton, 1997; Norman, 1981). Therefore, Stapel et al. (2019) emphasize the necessity to compliment the subjective data with objective measures of mental workload. In addition to self-reports, physiological data such as heart rate, skin conductance and concentration of oxygenated haemoglobin could be measured as well, or several other subjective questionnaires could be presented to participants. Their results could be combined to obtain a more wholesome and overall measure of the person's mental workload.

Another general limitation of this study is the differentiation between driving experience and age of drivers. Young drivers are mostly novice and inexperienced, while elder people have a lot of driving experience, therefore separating the effects of these two factors can be challenging. In this study, the focus was on age, however it is very likely that the experience of the participants played a role in their mental workload during the conditions and influenced the results, since it was found that mental workload is reduced by experience

(Byrne, 2011). A review by McCartt et al. (2009) examined the effect of both age and experience in young drivers. They found that the decline in percentage of crash rates is more strongly associated with age than with the experience in years since licensure. Nevertheless, they acknowledge that the relationship is tricky to decipher. In addition, Mayhew et al. (2003) suggest the decline in person's involvement in car crash situations over years could be either due to driving experience or maturation which is often accompanied by lifestyle changes of decreased risk-taking opportunities.

In order to further untangle the interaction between the two across a span of different age groups, we suggest future research to look into mental workload in young but experienced drivers and old but inexperienced car drivers, while controlling for several factors such as exposure to driving and years since obtained driving licence.

Interestingly, previous experience with automated systems also plays a role in mental workload of drivers. A study by Stapel et al. (2019) found lower mental workload in automation-experienced drivers while those with no such previous experience perceived their mental workload at similar level as manual driving. This suggests, automation and the feedback levels connected to it would only be useful if the drivers are accustomed and have previous experience with such automation systems in vehicles. Thus, future studies could investigate the degree of automation-experience needed in both young and older drivers, for automation to significantly reduce their mental workload.

To conclude, majority of the car crashes are a consequence of a driver's elevated mental workload therefore incentives to lower it are an important part of ensuring safety on roads (Michaels et al., 2017). The current study provided insight into feedback and age effects on drivers' mental workload and although the results were found to be non-significant, several applications can still be taken into consideration and implemented to improve safety of everyone on the road. The feedback provided to particularly older drivers should be simple, with no text and symbols to avoid crowding and should implement numbers. For younger drivers, it would be useful to expose them to automation from an early stage onwards, since only automation-experienced drivers had a lower mental workload while on the road. Thus, several suggestions for future areas of research as well as implications have been proposed which would in the long term reduce the mental workload and subsequently also the risk of car crashes in young novice as well as older drivers, increasing road safety for all.

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