Using Task Switching to Explain Effects of Non-Driving Related Activities on Takeover and Manual Driving Behavior Following Level 3 Automated Driving

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ABSTRACT

Effects of non-driving related activities performed during Level 3 automated driving phases on following takeover behavior have been investigated in multiple studies. If studies refer to a theoretical basis, usually the task switching paradigm is referred to, while at the same time multiple task performance theories are applied to explain effects of previously performed non-driving related activities on following takeover behavior. In this article, we apply task switching theory to explain and predict non-driving related activities' effects on takeover and following manual driving behavior. Additionally, we report experimental work in progress that investigates the theoretical basis in a real driving setting on a test track using a Wizard-of-Oz vehicle to simulate Level 3 driving automation in traffic jams on highways. We aim to contribute to differentiation approaches for non-driving related activities' effects on takeover and following manual driving behavior. Furthermore, this study can provide insights into user behavior under real driving situations.

CCS CONCEPTS

• **Human-centered computing** → Human computer interaction (HCI); Interaction design.

KEYWORDS

task switching, SAE Level 3, automated driving, non-driving related task

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1 INTRODUCTION

Effects of non-driving related tasks in the context of Level 3 automated driving have been investigated thoroughly so far, leading to reviews and meta-analyses that examine their overall effects [4, 12, 15, 18, 21]. Notably, these studies claim that the examined situation corresponds to the psychological task switching paradigm [3, 18, 20], which is defined as follows: "In task-switching experiments, participants perform a discrete task on each trial. On some trials the task changes (switch trials), and on others it does not (repeat trials)." [5]. The most prominent finding from task switching research is the switch cost which describes the relative performance decrement in reaction time and error rates in switch trials compared to repeat trials [5]. Regarding Level 3 automated driving, there is always a switch trial because users switch from a non-driving related activity to the driving task upon a request to intervene (see section 1.2 for application of task switching to performing non-driving related activities in SAE Level 3). There cannot be a repeat trial in the context of Level 3 automated driving, because before the request to intervene, the Level 3 driving automation system is active and thus performs the entire driving task on a sustained basis (see section 1.1 for technical definition of SAE Level 3). Interestingly, although literature declares task switching as the underlying paradigm, multiple task performance theories are still applied to explain and predict effects of non-driving related tasks on takeover behavior [e.g. 18] (see section 1.2 for research gap). The study outlined here contributes to current literature by applying task switching theory to explain and predict effects of non-driving related activities on takeover behavior and following manual driving behavior following a Level 3 automated driving phase.

1.1 Level 3 Automated Driving: Technical Definition and User Perspective

According to SAE International Standard J3016, driving automation systems that perform the entire dynamic driving task on a sustained basis are referred to as Level 3 driving automation systems when they still require the human user to remain fallback-ready which means to take over the driving task upon system request both in order to ensure road safety and to continue the journey [11]. In contrast to SAE Level 2, systems of SAE Level 3 can perform the subtask "object and event detection and response" reliably which allows Level 3 systems to issue a request to intervene before reaching a system limit. According to UN R157 [17], Level 3 driving automation systems are required to issue a request to intervene with at least 10 seconds lead time, and to perform a minimum risk manoeuvre in case the user does not take over the driving task upon system request. This is unlike the technical definition [11], according to which a Level 3 system does not need to be capable of achieving a minimal risk condition.

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Figure 1: Level 3 automated driving ©BASt (https://www.bast.de/EN/Automotive_Engineering/Subjects/f4-user-communication.html?nn=1844934)

Figure 1 depicts Level 3 automated driving over time. The driver activates the Level 3 driving automation system and after the system takes over the driving task, the former driver switches to the role of a fallback-ready user who can engage in non-driving related activities as long as s/he remains receptive to a system request to intervene. Upon such a request, the user is expected to take over the driving task again and continue the journey. From the user's perspective, upon a request to intervene, s/he needs to switch from a non-driving related activity to the driving task (this article focuses on system-initiated takeovers under normal / routine operation [11] and leaves out failure-initiated and user-initiated takeovers. The described switch precedes any takeover.). The responsibility for performing the driving task thereby alternates between system and human. This is the crucial difference between Level 2 and Level 3 systems. When using Level 2 systems, the driver is always in charge of driving, even after activation of the Level 2 system. Performing a non-driving related activity needs to occur concurrently to performing the driving task (yielding a multiple task performance situation). In contrast, after activation of a Level 3 driving automation system, the entire driving task is performed by the system and the non-driving related activity may become the primary activity as long as the Level 3 system is active. Upon request to intervene, the user needs to switch to driving again (yielding a task switching situation).

1.2 Research Gap

As outlined earlier, researchers point out that advancing from Level 2 to Level 3 driving automation incurs a paradigm shift from multiple task performance to task switching in terms of non-driving related tasks [3, 18, 20]. Yet, mostly multiple task performance theories, such as [19], are applied to explain and predict effects of non-driving related activities in the Level 3 automated driving context.

Results from research applying multiple task performance theories indicate that handheld tasks and tasks requiring the visual sensory system lead to decrements in takeover compared to non-handheld tasks and tasks not requiring the visual sensory system [18, 21]. This seems consistent with the applied multiple task performance theories.

Yet, this does not argue against task switching theories being applicable as well. Furthermore, the differentiation between handheld vs. not handheld tasks, and visually demanding vs. not visually demanding tasks may be applicable to tasks implemented in experiments. These tasks are artificially designed to serve experimental purposes and to be either handheld or not, or to be visually demanding or not. However, from a road safety perspective, differentiating natural activities is of greater interest than differentiating experimental tasks. In this regard, [8] differs between "everyday NDRTs" and "standardised NDRTs". To extend the range of differentiable effects of non-driving related activities, a task switching approach is proposed. In contrast to previous multiple task performance approaches, this task switching approach considers the characteristics of the Level 3 driving automation more strongly and contextualizes the performance of non-driving related tasks (see section 1.3).

1.3 Applying Task Switching to Level 3 Automated Driving

By definition, under normal/ routine operation, a Level 3 automated driving system performs the driving task before a request to intervene, and the human driver performs the driving task after the request to intervene. These characteristics make Level 3 automated driving a special task switching situation:

- The imperative stimulus that calls for either a repeat or switch trial is the system's request to intervene.
- There is always a switch trial (from a non-driving related activity to the driving task).
- The task following the request to intervene is always the driving task, thereby the task is known beforehand.

1.3.1 Task Switching in Level 3 Automated Driving. As outlined earlier, Level 3 automated driving inherently involves a switch trial and cannot involve a repeat trial. A repeat trial would mean that the driver performs the driving task both before and after the request to intervene. From a task switching perspective, a repeat trial can therefore only be approximated. This leads to the assumption that there is a performance difference in terms of takeover time and takeover quality between approximated repeat trials and switch trials. How can repeat trials be approximated? To answer this question, a task switching theory from basic cognitive psychology is introduced in the following.

1.3.2 Task Switching Theory to Explain Switch Costs in Level 3 Automated Driving. There are two prominent theoretical approaches when it comes to explaining switch costs in the task switching paradigm. There is also empirical evidence for both approaches. This leads to a theory that integrates these two approaches into one model which is the stage model of executive control for task switching [10]. This model differentiates between task processes that take place whenever working on a task, and executive control processes that take place when switching from one task to another. These executive control processes include goal shifting and rule activation. Goals and rules need to be changed from the previous to the upcoming task. Task processes include stimulus identification, response selection and movement production. Stimuli relevant for the task need to be identified, an appropriate response needs to be selected depending on the task and the response movement needs to be executed. In the context of task switching, the modality shifting effect [16] might influence task processes. The modality shifting effect describes costs when switching from one modality to another [16].

To approximate repeat trials in the context of Level 3 driving automation, the stage model of executive control for task switching is applied. The assumption is that a repeat trial is approximated when task processes of the preceding non-driving related activity and the following driving task resemble, i.e. non-driving related activity and driving task are similar in terms of demands. To assess this similarity, the working memory model by Baddeley is applied [1, 9]. This is a state-of-the art working memory model that also considers modality specific modules. Contrary to the original concept of a visuo-spatial sketchpad, however, later research rather suggests two separate systems with one handling visual information and one handling spatial information, instead of one system that integrates both visual and spatial information [6, 7, 14]. Therefore, visual and spatial characteristics of a task are assessed separately in the case at hand.

Based on this, high similarity compared to low similarity between demands of the non-driving related activity and the subsequent driving task should lead to lower takeover times and better takeover quality. Furthermore, it shall be investigated if effects can be found in the manual driving phase after takeover, too.

1.4 Aim and Scope

This article focuses on effects of non-driving related tasks on takeover behavior and manual driving behavior in the context of SAE Level 3 automated driving under routine/ normal operation. The article refers to system-initiated takeovers and describes an experimental setup to investigate whether task switching (and modality shifting) cause differences in takeover time and takeover quality as well as following manual driving behavior. Relevance to road safety guides this research. Therefore, natural non-driving related activities are selected and participants are provided with a real driving situation using a Wizard-of-Oz vehicle to simulate Level 3 automated driving.

2 METHODICAL CONSIDERATIONS AND NEXT STEPS

The study is conducted on a test track rented for exclusive use due to safety reasons. A Level 3 system operating in a traffic jam based on UN R157 [17] is simulated. Participants are asked to engage in three natural non-driving related activities during the experiment. One condition is defined by the performed non-driving related task and lasts approx. 15 min. Each condition ends with a takeover. Then the next condition is started. Order of non-driving related tasks is counterbalanced across participants. To describe takeover behavior, takeover time is measured, and takeover quality is measured by longitudinal and lateral acceleration. Thereby, in terms of takeover behavior, the experiment follows a repeated-measured design. In contrast, manual driving behavior is only assessed once in the final round. To assess manual driving behavior, participants are confronted with a suddenly appearing balloon-car on the ego-lane that needs to be evaded. Since this scenario requires novelty, manual driving behavior is measured only in the final round and not repeatedly. Thereby, in terms of manual driving behavior, the experiment follows a between-subjects design with three groups of participants performing different non-driving related tasks in the final condition.

2.1 Non-Driving Related Tasks

Participants are instructed to engage in playing Tetris, reading a text and typing a summary of it, and watching a documentary film. These tasks are chosen because they are natural activities and likely to be performed when users have the choice [2, 13]. Since these activities are applied in an experimental setting with instructions, they will be referred to as tasks in the following. The non-driving related tasks reflect different extent of similarity to the driving task. For playing Tetris, the visual and spatial system is required, as well as the central executive to align stimulus processing with the task goals. Furthermore, a response needs to be selected and a respective movement needs to be produced for each stimulus. Response selection is dependent on the stimulus' characteristics, and movement production is time-dependent on the stimulus. For watching a documentary film, response selection and movement production are not needed. Regarding working memory demands, the phonological loop and the visual system are required. The spatial system is not necessarily required, at least less than for playing Tetris. For reading a text and typing a summary, the phonological loop and the visual system is required as well as the central executive to align stimulus processing with the task goals. The spatial system is not required. Response selection is dependent on the read text, and a movement needs to be produced based on the selected response, however, in contrast to playing Tetris, movement production is not time-dependent on the stimulus. Playing Tetris is implemented as the task with the highest similarity to the driving task. Both require visual and spatial systems and the central executive to align stimulus processing with the task goals. The phonological loop is not required.

All non-driving related tasks are performed using a handheld device. For playing Tetris a tablet was used and for watching a documentary film and reading and typing a summary, a convertible laptop was used.

3 CONCLUSION

This study may provide first experimental support for a task switching approach to explain effects of non-driving related tasks on takeover behavior and following manual driving behavior. A meta-analysis has found first indication that support a task switching perspective [12]. This experimental setup shall provide further insight into causal effects. It is assumed that similarity between a non-driving related task and the following driving task is beneficial in terms of takeover and manual driving. For the experiment at hand, playing Tetris is implemented as the task with highest similarity to the driving task as both require similar task processes based on the stage model of executive control for task switching [10]. If the assumptions hold true, playing Tetris should be associated with lower takeover time compared to the other two conditions and better takeover quality, as well as higher time-to-collision in terms of evading the balloon car in the manual driving phase after takeover. This prediction is contrary to multiple task performance theories. According to multiple task performance theories, shared resources should hamper performance. This would result in longer takeover times, and in worse takeover and manual driving behavior in the Tetris condition compared to the other two conditions.

Besides the outlined theoretical implications, the study also includes practical relevance. Since the experiment is conducted in a real driving setting, takeover times can be compared to both results from driving simulator studies and to the time budget suggested by UN R157. Furthermore, observation of participants' in-vehicle behavior during takeover allows to draw inferences on road safety and HMI design.

This article describes work in progress. Final results and implications are to be reported elsewhere

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