LEARNING MULTITASKING IN APPLIED CONTEXTS

A thesis submitted for the degree of Doctor of Philosophy

by

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Declaration

I hereby declare that this thesis has not been, and will not be, submitted, in whole or in part to another University for the award of any other degree. At the time of submission, chapters 1, 3, and 4 are in preparation to be submitted to the following peer-review journals: *PLOS One*, *Journal of Experimental Psychology: Learning, Memory and Cognition*. The second chapter was submitted to *PLOS One* and is currently under review.

Abstract

This thesis examined the learning of complex multitasking activities. Multitasking (MT) involves performing more than one task at a time and is commonplace in daily life.

Previous research has shown the benefits of dual-task training in comparison to single-task (ST) training, a phenomenon which has been termed Dual-Task Practice Advantage (DTPA). DTPA has been consistently demonstrated in MT studies comprising simple experimental designs; however, there is a lack of research into the ways in which people learn complex multitasking activities in real-life contexts, such as driving. Therefore, the aim of this thesis was to examine how people learn to multitask in everyday life and to identify potentially effective MT learning regimes.

In the first study, an online survey was conducted to explore 72 participants' experiences of multitasking, their implicit and explicit multitasking learning strategies, and their opinions and attitudes towards MT. Participants' data showed that, for everyday activities, particularly learning to drive, the most used and most preferred method was a mixture of MT and ST training conditions, the so-called mixed (Mix) learning regime.

In the second study, participants completed an online MT learning experiment in which they could choose their preferred learning regime (ST, MT, or Mix). The online MT study involved an auditory task with four differently pitched tones and a visual task with four different numbers. Participants were divided in two groups, the Fixed group trained in a pure MT regime, and the Choice group who had a free choice of training conditions. The results from both groups demonstrated significant learning effects, which did not differ significantly from each other. A further analysis of the Choice group showed a significant overall trend in choices (better performance leads to choosing more challenging tasks). The DTPA phenomenon was observed in the analysis of the MT learning effects, specifically in the positive correlation between the number of MT blocks chosen by participants and the MT learning effects obtained after the training phase.

The third study was conducted in a Driving Simulator Laboratory to compare three regimes (ST, MT, or Mix) and to identify the most effective MT learning regime. The study included four tasks – a driving task, a math task, a memory task and a monitoring task – performed separately as ST or in parallel as MT. Results showed that the most effective way to train a complex MT activity was the MT regime. The ST regime was the least effective. Moreover, the results supported the proposition that the DTPA phenomenon is applicable to learning challenging applied MT activities.

Overall, the results showed that while the most used and preferred MT learning approach was the Mix regime, training in MT is the most effective approach to learning MT activities.

Keywords: Learning Multitasking, MT training, PRP, dual-task, task-switching, behavioural experiments.

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1 Introduction to Learning Multitasking

1.1 Introduction to Multitasking

Multitasking (MT) is defined as performing more than one task at a time (Burgess et al., 2000). According to Burgess' (2000) definition, multitasking may involve performing different interwoven tasks in parallel with unpredictably changing priorities. These tasks may differ in complexity and, to use time efficiently, the sequence of task performance may require adjustment to accommodate unexpected interruptions or changes.

Multitasking activities, such as driving, are omnipresent in everyday life. MT activities range from highly skilled and demanding ones such as driving, operating a train or flying a plane, to more mundane ones such as cleaning while listening to a podcast. MT behaviour has increased with the accelerating pace and complexity of everyday life, and the development of technology (Carrier et al., 2015). Multitasking abilities are necessary to thrive in many occupational contexts, including management (Mark et al., 2005), medicine (Bechmann & Lomborg, 2013; Chisholm et al., 2001; Ferris & Sarter, 2011), aviation and the military (Chérif et al., 2018; Loukopoulos et al., 2016a).

People often engage in multitasking because it seemingly allows them to complete several tasks, e.g., at work or in daily life, in less time (Carrier et al., 2009, 2015; Frisch et al., 2012). In daily life, one may engage in a phone conversation for an hour while cooking a meal for a family and watching over children. This example also demonstrates that multitasking cannot always be avoided by doing the tasks serially one after the other as single tasks. One could indeed defer the phone call after the cooking, but it would increase the overall completion time for these two tasks. The reality is that parents often have to do certain activities while watching their children. Therefore, multitasking is necessary to manage daily demands – especially in the presence of challenging stressors such as time pressure and workload (Kudesia et al., 2022).

People often find MT beneficial, because it may indeed allow to complete a set of tasks more quickly - the overall completion time is shorter. However, this reduction of completion time often comes at the cost of increased risk of errors. MT may temporarily slow down individual tasks, or some elements of tasks may potentially take longer to complete. In the same example of talking on the phone, cooking and watching over children, the increased error rates may range from losing track of a conversation to burning food, or worse, a distracted parent may not have enough time to react to a risky situation for a child. Thus, although multitasking may seem a solution to deal with the speed and demands of modern life, earlier research has shown that in comparison to single-tasking, multitasking may also incur so-called multitasking costs in form of increased error rates and slowing down (Borst et al., 2010; Pashler, 1994b). Such multitasking costs are usually calculated as performance decrements in a task when the task is done in the context of dual-task performance (Lin et al., 2016). Usually dual-tasking (DT) is also defined as multitasking (MT), i.e., when a task is performed simultaneously with two or more other tasks, rather than being performed in isolation, i.e., as single-task (ST). Moreover, although MT may save time overall, there are still focal points in time where tasks may be processed slower with an overall increased risk of errors. In other words, engaging in MT may have both benefits and costs at the same time (Fischer & Plessow, 2015).

Multitasking can involve a wide range of different tasks: a task has been defined as a goal-oriented activity observed in an experimental setting by a researcher (American Psychological Association, 2023). However, there is no singular definition of what constitutes a task, and relatedly experimental investigations of multitasking have included a wide variety of tasks (Kiesel et al., 2010; Monsell, 2003). These tasks vary from choice reaction time tasks, such as pressing a button in response to a round shape appearing on a screen, continuous tasks, such as tracking a moving target with a mouse or steering a car, or combined cognitive and motor tasks, such as calculating the answers to mathematics problems while throwing and catching a ball. Hence, there are theoretically infinite tasks and task combinations, which means that multitasking costs differ greatly in their severity (Trick et al., 2004). For example, driving comprises low-risk and high-risk errors. A low-risk error would be missing a turn while driving and having to drive a little longer to turn around and get back on the original route. A high-risk error would be an accident, which shows how a seemingly small mistake or deferment in response may cause a disastrous outcome. As a result, compulsory driving schools teach driving skills to a standard which is assessed via driving theory and practical exams. Due to the high risks involved in driving, it is crucial to learn such multitasking activities to a high standard of performance.

Further research is urgently needed to elucidate how learning multitasking aspects of activities such as driving might affect performance and improve the MT learning experience. Overall, even though MT may also save time in everyday activities, it has the disadvantage of increasing the opportunities to make mistakes. Higher likelihood for mistakes is caused either by being distracted (e.g., making a wrong choice, missing a signal), or by local/small deferments which prevent fast actions, e.g., swift responses to changing situations (such as braking/avoiding hazards on the road) (Ashraf et al., 2019).

While the increased risks of engaging in multitasking caused by multitasking costs may be small for many activities, there are activities for which multitasking costs pose critically high risks. Consequently, efficient multitasking is an essential requirement for a range of occupations, such as surgeons, nurses, train drivers, pilots, air-traffic controllers, police and fire officers, and certain military jobs (Kreckler et al., 2008). These occupations carry responsibilities for the safety of other people. For medical staff, such as surgeons and nurses, the smallest mistake may lead to deterioration in a patients' condition. Although the progress in medical equipment and technology is improving medical services, it is important to teach medical staff how to operate such technology, often in stressful and time-critical environments. Importantly, training or learning specifically the multitasking aspect of activities described above may significantly reduce the multitasking costs and benefit a range of highly demanding occupations (Chérif et al., 2018).

Multitasking abilities can be learned and improved through training (Dux et al., 2009). There are two general improvements during MT learning. First, similarly to ST learning, one gets better at the individual tasks, i.e., the tasks themselves are learned. Secondly, one learns how to multitask, specifically how to coordinate multiple tasks at the same time, e.g., by learning how to divide one's attention or how to switch back and forth between the tasks (Bock & Vielcker-Rehage, 2020). While learning multitasking is assessed by a reduction in MT costs, the individual tasks improvements are assessed by a reduction in raw performance (e.g., RTs, error rates) in task performance. The main focus of this study is on the MT learning, i.e., ways to reduce MT costs, and not on the improvements of individual tasks.

MT training can be described as learning or training how to perform two or more tasks simultaneously. Most studies usually employed training periods of 7-15 hourly sessions. Previous behavioural studies, which examined multitasking in controlled lab-based environments, reported reduction of MT costs after MT training (Bender et al., 2017; Dux et al., 2009; Fischer & Plessow, 2015; Kudesia et al., 2022; Ruthruff et al., 2001, 2003;

Schumacher et al., 2001; Strobach, 2020). These studies have consistently found a profound reduction of MT costs over the period of the training.

However, the tasks described in these dual-task studies are considered as basic, e.g., simple shapes (or images) and beeps. Often these dual-task settings include two or more buttons to press with one or both hands. One can argue that these are very simple tasks and do not reflect more the complex challenges and pressure of real-life multitasking. Improving the learning process of such complicated multitasking activities may potentially decrease the pressure by reducing the number of occurring errors, from small mistakes at the office to accidents on the road. While lab-based studies provide substantial knowledge regarding multitasking behaviour and the underlying cognitive mechanisms, we do not know whether these findings can be applied to real-life multitasking. At the time of writing, only two studies have investigated MT in applied contexts.

Understanding how to learn multitasking in applied contexts is central to this thesis. The main focus is on how people learn multitasking complex activities and which learning approach is the most effective to learn multitasking. Additionally, I also investigated the attitudes and opinions regarding multitasking in general, as well as regarding learning multitasking activities in everyday life.

1.2 Experimental non-applied studies of Learning Multitasking

1.2.1 Introduction

Over the past few decades, the learning of multitasking activities captured the attention of many researchers from different fields of psychology (e.g., cognitive, educational, clinical and neuropsychology) and other disciplines, such as medicine and even computer sciences (Karbach & Strobach, 2022). As a result, these disciplines covered a variety of cognitive processes; for example, attention, perception, working memory, executive functions, perception, attention, and other processes. Different experimental paradigms have been used to investigate the effect of dual task on MT costs, such as PRP paradigm (Pashler, 1994a) and task switching (Allport et al., 1972). Before discussing the learning of multitasking in lab-based studies, I will introduce the dual-task theories and one of the most used paradigms in multitasking research, the so-called Psychological Refractory Period (PRP) paradigm.

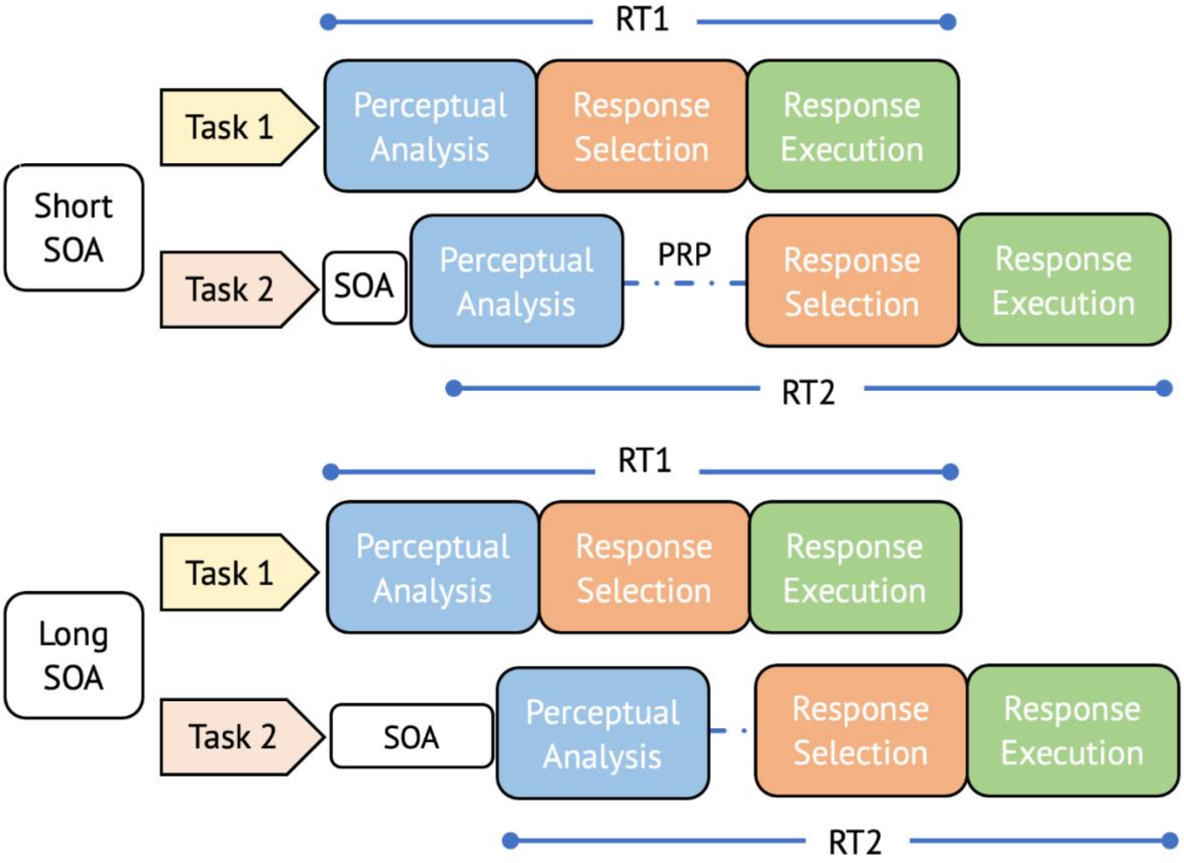
1.2.2 Task Processing

One of the most common paradigms employed to investigate multitasking is the Psychological Refractory Period (PRP) paradigm (Figure 1.1), which involves performing two speeded choice-response tasks. In the PRP paradigm, two stimuli (S1 and S2) are presented in rapid succession (separated by the stimulus-onset-asynchrony, SOA), with each stimulus requiring a response (R1 and R2, respectively). The task overlap becomes high when the SOA is short (e.g., 50 milliseconds); with a long SOA (e.g., 1,000 milliseconds), the task overlap is low or even absent. A typical observation is that the reaction times (RTs) of the second task (RT2) increase with shorter SOAs, while the response times of the first task (RT1) are rather independent of the SOA, a pattern which is referred to as the PRP effect.

One of the most widely used explanations of the PRP effect is based on the concept of processing stages. According to this concept, each task can be divided into different stages. In the case of speeded choice-response tasks, it is usually assumed that the first processing stage is the *perception* stage, in which the physical stimulation is translated into an abstract code. The next stage is the *response selection* stage, where a decision is made to select a response to the physical stimulation, which is then executed in the last stage of response execution. Pashler (1994) explained that the respective perception and motor execution stages of the two tasks can work in parallel during dual-task performance. However, the response selection stage is limited to serial processing, i.e., it can process only one task at a time, and in dual-task performance the tasks have to be processed one after the other. Thus, the response selection stage constitutes an attentional bottleneck, delaying the processing of operations in the second task (Tombu et al., 2011). This delay, i.e., the waiting time for the second task at the response selection stage until it has finished processing the first task, is called the psychological refractory period, PRP (Green et al., 2011; Telford, 1931; Welford, 1952).

Figure 1.1

The PRP Paradigm. Processing stages model of dual-task performance, where the response-selection stage of Task 2 is delayed until the response selection stage of Task 1 is completed. This delay is presented as a dash line and is called "PRP". The line RT1 is reaction time for Task 1 and the line RT2 is a reaction time for Task 2. SOA is stimulus onset asynchrony. (Adapted from Pashler & Johnston, 1989).



The PRP paradigm demonstrates that even a basic task, such as responding to a stimulus by pressing a button on a keyboard, can delay a second response by half a second or more in dual-task performance. A demonstration of how this delay can manifest in real life would be an example of driving a car with a speed of about 30 mph, where the severity of such delay is an increase of the braking distance by approximately 7 m (Wechsler et al., 2022). When comparing the PRP results to driving a car, it is important to note that driving includes far more tasks than dual-task paradigms. Harrington et al. (2015) examined the PRP effect in the driving environment, reporting that braking was delayed when the speeded-response task was presented with a short SOA. Overall, multiple PRP studies investigated driving as multitask and examined MT costs (in RTs and errors) in relation to driving performance and contributed important insights about driving (Hibberd et al., 2013; Levy et al., 2006; Levy & Pashler, 2008).

As described earlier, the PRP research examining dual task processing investigated the capacity limitations in cognitive processing, describing a processing bottleneck which occurs when two tasks compete for access to a capacity-limited processing stage (Borst et al., 2010; McCann & Johnston, 1992; Tombu et al., 2011). This response-selection bottleneck is described as a limited space for processing and creates a processing queue, where processing of the first task creates an interference with processing of the second task (Figure 1.2, de Jong, 1995; Pashler, 1994b; Pashler & Johnston, 1989). According to bottleneck theories, the shorter the SOA, the stronger the interference, whereas a long SOA causes less competition with the processing of the second task (Meyer & Kieras, 1997; Pashler, 1994b). Such interference in dual task performance results in additional cognitive demands to resolve the interference, when comparing DT to performing each task separately as ST (Braun, 1998; Logan & Gordon, 2001; Meyer & Kieras, 1997).

Figure 1.2

The Bottleneck (i.e., capacity limited processing stage) illustrated as shaded grey area. The figure, adapted from Szameitat et al. (2002), represents a simplified version of the central bottleneck in dual task paradigm where the dotted line illustrates the inhibition of Task 2 while the processing stage is occupied by the Task 1.

Task 1 Task 1

Task 2 Task 2

Next, I will describe task processes involved in MT, such as task-coordination, switching and inhibition from different perspectives besides PRP studies. These perspectives include divided attention and task switching.

The task coordination processes can be described as organising or scheduling the concurrent tasks or overlapping task-sets (Koch et al., 2018; Schubert & Szameitat, 2003). According to PRP studies described above, the competition for access to a capacity limited processing stage is resolved by employing control mechanisms which allow coordination by planning and controlling the order of the task processing (De Jong, 1995; Strobach, 2023; Szameitat et al., 2006).

One of the approaches to coordinating tasks is switching, which can be described as switching back and forth between the tasks, mental sets, or operations with different procedural variations. More specifically, this coordination involves the rapid shifting of task activation and inhibition, which requires adaptation of processing strategies (De Jong et al., 1995; Monsell, 2003; Strobach, 2023). The task-switching was applied in multiple MT paradigms, including bottleneck theories, (e.g., MT processing mechanisms of switching the bottlenecks between the tasks). The underlying mechanisms of the MT studies and the variety of the interferences (such as inhibition and response-repetition costs) in task switching research could have theoretical commonalities (Koch & Kiesel, 2022a).

In the task-switching approach the important role is played by inhibition, which refers to mechanisms of resolving a conflict between the tasks. Koch et al. (2010) evaluated the empirical evidence of the role of inhibition in task switching processes describing the influence of inhibition on different conflict levels of processing stages, such as level of cue processing, level of stimulus processing, and the level of response selection and execution. They found that the main trigger of task inhibition lies in conflict at the level of response selection, although there is some indication that other processing levels may contribute to task repetition as well. For instance, when one task includes several subtasks (e.g., participants presented with coloured shapes and required to determine the colour, the shape, and the size) the task inhibition may be triggered by selecting a response order. Costa and Friedrich (2012) reported that inhibition of tasks may provide functional benefits to task switching by reducing interference, however it may produce additional costs when the task requires immediate reengaging.

Another approach to coordinating tasks is dividing attention between the tasks, which can be used in combination with task-switching. Divided attention is described as splitting attention between two or more sources of information (Wickens, 1976). It must be noted that there is a distinction between research on divided attention in visual perception, auditory perception, and multitasking. The divided attention in visual perception is referred to as the spotlight metaphor, where the visual attention is split to focus on two different areas of the visual field (Delvenne & Holt, 2012; Pashler, 1998). Similarly, dividing attention of different sound inputs between both ears is associated with auditory perception (Massaro & Warner, 1977); whereas the divided attention in multitasking involves more complex levels of processing, e.g., listening to a podcast while writing an email would include action control/text production and speech perception or/and recognition (Himi et al., 2019). Naturally, in daily life people often engage in activities which require dividing attention in several sensory modalities, e.g., visual and auditory. Costa et al. (2012) found that visual and auditory modalities involve different control processes and suggested that this has important implications in relation to real-life situations with dynamic, information-rich environments which require dividing attention between multiple tasks involving processing in different sensory modalities.

Additionally, in the context of general attentional control, it is vital to maintain the goal-related and other task-relevant information active during controlled processing. In this instance, inhibition plays a role in focusing on the cognitive processing relevant to the task, while ignoring or suppressing the attributes irrelevant to the task (Howard et al., 2014).

Next, I will describe how MT learning may potentially change task processing. Strobach et al. (2018) described the underlying cognitive mechanisms of task processing and highlighted three main principles involved in these processes. The first principle is the optimized task processing principle, which shortens and automatizes the capacity-limited processes within the component tasks. Task automatization occurs when the task is over-learned or practised to the extent of automatic performance, which in turn frees attentional resources otherwise engaged in the task performance; for example, in driving, changing the gear and pressing the clutch pedal without thinking (Logan & Etherton, 1994). The second principle is the optimized attention allocation principle, which improves allocation of limited attentional resources to tasks and allows to obtain necessary skills outside of the component tasks. And the third principle is the optimized task coordination principle, which improves control and regulation of tasks and enables the acquisition of required skills outside of the component tasks.

Additionally, Strobach (2020) presented a review highlighting two main theories which explain mechanisms involved in MT learning, the allocation and scheduling theory and the integration theory. According to the allocation and scheduling hypothesis, during MT training participants learn a strategy of coordinating the concurrent tasks and allocation of required cognitive resources. This was derived from the executive process interactive control theory introduced by Meyer & Kieras, (1997). According to this theory, the processing stages of two tasks can be performed in parallel by employing the respective strategies when performing the tasks, whereas classical bottleneck theories suggest that the bottleneck cannot be avoided (Pashler, 1994b; Pashler & Johnston, 1989; Schumacher et al., 2001). Furthermore, in PRP studies researchers suggested that to control the interference caused by these bottlenecks, there is a requirement of allocation and scheduling processes (Szameitat et al., 2002, 2006) by assuming that the switching processes involved in inhibition and activation of relevant information between tasks and bottleneck stages (Band & Van Nes, 2006; Lien et al., 2003).

According to the integration theory, MT training may enable an integration of two tasks, combining them in into one super task (Hazeltine et al., 2002, 2007; Oberauer & Kliegl, 2004). In this instance, MT training enables a single capacity-limited process for combined tasks, Salvucci and Taatgen (2008) proposed a concept of threaded cognition (in the context of integration theory) where the stream of thought is considered as processing threads. These cognitive processes are coordinated by procedural resources and carried out by other available resources, for example, motor resources. The integration theory describes mechanisms involved in simultaneous execution and overcoming the resource competition, without involving additional executive processes. Salvucci and Taatgen discussed this concept being applicable in both more simple laboratory tasks (e.g., basic dual-tasking) and more complex, applied tasks like driving. Although there is still a need to conduct more experiments in learning MT to test this concept, it does provide some theoretical explanation to potential mechanisms involved in human MT learning.

Lastly, I will describe additional research beside PRP studies, specifically the relation of working memory research to MT performance. Several studies have found a link between multitasking and working memory (WM), where WM was described as a crucial component of multitasking ability (Ackerman & Beier, 2007; Bühner et al., 2006; Redick, 2016; Szameitat, 2022). In the Baddeley & Hitch model, there is a distinction between short-term memory (STM) which is defined as the information which can be held in mind and retrieved to execute cognitive tasks and WM. In their model WM includes STM plus executive functions, i.e., maintenance plus manipulation of information (Baddeley & Hitch, 1974).

The role of WM was emphasised by Redick (2016), stating that functions related to memory, such as decision-making, attention and memory search, are central for many MT activities both in the lab and real life. Colom et al., (2010) conducted a study with 302 applicants for air traffic control training, emphasising that only WM capacity predicted MT performance in a study examining WM and intelligence as predictors of MT. Colom et al., suggested that from an applied view, WM capacity is a reliable measure for personnel selection for roles with MT requirements.

In the light of the PRP concept, Otermans et al. (2022) gave participants a hybrid WM span task: they combined the traditional PRP paradigm with a WM task, creating a complex WM span task. In this study, participants were instructed to memorise a sequence of letters, then perform additional processing blocks either in ST or MT mode, after which they were instructed to recall the letters. They measured the WM performance by the number of letters memorised in the correct order. The results showed that the MT costs were higher in MT mode in comparison to ST mode; this was supported with further experiments with variations of MT difficulty. The authors supported the evidence of a link between WM executive functions and MT performance and proposed additional control processing in a form of active scheduling regulating serial processing in MT demands.

To conclude, in this Task Processing section I described a number of processes which are related to MT performance and MT learning. In the next section I will describe studies investigating what effect learning has on MT performance from different perspectives. In particular, the focus of this thesis is MT-specific learning, following the logic compatible to Szameitat et al., (2011) examining the MT-specific effects, where ST learning is not central and considered only for the purposes of measuring MT costs. In this instance, the performances in the ST and MT modes were measured at the pre-session and then after the learning phase at the post-session. Following this, the MT costs (MT performance minus ST performance) were calculated separately for the pre-and post-session. Therefore, to calculate the MT learning effect, the MT costs produced at the post-session were subtracted from the MT costs produced at the pre-session. In this way, specifically MT learning was compared, instead of absolute performances in ST and MT mode. Therefore, the reduction of the MT costs over the period of training showed acquisition of MT ability.

1.3 Behavioural evidence of MT Learning

Multiple dual-task studies have investigated how MT can be learned (Ahissar et al., 2001; Liepelt et al., 2011; Ruthruff et al., 2001, 2003; Strobach et al., 2015; van Selst et al., 1999). Extended dual-task training leads to a reduction in MT costs and reduces interference between tasks. There are studies which found that these MT costs could even be completely eliminated in some cases (Schumacher et al., 2001; van Selst et al., 1999). This successful dual-task processing optimisation is achieved by training the coordination of two or more tasks, e.g., visual and auditory tasks, to the level of performance in single-task condition.

1.3.1 Conceptual considerations in MT Learning

There is an established methodology for evaluating learning in cognitive training including multitasking (Eide & Showalter, 2012; Schmiedek, 2021). A commonly employed study design involves a pre-testing, a training phase of the study, which usually varies from 3 to 7 training sessions (some studies included up to 36 sessions), each around an hour in duration, and a post-testing. Additionally, some studies also include a follow-up testing to evaluate retention of the learned tasks after a prolonged period (e.g., 6 months) or a transfer testing, assessing whether learned skills can be transferred to a different task or set of tasks. According to the American Psychological Association (2023), a session includes multiple trials, and a trial may be very short in duration (e.g., include one stimulus, such as an image or a sound), or a trial may be prolonged (e.g., 6 minutes of driving on a simulator). In PRP studies, it is common to have hundreds of trials per session because they are very short in time (e.g., 3 seconds), whereas in applied studies there are fewer trials, which are longer in duration (e.g., 10 minutes).

It is common in MT training studies to differentiate the “pre-test” and “post-test” sessions from the training sessions to assess the baseline performance (Karbach & Strobach, 2022). At the pre-session and post-session all participants perform identical trials in ST and MT modes. Usually, participants are randomly divided into groups for different training regimes after the pre-session to establish a baseline of performance before the training takes place and to avoid bias distribution among the groups. The performances at the pre- and post-sessions are often compared with respect to the MT costs. And the MT costs are calculated by subtracting performance at post-session from the performance at pre-session. This means that training studies often test for a reduction of MT costs from pre- to post-session.

Since participants in all groups perform in MT and ST modes in the pre- and post-sessions to calculate the MT costs, this approach allows evaluating specifically the differences caused by the training regimes. As mentioned before, when calculating the MT costs both ST and MT measurements are required, and the disadvantages of ST and MT training regimes in comparison to Mix regimes are that one does not get a continuous indication of how the MT costs reduce over the course of the training. Whereas in a Mix regime, both ST and MT can be calculated during the training, pure ST regime or pure MT regime training lack either MT or ST measurements, respectively. To overcome this disadvantage and demonstrate specifically the MT costs reduction throughout the training, a mid-test for MT costs can be added in the middle of all training sessions. It is worth emphasising that there are disadvantages to adding a mid-test in training studies because this gives the ST group additional practice of MT (as well as the DT group getting additional practice in ST training), and it is a time- and resource-consuming addition.

Finally, there is variation of the duration and of the number of training sessions across multiple studies (e.g., 5-7 sessions with a 30-60 min duration), usually involving a training phase for a prolonged period (e.g., 2-5 weeks) (Karbach & Strobach, 2022). Sometimes MT learning studies use different definitions for training regimes (hybrid for Mix) and a variety of different tasks. Therefore, there is a need to introduce clear definitions of training regimes.

1.3.2 Methodological Considerations of MT Learning Regimes

Before I describe different types of learning, it is important to clarify the definition I will be using from here on. Since MT (multitasking) is performing two or more tasks simultaneously and DT (dual task) is specific to performing two tasks simultaneously, I will use the more generic term “MT”.

Study of learning MT is central to this thesis, and for the purposes of evaluating different regimes of MT learning introduced in previous research, there is a need to provide specific definitions of MT learning regimes. Therefore, for this thesis I have defined three main training regimes: (1) ST regime; (2) MT regime; and (3) Mix regime. To define these regimes, it is important to note that there is a distinction between the terms “mode” and “regime”, where the term “mode” (e.g., ST or MT) describes the condition in which the trial is conducted, and the term “regime” (e.g., ST, MT or Mix) is a training regime which can include multiple modes. For example, an ST regime consists of solely ST mode trials and an MT regime consists of solely MT mode trials, whereas a Mix regime includes trials in both ST and MT modes.

In the ST training regime, the most common way is to repeat the same action or a task for a predetermined number of trials. For example, when learning MT involving auditory and visual tasks, in ST regime participants would first perform one task (either auditory or visual) and then separately perform the second task; in other words, all tasks are performed in 100%

ST mode. In the MT regime, there are two or more tasks which are practised at the same time. In the same example with auditory and visual tasks, participants would perform both visual and auditory task at the same time or in parallel; in other words, all tasks performed in 100% MT mode.

Finally, the Mix regime can vary the combinations of the ST and MT modes (e.g., half of the trials in ST mode and another half in MT mode); for example, one first practises in the ST mode only, then only practises in MT mode. Mix regime can also involve a quick switch from ST to MT mode in the same training session and other forms of combinations with different durations of training modes. In the same example with auditory and visual tasks, learning in both ST and MT modes could be done by first performing visual task separately, then performing auditory task separately (for example 50% ST mode for the first half of a session) and then joining them together in the same session (50% MT mode for the second half of a session).

It is noteworthy that virtually all previous MT learning studies used a terminology different to the one suggested here. In more detail, previous studies often referred to a mixture of MT and ST modes as MT regimes (i.e., participants in the DT groups performed trials in both ST and MT modes throughout training phase of the experiment), instead of pure ST and pure MT regimes. In this thesis I will refer to the learning regimes described in other studies based on the specific modes in which the training took place. For example, if a learning study described the mixture of both ST and MT training as a learning regime of DT group, I will refer to it as Mix group.

In studies of MT learning, there is a wide range of tasks in different modalities (e.g., visual and auditory), and a common approach to measure performance in different tasks is to record RTs, error rates, and calculate MT costs. The reduction in MT costs after the training phase is considered as the MT learning effect, or the outcome of training the coordination of tasks. For example, Liepelt et al., (2011) conducted a study examining whether dual-task training can result in acquisition of task coordination skills. They trained 16 participants for 7 sessions. Participants were divided into two groups, a ST training regime and a Mix training regime (which the authors termed as a hybrid regime). The first task was a visual manual (VM) task, where participants were required to press three buttons with fingers on the right hand when the circle appeared on the left, middle and the right side of the screen. The second task was an auditory vocal (AV) task where participants were required to vocally respond to three different pitched tones. They reported that the Mix regime significantly reduced the MT costs in comparison to the ST group in the AV and VM tasks. Liepelt et al. (2011) suggested that MT training improved coordination of tasks, which may be a result of learning to speeded task-switching operation.

Furthermore, there is evidence showing benefits of MT training in contrast to ST training in a form of MT costs reduction. Strobach (2020) conducted an extensive review of empirical evidence investigating whether better MT learning (referred to as dual-task learning in Strobach's review) was achieved after training in Mix regimes in comparison to training in single-task regimes. The higher reduction of MT costs in Mix regimes than in ST regimes is defined as dual-task practice advantage (DTPA) phenomenon. He discussed potential underlying cognitive mechanisms of multitasking, which could explain the DTPA phenomenon of dual-task acquisition, but emphasised the diversity of specific skills discussed in empirical findings. Importantly, Strobach, (2020) described the DTPA phenomenon in relation to real life problems, such as how dual-task training could be transferable to real life situations. This review provides a crucial value to the present study, indicating that there is a potential field to explore learning multitasking activities in applied contexts. Although the DTPA phenomenon was found in a range of dual-task paradigms, such as the PRP paradigm, task-switching, divided attention, it is still unclear which MT learning approach is the most efficient in everyday tasks.

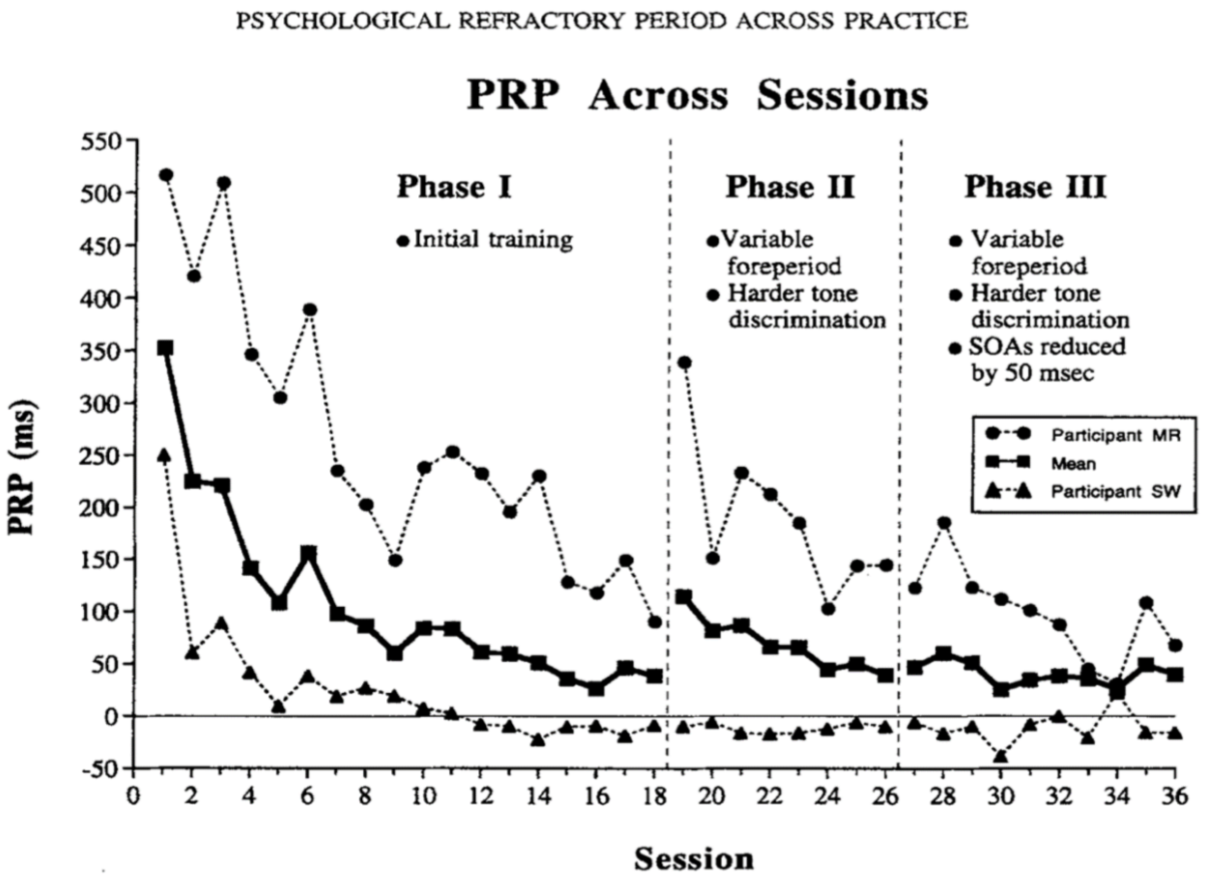
1.3.3 Studies of MT Learning

As described above, laboratory-based dual-task research with relatively simple cognitive tasks has shown that MT learning is indeed possible and that there is a significant reduction of MT costs after MT training. Van Selst et al., (1999) investigated whether multitasking training can reduce the multitasking costs in form of the PRP effect. Van Selst et al., (1999) conducted a dual-task training study with 36 sessions using a PRP task. In this study participants were asked to verbally respond “high” or “low” to four differently pitched tones for Task 1. For Task 2, participants were asked to press keys in response to visual stimuli with four letters (A, B, C, D) in alphabetic order. Participants were asked to respond to both tasks as quickly as possible with the emphasis on the first task. Van Selst et al., (1999) reported that over the course of practice in Phase 1 (1-18 sessions) a large PRP effect in the first session (353ms) significantly decreased to 38ms. Additionally, substantial reduction in RTs and a modest reduction in errors rates were also reported. A visual representation of how MT costs (in form of PRP effect) reduced over the period of practice can be seen in Figure 1.3.

Van Selst’s findings have been supported by numerous PRP studies showing that the PRP effect can be reduced by training (Allen et al., 2009; Bherer et al., 2005; Kramer et al., 1995; Lussier et al., 2012; van Selst et al., 1999). This suggests that training can help individuals to improve their ability to perform multiple tasks simultaneously which includes reduction of MT costs, reduction of RTs, reduction of errors, and ultimately a reduction of interference between tasks.

Figure 1.3

Psychological Refractory Period (PRP) effect of 36 dual-task practice sessions. The bold line demonstrates the mean PRP effect across all participants (N=6): The thin line (SW) demonstrates the minimal PRP effect and the thin line for MR for maximum PRP effect (from Van Selst et al., 1999, Figure 3, page 1274).



Additionally, from the perspective of the research on divided attention, training divided attention may considerably contribute to improving task coordination. For instance, McDowd (1986) found that training divided attention for six sessions significantly reduced MT costs and subsequently improved MT performance. In this study, McDowd compared two groups of participants, 6 younger and 6 older adults under both ST and MT training regimes after six 1-hour sessions. The tasks consisted of an auditory task with three tones (low, mid, high tones) and a continuous visual task, where participants were required to keep an object on a target with a joystick. The MT regime involved simultaneous performance of both tracking visual task and auditory task, additionally, before each session participants were allowed to refamiliarize themselves with the three tones for a short time before the experimental trials. In this study participants in both older and younger groups were training in MT regime, because the aim of the study was to determine whether there is age difference in learning rather than comparing training regimes. The results showed that after six sessions the performance improved (in a form of reduction of MT costs) for both groups. Overall, the findings were consistent with other behavioural studies on MT training (e.g., Ducrocq et al., 2016; Ewolds et al., 2020; Garner & Dux, 2015), showing that training resulted in reduction of MT costs in divided attention experiment.

Furthermore, from a perspective of WM studies, one of the earlier studies which addressed whether training working memory would have a positive effect on MT ability was conducted by Oberauer & Kliegl (2004). They trained six students for 24 sessions (45 minutes per session), where participants practised numerical and spatial tasks presented either sequentially or simultaneously. In the numerical task, the participants were required to add 2 from the presented number when they heard a high-pitched sound and subtract 1 when a low-pitched tone was played. The spatial task involved arrows located in the central object in the form of a cell which could point in 8 possible directions and the participants were asked to mentally shift a red dot to the pointed direction from the current position by one cell. At the beginning of the training, participants demonstrated substantial MT costs which statistically reduced after 24 sessions of training. Oberauer & Kliegl (2004) found that the participants who practised two WM tasks in a dual-task condition had shown only 14% of the MT costs of the participants practsing in single-task condition.

Oberauer and Kliegl (2004) proposed that the best explanation for their findings is the existence of a functional bottleneck for cognitive processing in WM. They suggested that there is a constraint on parallel processing, inducing serial processing, which can be reduced by learning to efficiently merge the tasks. According to Logan and Gordon's (2001) theory of executive control, there is a functional bottleneck, meaning that to resolve the competition for resources, the cognitive system employs a strong tendency for serial processing (e.g., coordinating which stimulus is paired with which response). Oberauer and Kliegl argued that a serial scheduling scheme is not required, because the cognitive system can set up two sets of tasks in parallel streams of updating processing in WM. In this instance, the participants might achieve performance without interference due to automatized individual operations, where the two task sets are learned simultaneously, allowing a parallel performance without interference of unrelated control signals. They concluded that it is possible to overcome the response-selection bottleneck under specific learning conditions, which is in line with previous PRP research (Hazeltine et al., 2002; Schumacher et al., 2001; Van Selst et al., 1999).

1.3.1 Comparison of learning regimes and applied studies

Generally, the research investigating MT training often compares two different training regimes (Bender et al., 2017; Bier et al., 2014; Bock Otmar Leo & Vielcker-Rehage Claudia, 2020; Junco, 2012; Monsell et al., 2000; Ruthruff et al., 2001, 2003; Schumacher et al., 2001). As mentioned before, to the best of my knowledge, most of these studies usually train DT or MT groups in Mix training regimes, meaning that some trials in a training phase of the experiment were conducted in pure ST mode and some in MT mode.

One of the studies which compared pure MT training to ST training was conducted by Bender et al. (2017). The first task was a shape discrimination task, and the second task was visuomotor tracking task. Each task included 36 trials with a duration of 3 minutes for the ST group (a sum of 72 three-minute trials) and 72 trials (3 minutes per trial) for the MT group over six training sessions. After six training sessions they concluded that the MT training group showed a significant overall MT-cost reduction by 55%, while the ST group demonstrated a 7% increase of overall MT cost.

Another example of a pure MT regime design was conducted by Anguera et al. (2013), where they tested 174 participants using a Neuroracer videogame. Participants were divided into pure ST and pure MT groups. The training in ST and MT regimes took place for 12 sessions over the period of 4 weeks. The first task included a continuous condition where participants were required to track a car on a road in a simulation videogame. The car could move right or left as well as downhill and uphill. The second task was designed as a detection condition, where participants were required to respond only to a green light, mimicking the traffic light (i.e., green, amber, and red). Results showed that both ST and MT groups exhibited improved performance in component tasks, but only the MT group achieved significant MT costs reduction after the training. Specifically, while before the training both groups showed the same costs, after the training, participants in MT group showed only 37% of the MT costs of the ST training group. Noteworthily, the follow-up test after 6 months showed that participants in the MT group kept the obtained skills without additional training which indicates that MT training can result in lasting performance improvements. This study demonstrated consistency with the DTPA phenomenon and showed a potential for lasting performance gains after the training.

Most research conducted in training MT activities is lab-based, and there is a lack of applied studies which specifically evaluate the effects of training regimes. When examining the learning multitasking literature, one could argue that these experimental studies were conducted with very simplistic tasks (e.g., pressing buttons on a keyboard in response to tones, or figures). Such applied studies could play an important role by providing valuable information for designing and managing training protocols for real-world complex activities. Although some studies did experiments to investigate the transferability of learned tasks and multitasking skills to other lab-based tasks (Bender et al., 2017; Bier et al., 2018; Cassavaugh & Kramer, 2014; Lussier et al., 2012), it is still unclear to what extend the cognitive principles of MT learning from lab-based research might be generalisable to more applied contexts. Additionally, further applied studies are required to examine whether the DTPA phenomenon would still hold in real-life MT activities.

To the best of my knowledge, there are only two applied studies (Bongers et al., 2015; Kobiela et al., 2018) which examined MT learning. These studies investigated the outcomes of surgical training in the applied context. In the next section, I will describe these studies and discuss whether cognitive tasks and applied tasks might follow different principles.

An applied study on learning in the context of laparoscopic surgery was conducted by Kobiela et al., (2018) with 58 medical students. To imitate the surgery situation, they used a laparoscopic colorectal surgery box mimicking the skin of a potential patient. In this study the pre-test and post-test were performed in four tasks: traction (Task 1a), traction and operating the camera (Task 1b), countertraction (Task 2a), countertraction and operating the camera (Task 2b). The training involved surgical box protocol and consisted of seven sessions (five trials per session) with four weeks intervals between the sessions throughout a year. In the study the Task 1a and Task 2a were performed in ST training regime, which included practical lessons from a laparoscopic surgery training protocol. Tasks 1b and 2b were considered as MT performance, because trainees were expected to switch between navigating the camera in one hand and operating the laparoscopic tool in the other hand. It should be noted, that the MT tasks 1b and 2b were performed only for the pre- and post-tests, but not during the training phase. The main aim of the surgical box training was to learn the procedure using a force up to 5N as steadily as possible. They measured standard deviations (SDs) of the force, minimal and maximal force values, and force range for 120 s in each task. In the pre-test they reported a decrease of performance in MT mode as compared to ST mode, i.e., MT-costs: greater SDs of force for Task 1 and Task 2, greater maximal exerted force above 5N, and a greater range of force. These exerted force results indicated non-steady performance, while steady performance was required, since this can prevent unintentional injuries during surgeries. After the training (which was purely ST regime), in the post-test, Kobiela et al., (2018) reported a statistically significant reduction of SDs of force (e.g., maximal force and a range of force) and improved stability of traction in MT performance, while the ST performance remained similar from pre- to post-session. Importantly, they emphasised that the surgical box training enhanced the MT performance and enabled medical students to improve the stability of needle retraction.

The conclusion was that after the training, participants in both tasks showed as effective retraction skills during multitasking (with camera, task 2b) as compared to single tasking (without the camera, task 2a). While participants showed improvement in stability of traction in MT performance (task 1b) after the training, participants showed no improvement in stability of traction in ST performance (task 1a). Kobiela et al.'s training study brought valuable insights for the field of laparoscopic surgery, showing that surgical ST-training improved MT performance. However, the aim of Kobiela et al.'s study was not to compare the MT costs of ST and MT training regimes; the aim was to assess whether the structured box-training protocol was an effective approach to improve the stability of retraction while multitasking in laparoscopic surgery simulation. Therefore, all 58 participants completed the training in the task-switching paradigm, rather than fully parallel multitasking training.

On the one hand, one may argue that training in ST regimes may improve MT performance; for example, if a task in the ST mode was cognitively demanding, then only limited cognitive resources (resources such as controlled attention, WM) were available for task-coordination in the MT mode. This would result in high MT costs, because the cognitive demands would increase when two tasks compete for limited resources. However, when participants improve their performance in a task in ST mode, it is plausible that such task would demand less cognitive resources (up to an extreme of fully automatic ST performance, freeing up all limited resources). Therefore, MT costs would be reduced, because additional central cognitive resources would be available for the performance in the MT mode (Logan & Etherton, 1994; Ruthruff et al., 2006).

Furthermore, if participants indeed improved their MT skills through ST training, such MT costs reduction would not be related to the learning of task coordination; instead, they would have more resources available for MT coordination. However, if indeed participants had reduced demand on limited central resources in the ST regime, one would expect a performance improvement in the ST mode as well – which they didn't find. Thus, one **may** use this point to reject the idea that ST training reduced central demands. Alternatively, such MT costs reduction (or MT learning) in a context of highly complex tasks may behave somewhat differently to simplistic lab-based tasks.

To the best of my knowledge, the only applied MT training study to compare ST and MT training regimes was conducted by Bongers et al., (2015) using a virtual-reality simulation and a paradigm related to task-switching. They divided 42 students without a prior surgical training into two groups: an intervention (MT regime) group, and a control (ST regime) group. The virtual-reality simulation included laparoscopic skills training and the insufflator module (i.e., an insufflation needle is used to inflate the abdominal cavity). The pre-test and post-test consisted of five trials each. The training consisted of four repetitions of three trials for laparoscopic skills training and seven different insufflator problems in an insufflator module. When insufflator problems occurred, the time of laparoscopy was paused and restarted after the problem was successfully solved. Therefore, participants trained MT, in the sense that they had to switch between two ongoing tasks, but they did not train the parallel performance of both tasks. In the ST training regime, the laparoscopic skills exercise (Task 1) and insufflator simulation module (Task 2) were trained separately. In the MT training regime the laparoscopic skill task was randomly interrupted when the insufflator problems occurred.

This study measured means and SDs of time needed for laparoscopy, time of insufflator, and errors of absolute performance. Bongers et al., (2015) reported that there was no significant difference in error rates between the learning regimes of the two training groups. And both MT and ST groups had a significant improvement in handling the distractive insufflator problems after the training, however the improvement was significantly larger in the MT group. Bongers et al. explained that the MT group learned to switch their attention significantly faster or gotten less distracted by the occurring problem with the insufflator. While Bongers et al.'s study brought helpful insights for our understanding of the laparoscopic skills training, in the context of MT training there is still a gap in understanding the outcomes of different MT learning regimes. For example, while specifically in task-switching paradigm the results were consistent with the DTPA, it would be helpful to examine whether these findings would also hold for more complex MT activities with extremely high cognitive demands. Therefore, there is a need for further research on MT training, investigating which learning regime best fit to train complex MT activities mimicking the real-life demands.

Overall, multitasking is a big part of everyday life and for some instances cannot be avoided. Laparoscopic surgery is a vital example of how surgeons have to multitask by handling tools in both hands and pressing a pedal with the foot, while monitoring the process of the surgery on the screen. Although surgical simulation training studies provide valuable insights in MT training, there is still a need for investigating general training of MT activities in more depth. The assessment of learning complex MT activities could promote a potential development of effective general MT training programmes. The only two applied studies I am aware of, discussed above, were designed in a context of surgery to train laparoscopic tasks and achieved their aims; however, they might not necessarily transferrable to other everyday MT situations, such as driving.

The research question of the current thesis was to investigate the learning of MT activities which mimic everyday MT activities. In the first experiment, I attempted to answer this question by exploring what experiences people reported from learning MT in everyday life, and their opinions about learning MT in daily life. This exploratory study was conducted to find out whether there are any patterns in beliefs which may influence peoples' choices towards learning MT in a particular training regime. The second experiment was designed to investigate what regime people choose if they were given free choice; and in addition, to compare the MT learning in this free-choice group with MT learning of a pure MT group (which theoretically is expected to result in the best MT learning). Although this was a computerised (more lab-based) study, the tasks were designed to be very difficult and as demanding as the daily life MT activities. The second study was designed to understand the patterns of choosing the modes of training and whether having a choice of training modes may affect the MT learning outcome. Finally, in the third experiment I aimed to answer the question of what training regime would result in the most efficient MT learning in a complex driving simulating task, by comparing ST, MT and Mix regimes. This lab-based study also included additional demanding tasks to mimic highly challenging activities in real life.

2 Online Survey Study: “Experiences of learning MT activities in everyday life”

2.1 Attitudes Towards Multitasking

People’s attitudes towards a desired behaviour strongly influence their intention to engage in behaviour, and whether they ultimately perform it (Glasman & Albarracín, 2006).

Consequently, an individual’s attitudes towards MT may affect their MT behaviour, including their learning regime preferences. To assess whether people like to engage in MT, Slocombe & Bluedorn, (1999) introduced the term “Polychronicity”, which they defined as one’s preference to engage in MT as a lifestyle, as opposed to completing tasks individually. To measure polychronicity, they designed the “Multitasking Preference Inventory” (MPI) which was found to be a reliable method (Poposki & Oswald, 2010). Depending on their answers, participants were assigned low or high scores which would then determine the polychronicity levels. It is conceivable that people with a high MPI score might prefer MT learning regimes, and that people with a low MPI score might prefer ST learning regimes.

Since MT is omnipresent in our daily lives, it is evident that people ultimately manage to learn how to do it. However, it is not clear *how* people learn multitasking activities. The primary aim of the current study was to better understand how MT activities are learned in everyday life, by asking participants about their experiences of MT; for example, the kinds of MT activities they learned, the regimes they used, and whether they were satisfied with the outcomes of those regimes. Additionally, the second aim of this study was to explore the relationships between MPI scores and participants’ expressed preferences regarding learning regimes. To address this, I obtained MPI data from survey respondents and correlated the resultant scores with their preference ratings, obtained via a series of bespoke questionnaire items.

2.2 Methods

This online survey was designed to explore current opinions and trends regarding learning MT among the population. The questions were formulated to specifically distinguish MT activities from non-MT activities and related to daily MT situations. The only inclusion criteria for the participants was the requirement to be over 18 years old. The study was approved by the College of Health, Medicine and Life Sciences Research Ethics Committee at Brunel University London.

The data analysis involved descriptive analyses and reporting frequencies for items of a particular type (such as responses towards MT activities). The average scores were calculated to specify the percentages for each question category; then to assess and summarize open text comments by finding common themes (qualitative analysis). Finally, the correlations were assessed between MPI and questionnaire items involving different MT learning regimes.

2.2.1 Participants

Seventy-two participants – 49 men (M=29 yrs; SD=7.09 yrs; 18-44 yrs) and 23 women (M=32.4 yrs; SD=7.58 yrs; 18-44 yrs) – were recruited online via Testable Minds (https://www.testable.org), an online platform where participants can register to participate in experiments and surveys for payment. Survey completion times ranged from 20 to 45 minutes. All participants gave their informed consent before taking part and each of them received £3 for completing the survey.

2.2.2 Procedure

The online survey was presented via the Qualtrics (Provo, UT) online survey platform. The survey consisted of four blocks. In the first block, participants were presented with an information sheet and the consent form. Once they had given their consent, participants read instructions that provided definitions of MT and learning regimes, and examples of MT activities. Afterwards, participants provided demographic information, including their age, gender, occupation, driving license status, and self-reported MT ability. The second block comprised of questions about their MT experiences including how they learned them, for example whether they learned in a manual or automatic vehicle, whether there was an instructor present, and, if so, whether the instructor provided explicit MT instructions. However, if someone indicated that they had not learned to drive, they would be redirected to a response box in which they could provide another example of an MT learning experience. The third block included MPI questionnaire. Lastly, the fourth block included questions about participants' experiences and attitudes regarding MT learning. This block was designed to gather their opinions on the best approaches for learning to multitask, as well as open-ended questions about factors that had either facilitated or hindered their learning in such contexts, whether current MT learning practices could be improved, and whether participants would have benefitted from training focused on MT. The data collection period was from 03 November 2021 until 26 November 2021. All the personal information of participants was strictly confidential, as the collected data was anonymised by Testable Minds. Testable Minds is a platform for convenient search of participants all over the world to complete online studies.

2.3 Results

2.3.1 Experiences of Learning Real-Life Multitasking Activities

In the analysis of responses provided by 72 participants, I excluded 14 people who, when asked about previous experiences of learning an MT activity, either indicated a single-task activity or no activity at all (Table 2.1). Therefore, I analysed the responses of the remaining 58 participants.

Table 2.1

MT and non-MT learning activities identified by participants (n = number of times mentioned).

Multitasking Activities	**n**	**Non-Multitasking Activities***	**n**
Driving	34	Office job	3
Videogames	9	Studying	3
Cooking	6	Archery	1
Playing musical instruments	4	Cricket	1
Working on two computers/ computer applications	3	Preparing Power Point presentation	2
Cycling	2	Sewing	2
Total:	**58**	**Total:**	**12**

Note. Non-MT activities were excluded from the subsequent analysis, as were 2 non-responses.

The results indicate that 43% (25 out of 58) of the participants had learned their MT activity in a Mix learning regime; 33% (21 out of 58) in a single-task (ST regime) and 24% (12 out of 58) in an MT (MT regime). This shows that all major variants of how MT activities can be learned seem to be practised to some extent in everyday life.

Participants were asked to describe their learning experiences in more detail via open response boxes, but many participants did not do so. Of the 25 (43%) participants who said they learned the MT activity in a Mix regime, 6 provided comments. For example, Participant № 49 stated, “Because driving a car is a practical way, I used to learn each activity first and then drive around only on the training grounds until I was comfortable to drive on the road with normal traffic”, and Participant № 68 stated “For me learning to drive a car was very challenging as it was difficult to remember all the instructions and follow the sequence, for example, remembering to check the blind spots before you manoeuvre and clutch and gear sequence.”. The majority of the comments acknowledged the demands on their concentration and their ability to remember the sequencing of the tasks.

Of the 21 (33%) participants who said they learned the MT activity in a ST regime, 7 provided comments. Seven participants described mastering tasks individually; examples included “I learned driving or any other skill by doing one thing at a time. I cannot do all together right away or mixture of this because that confuses and frustrates me” (Participant № 6), and “I started to learn step by step by practising it day by day” (Participant № 32).

Finally, of the 12 (24%) participants who said they learned the MT activity in an MT regime, 3 provided comments. Examples of comments included “Learning to drive was easy. Some people have hard time concentrating on both gear shift and steering control, but it was easy for me to concentrate on both” (Participant № 2), “I think that I multitask a lot of times in my daily life, like listening to a podcast while working. Also, it seemed quite easy to learn to drive, I didn't feel like I was multitasking.” (Participant № 18) and “I multitask when playing games. I have to constantly be listening to what my friends are saying on the mic while using my hands on the controller and playing the game” (Participant № 54). The comments suggest that these participants found it easy to perform MT learning from the outset.

Of the 58 participants who reported learning an MT activity, 67% (39 out of 58) learned with an instructor and 33% (19 out of 58) learned an MT activity without one. Eighty-two percent (32 out of 39) of the former indicated that the instructor had given them explicit MT instructions, whereas the remaining 18% (7 out 39) stated that their instructors did not teach how to perform or manage MT aspects of the activity. In another question, 85% (33 out of 39) of participants liked the instructor's approach to teaching the MT aspects of the activity, and only 15% (6 out of 39) of participants would have preferred a different approach. Therefore, most instructors seem to explicitly teach how to manage multiple tasks when teaching MT activities, and the learners were mostly satisfied with this approach.

2.3.2 Opinions on Learning Multitasking Activities

Participants were asked to select statements indicating their agreement with a series of opinions regarding the best approaches to MT learning; multiple answers were allowed. The statement "I prefer to first learn each task on its own until I master them all, and only then train them together" was selected by the majority (65%; 47 out of 72) of participants, which indicates that they preferred a Mix learning regime. Only 25% (18 out of 72) reported preferring an MT regime by selecting the statement "I prefer to start right away learning all tasks together". Fifty-four percent (39 out of 72) of participants agreed with "I think the best strategy depends on the nature of the task", which indicates that the learning regime preference would be task-specific. Additionally, 18% (13 out of 72) of participants agreed with the statement “it is useful if instructors/teachers explicitly teach how to integrate the tasks (in other words, they teach how to multitask)”.

Forty-six percent (33 out of 72) of participants provided additional comments on how to best learn MT activities. These comments were categorised into recurring themes (see Table 2.2). For example, “…yes, because I can't just jump into a task that I have no knowledge of, I have to first familiarize myself with each task then later I could multitask to get better results” and “I personally prefer to accomplish one task perfectly before moving onto the next task” were organised into the theme *First, familiarising and/or mastering individual tasks*. Thirty-five per cent (25 out of 72) of all participants provided responses within this theme.

Table 2.2

Recurring Themes in Comments Regarding the Statement: “How to best learn multitasking activities".

Themes	**%**	**N**
First, familiarising and/or mastering individual tasks until performance is improved, then MT	35	25
Improving one’s levels of focus and attention towards practising MT	4	3
Belief in oneself and confidence boost from the progress of learning	4	3
Improving one’s timing and planning to be efficient at MT	3	2

Note. 54% (39 out of 72 participants) did not provide any comments.

Next, participants were asked to indicate the extent of their agreement, on a 5-point Likert scale, to the question “learning an MT activity differs from learning a single-task activity”. Of 72 participants, 43% (N=31) strongly agreed and 46% (N=33) somewhat agreed with the statement. Just 7% (N=5) reported that they neither agreed nor disagreed with the statement, and only 4% (N=3) reported that they somewhat disagreed, and no participants strongly disagreed with the statement. Therefore, the majority of the participants believed that learning MT and ST activities differs.

For the statement “Learning an MT activity would benefit from a learning strategy which takes the MT aspects explicitly into account.” (1 – 5 Likert scale), 36% (26 out of 72) of participants reported that they strongly agreed, and 56% (40 out of 72) somewhat agreed. Only 5% (4 out of 72) reported that they neither agreed nor disagreed, and only 3% (2 out of 72) reported that they somewhat disagreed with the statement. Therefore, most participants indicated that there is a need for MT-specific strategies in learning.

For the statement “that the current practices of learning MT activities could be improved” 44% (29 out of 72) of participants reported that they strongly agreed, and 38% (27 out of 72) somewhat agreed. Also, 17% (12 out of 72) participants neither agreed nor disagreed, 10% (7 out of 72) indicated they somewhat disagreed and only 1% (1 out of 72) strongly disagreed with the statement. Therefore, the majority of participants agreed that current practices of learning MT activities require improvement.

Additionally, participants were asked whether they might benefit from a generic MT training. Overall, 79 % (57 out of 72) of the participants reported that they might benefit from a generic MT training, and 21% (15 out of 72) did not believe that MT training would benefit them.

3.2.1 MPI questionnaire

The mean MPI score was -0.18 (SD = 0.826, scale -2 to +2), which indicated no strong preference regarding MT. A significant positive correlation (r = .24; p= .04) was found between MPI scores and participants' agreement ratings for the statement "I prefer to start right away learning all tasks together", which indicates preference for MT learning regimes (Table 2.3). The correlation assessing the relationship between the average MPI scores and the statement indicating preference for ST learning regime: "I prefer to first learn each task on its own until I master them all", was negative (r= -.19), i.e., the lower the expressed preference to engage in MT, the higher the preference for ST learning, but this failed to reach statistical significance (p= .113).

Table 2.3

Correlations of MPI Scores with Participants' Responses to Selected Survey Items

Item	**MPI-Score**	
	Pearson's *r*	*p*-value
I prefer to start right away learning all tasks together	0.242*	0.041
I prefer to first learn each task on its own until I master them all	-0.189	0.113
It is useful if instructor teaches explicitly MT aspect of the activity	-0.117	0.327
The best strategy depends on the nature of the task	0.010	0.933
Learning in MT regime differs from learning in ST regime	0.214*	0.035
I would benefit from a generic MT training	-0.031	0.794

Note. * p < .05; r* indicates Pearson's r and p* indicates p-value.

The correlation between participants' responses to the question "Would you benefit from a generic MT training?" and to the statement "It is useful if the instructor teaches explicitly the MT aspect of the activity" was statistically significant (r= .22; p=.033). This suggests that the more people believe that they would benefit from generic MT training, the more likely they are to believe that explicit instructions regarding how to learn MT from the trainer would be helpful to improve MT learning outcomes.

A strong negative correlation (r= -.49; $p < .001$) was found between participants' responses to the statement "I prefer to first learn each task on its own until I master them" and to the statement "I think the best strategy depends on the nature of the task" (Table 2.4). This correlation indicates that those who prefer learning in ST regime do not believe that the regime of learning depends on the task. The more participants preferred to learn using an MT regime (as expressed by lower scores on "first learn each task on its own"), the more differentiated their view on "it depends on the task". This shows that even those who preferred MT learning may be aware that it might not be the best approach for all situations.

Table 2.4

Questions Assessing Participants' Opinions Regarding MT Learning: Correlation Matrix

		I prefer to start right away learning all tasks together	**I prefer to first learn each task on its own until I master them all**	**It is useful if instructor teaches explicitly MT aspect of the activity**	**The best strategy depends on the nature of the task**	**Learning in MT regime differs from learning in ST regime**	**I would benefit from a generic MT training**
I prefer to start right away learning all tasks together	*r**	-	-0.003	0.229	0.115	0.112	-0.115
	*p**	-	0.980	0.053	0.337	0.347	0.337
I prefer to first learn each task on its own until I master them all	*r*	-0.003	-	0.016	-0.495***	0.151	0.214
	p	0.980	-	0.893	<.001	0.205	0.070
It is useful if instructor teaches explicitly MT aspect of the activity	*r*	0.229	0.016	-	0.286	-0.042	0.217
	p	0.053	0.893	-	0.015	0.728	0.067
The best strategy depends on the nature of the task	*r*	0.115	-0.495	0.286*	-	-0.116	0.057
	p	0.337	<.001	0.015	-	0.331	0.635
Learning in MT regime differs from learning in ST regime	*r*	0.112	0.151	-0.042	-0.116	-	0.230
	p	0.347	0.205	0.728	0.331	-	0.052
I would benefit from a generic MT training	*r*	-0.115	0.214	0.217	0.057	0.230	-
	p	0.337	0.070	0.067	0.635	0.052	-

Note. * $p < .05$, *** $p < .001$; *r** indicates Pearson's *r* and *p** indicates *p*-value.

2.4 Discussion

The present study investigated how people learn MT activities in everyday life and whether they are satisfied with their learning experience. The results showed that the majority of participants (43%) learned MT activities in Mix learning regimes, 33% of participants in ST regimes and the least used approach was learning in MT regimes (24%). Most of the participants were satisfied with their experiences of learning an MT activity. In addition, polychronicity, i.e., the propensity to engage in MT, positively correlated with a personal preference for pure MT learning regimes.

The key finding is that the Mix regime is the most widely used and preferred learning regime for everyday tasks such as driving, which is in contrast with findings from laboratory paradigms (Cassavaugh & Kramer, 2014; Levy et al., 2006; Levy & Pashler, 2008). As mentioned before, the previous research comparing different MT learning regimes mostly compared Mix regimes; therefore, research with comparatively simple tasks has shown that Mix learning regimes are the most efficient regimes to learn MT, the so-called DTPA (Strobach, 2020). The prior evidence showed that mostly people also preferred Mix regimes, which indicates that the basic research and applied research may align.

First, it seems plausible to assume that MT learning should only begin after the learner has at least understood how to perform the single tasks. In basic science, the single tasks are often very simple (e.g., respond with a left-button press if you hear a low-pitched beep and with a right-button press if you hear a high-pitched beep). Even in studies with such basic tasks, participants have a brief practice period where they can familiarise themselves with the tasks and practise each of the tasks. Given the simplicity of the tasks, this practice period often only needs to be a couple of trials or a few minutes long. But strictly speaking, one may consider this already a very basic form of a Mix learning regime: First learn the single tasks until they are mastered to a basic level, and then switch to MT practice. In everyday tasks, such as driving, the single tasks are often considerably more complex, so the familiarisation and initial practice periods to master them to a basic level is profoundly extended, such that it could be construed as a Mix learning regime. For future studies, it would be beneficial to test whether highly difficult component tasks would result in a preference for a Mix learning regime – even when learning basic computerised laboratory tasks.

Unfortunately, I did not acquire information about the exact amount of time and schedule of practising in an ST regime and in an MT regime, for participants who reported having learned in a Mix regime. For some activities, such as driving, it is likely that there is an initial period of extensive ST mode learning (e.g., practicing clutch-gas pedal interplay in a training area), which is followed by predominantly MT mode learning (e.g., driving in traffic). But it cannot be ruled out that, even after MT learning has commenced, people revert to ST mode learning to refine the skills of individual tasks (e.g., practising more clutch-gas interplay). Therefore, it might be the perceived proficiency of the single tasks which determines the point at which the learner should switch to an MT learning regime. Future studies could investigate whether single-task performance is a valid marker for predicting the switch from ST learning to MT learning.

It should be noted that this study has some limitations. As described above one of the limitations of this study is not having specific time periods in which ST and MT practices took place. Additionally, although the instructions were explicit some examples provided by the participants as MT registered as ST or Mix instead. While additional limitations of survey studies apply, such as subjectivity of the self-reports, this study is the first (to my knowledge) to investigate the MT learning experiences and opinions. This study also helped in assessing the current awareness regarding MT activities and the MT learning regimes.

The notion that the difficulty of the single tasks affects the optimal learning regime is supported by these findings. First, participants often justified their preference for a Mix learning regime with the notion that multitasking straight away would have been too difficult. Starting too early with MT learning may be discouraging and frustrating for the learners. Second, more than half of the participants think that the best learning strategy depends on the nature of the tasks. Although this was not explicitly linked to task difficulty, it is plausible to assume that task difficulty is relevant at least to some extent.

Above I described that the optimal learning regime might at least partially depend on the nature of the single tasks. Another factor which may affect the optimal learning strategy is the individual preference to generally engage in MT, i.e., the level of polychronicity. Indeed, the results showed that higher levels of polychronicity, as assessed by the MPI, were linked to a stronger preference for MT learning regimes. Conversely, lower levels of polychronicity were tentatively linked to a stronger preference for ST learning regimes, although this correlation only approached significance ($p = .113$). This is interesting because it could imply interindividual differences which affect the optimal learning strategy. If these differences are known, they could be assessed before learning begins and training could be adjusted accordingly to optimise individual learning progress and outcomes. It is important to point out that I found a link between polychronicity, i.e., a preference to engage in multitasking, and preference for MT learning regimes, and future research is needed to test whether these preferences are important for actual MT learning success.

To expand our understanding of what contributed to the MT learning experience, it is important to evaluate the role of an instructor or teacher. More than half of the participants reported having an instructor, and 82% of these participants were given explicit instructions of how to learn the MT aspects of the activity by their instructors. While we found that most of the participants were satisfied with the approach their instructors used, it is conceivable that approaches to instruct and learn MT activities can still be optimised further.

In line with this, I found that 92% of participants believed that learning an MT activity would benefit from a learning strategy which takes the MT aspects explicitly into account. In combination with the finding that 79% of the participants said they would benefit from generic MT training, I tentatively propose that there is a need for explicit MT training.

For future studies it would be interesting to investigate the nature of the Mix learning regimes in more detail, e.g. how long participants spend in ST and MT training, how often they switch between ST and MT training, and why they switch. Furthermore, it would be interesting to expand the focus of investigated everyday multitasking activities beyond mostly driving. Somewhat related to this, one could investigate whether prior experience in MT learning is transferrable to learning of other MT activities. Finally, it could be informative to target specific occupations with high multitasking demands in their jobs, such as air traffic controllers.

2.5 Conclusion

To conclude, these findings indicate that Mix learning regimes are the most widely used approach among participants. Many participants indicated that they would benefit from MT training, so further investigation regarding the most efficient learning regimes to learn complex everyday activities is warranted. Furthermore, the findings showed that individual characteristics such as polychronicity may influence people's learning preferences.

3 Online MT Learning Study

3.1 Introduction

Learning any new skill may pose a challenge and requires multiple cognitive components, such as motivation, attention, memory, and self-regulation (Wulf & Lewthwaite, 2016). In a vast body of research assessing learning approaches, there are multiple textbooks describing different learning strategies, which include structures offering learners choices of certain aspects of the learning procedure (Clack & Dommett, 2021; Froehlich et al., 2014; Kyndt et al., 2013; Schneider et al., 2018). Although these textbooks provide valid guidance for teachers, and are popular, there is a lack of literature that investigates learning approaches for specifically challenging MT activities.

The benefits of learning MT have been examined by multiple researchers over the last several decades (Bender et al., 2017; Junco, 2012; Ruthruff et al., 2001, 2003; Schumacher et al., 2001; Strobach et al., 2012; Takeuchi et al., 2014). The common findings of the learning MT studies were in line with the DTPA phenomenon, showing that training in MT and Mix regimes resulted in better MT learning outcomes than training in the ST regimes (Karbach & Strobach, 2022; Strobach, 2020). However, these studies examine learning strategies set by the researchers, with little to no flexibility for the trainees to choose their own learning approach.

In these studies, participants were randomly assigned to groups with different training regimes (e.g., ST, Mix), which were pre-determined by the researchers. Specifically, in the training phase of the experiments, experimenters determined the conditions (ST mode, MT mode) and the number of blocks for each group. This approach was used to examine specifically MT learning by assessing MT costs in reaction times and errors. However, for the current study, this approach may not be informative enough regarding participants' preferences and choices in learning approaches.

There is virtually no research evaluating choice of learning regimes in the context of multitasking learning. To the best of my knowledge, the only study assessing the role of choice in multitasking was conducted by Buser & Peter (2012). It is important to note that this study was not a learning study, and no learning effects were reported. Buser & Peter examined how task-switching affects performance by introducing two cognitive tasks. The first task was sudoku (9x9 grid number puzzle) and the second task was to find words in a word search puzzle (17x17 grid). These sudoku and word search tasks were updated for each of the ten sessions (lasting in total for 1 hour 45 minutes) on the same day. For this, 218 participants were divided into three groups: the first group (N=70) performed tasks (for 12 minutes each) separately as an ST group; the second group (N=70) was forced to multitask by switching the tasks every 4 minutes (Forced group); and the third group (N=78) was given the choice to switch between the tasks (Choice group). In the Forced group, participants switched six times (24 min trials, switched approximately every 4 min) without being able to anticipate the switch, whereas the Choice group showed only 2.16 voluntary switches on average. To measure performance, all three groups performed both tasks (sudoku and words) sequentially (ST mode) during round one; whereas in round two each group performed accordingly, as ST, as MT (Forced group) or with a choice.

As expected, participants in the Forced group showed MT costs when switching from task to task as compared to the ST group. The unexpected finding was that the Choice group showed only slightly, non-significantly better performance than the Forced group, indicating that scheduling may impose additional demands during MT performance. This study was not designed to assess learning MT, but mostly to assess choice in switching and gender differences in MT performance. Buser & Peter (2012) reported no observed gender differences in MT performances and concluded that sequential scheduling may be a favourable approach to completing tasks in a high-pressure workplace environment. They suggested that the challenge created by MT may have a stimulating effect on productivity among participants and that the results were not in favour of self-scheduled work. The Choice group performed only slightly better (not significantly) than the Forced group and the ST group performed significantly better than both Forced and Choice groups.

Furthermore, Buser & Peter (2012) proposed an alternative explanation - that the planning and scheduling may have required so much additional effort that this also affected the performance in the Choice group. This was supported by the fact that in the Forced group participants switched six times without being able to anticipate the switch, whereas the Choice group showed only 2.16 voluntary switches on average. Yet, the Choice group showed almost as much MT costs as the Forced group. The authors concluded that, regardless of the interpretation, the data showed that choice might be detrimental to overall MT performance.

There are important divergences between Buser et al.'s study and the current study on the experimental and theoretical levels. The task switching and PRP design are fundamentally different, since in the PRP study, tasks can be performed in parallel, while switching refers to completely switching from one task and shifting focus on a different task. Additionally, when the scheduling demands are discussed in the context of task switching (Koch & Kiesel, 2022b), these are different to the task processing and scheduling in PRP studies (Pieczykolan & Huestegge, 2019). For example, in Buser et al.'s study, participants were keeping the first task information in mind while deciding whether to switch to another task and when potentially to switch back. In this case switching could be considered as "loading" the information of the switched-towards task. Therefore, from a theoretical perspective the scheduling demands in Buser et. al.'s study occurred while participants performed the tasks during the 24-minute trials; while in the current study, the 'scheduling' demand (e.g., deciding whether to switch or stay) occurred in between the blocks (i.e., deciding whether to change the ST mode to MT mode). Therefore, their reporting of costs of switching (comparison of the Forced and Choice groups) is not directly comparable to the reporting of costs in the current study.

As described previously (Chapter 2), the survey study showed that participants preferred learning in different training regimes (with the majority indicating Mix regimes). Additionally, participants reported that learning regimes may depend on the nature of the tasks. This could mean that, for complex demanding tasks, participants may benefit from an option to choose in what regime they would want to learn. It is plausible that for demanding tasks participants may perform poorly in MT mode (and actually may not learn MT at all) if they struggle already with the tasks in ST mode. Such a person could potentially learn MT overall much better if they first started practising the tasks separately in ST mode, until they feel confident to practice these tasks in MT mode.

It should be noted that the ST training would be needed only for very demanding tasks, because the tasks in ST mode would need to have a certain level of difficulty and complexity. If they were very easy to perform (like in virtually all PRP studies), then often the initial familiarisation period, where they practice each task for a few minutes, would probably be sufficient for participants to feel confident that they could do the tasks in ST mode, and could switch to MT mode. However, everyday life is different (such as driving with its various difficult challenges), and when the tasks are much more difficult even in ST mode, this may result in different findings to those suggested by previous studies.

Therefore, I aimed to link the lab-studies with simple PRP tasks on the one hand and real life with complex tasks on the other hand by creating a PRP task which was highly demanding. This included 2 rather difficult tasks. The visual task could potentially be learned rather quickly (visual 4-choice speeded response task with ‘inconsistent’ number-to-finger mapping), but the auditory task was made very difficult (auditory 4-choice speeded response task with inconsistent pitch-to-finger mapping), notably by making the sounds very similar, so that participants had to train their ability to distinguish between the tones.

In this study the main focus is on the role of the choice of training mode (ST, MT or Mix) in learning complex multitasking activities. Specifically, what do people choose if they have a choice when faced with difficult tasks? Will there be any mixture of ST and MT, or will most of the participants always choose pure MT or ST modes? And additionally, how much MT do they actually learn? And if DTPA is true (Strobach, 2020), then should the percentage of overall DT training and MT learning effect correlate positively?

The second part of this research involved the examination of learning MT and a comparison of different regimes. In particular, this research sought to clarify how much MT participants learned, in the context of the DTPA review (Strobach, 2020), which suggested that Mix training (mostly Mix regimes but authors referred to as DT) results in the optimum MT learning as compared to the pure ST regimes. For this I designed the study so that participants could pick from three regimes with pure MT, pure ST modes and a mixture of the two (Mix mode). The participants were divided into two groups: the Choice group with an option to choose the training condition, and the Fixed group with 100% pure MT training blocks. The study sought to observe how MT learning differed between the Choice group and the Fixed group. One possible outcome would be that the learning effects could be significantly different between both groups; for example, if the Choice group mostly trained in the ST modes. Alternatively, there might be equal probabilities that most of the participants in the Choice group would train in the MT mode or Mix mode instead. This would mean that the Choice group would have relatively similar training to the Fixed group, which plays the role of the control group.

Finally, the analysis continues with questions regarding the selection of modes in the Choice group. Specifically, if the above argument is true, that poor performance results in the choice for ST training, and good performance in the choice for MT training, then participants with relatively high error rates will most likely choose the relatively simpler (but still difficult) ST modes over more demanding complex MT modes. Conversely, participants with lower error rates (and therefore good MT performance) will pick more demanding MT modes. Also, some interesting additional conclusions can be reached by examining the Choice group in greater detail; for instance, examining learning effects and choice patterns.

3.2 Methods

3.2.1 Participants

Initially, 118 participants in total were recruited online via Testable Minds and 92 participants completed all 5 sessions (22% drop-out rate). Two participants were excluded based on error rates in all tasks above 90%. Therefore, a total of 90 participants were analysed, 45 female participants (age M=28.0 yrs; SD=4.86 yrs, 18-35 yrs) and 45 male participants (age M=26.9 yrs; SD=4.15 yrs, 18-35 yrs). The study was approved by the College of Health, Medicine and Life Sciences Research Ethics Committee at Brunel University London. Participants gave informed consent and received $25 for participation. To promote motivation, all participants were offered bonus payments for the best multitasking learning <= of up to 30$ in addition to the $25.

After the initial pre-testing, participants were divided into two groups, the so-called Choice group (N=68; M=27.6 years; SD= 4.63) and the so-called Fixed group (N=22; M=27.0 years; SD= 4.27). To rule out gender as a confounding factor the Choice group included 35 male participants (M=27.1 yrs; SD=5.14 yrs) and 33 female participants (M=28.1 yrs; SD=4.02 yrs), while the Fixed group included 10 male participants (M=26.3 yrs; SD=3.70 yrs) and 12 female participants (M=27.6 yrs; SD=4.50 yrs).

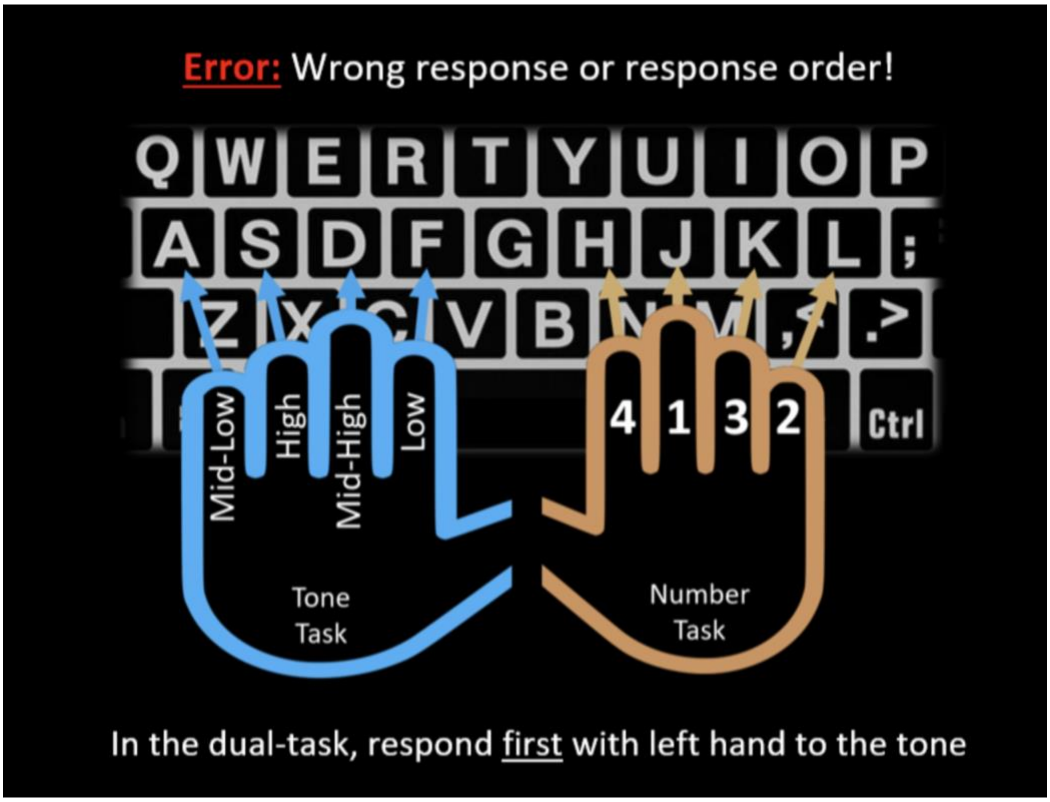
3.2.2 Materials and Procedure

For online data collection, the software PsyToolkit was used (Stoet, 2010, 2017). The online study began with a short questionnaire where participants were asked their age, gender, level of English and handedness. The first session was identical for all participants; after the questionnaire, participants were provided with instructions and practice rounds for each task.

Participants were presented with two tasks, the auditory task and visual task, either in ST mode (performing one task at a time) or in MT mode (performing both tasks at the same time). In the auditory task, participants were presented with 4 tones (mid low 500 Hz, high 600 Hz, mid-high 550 Hz and low 450 Hz, tone duration 250ms) and asked to press keys (A–little finger, S–ring finger, D–middle finger, and F–index finger) with their left hand, respectively. In the visual task participants were presented with numbers 4, 1, 3 and 2 and asked to press keys H, J, K, L (H–index finger, J–middle finger, K–ring finger, and L–little finger) with their right hand respectively. Participants had to respond within 15 seconds before the error picture would be displayed for a duration of 1500ms (Figure 3.1). In MT mode, participants were asked to always first press keys with their left hand in response to the auditory stimulus and then with their right hand in response to the visual stimulus. Responding in the wrong order would result in error feedback. When the task was done correctly, they would receive instant feedback in a form of a “+” on a screen and if they made an error, they would receive an error picture reminding the participant of the stimulus-response mapping.

Figure 3.1

The error image with instructions for both hands.



Because the tasks were designed to be challenging, before the initial pre-testing participants practised tasks with easier versions. While the original tasks had 4 choices in auditory and visual tasks, the simplified task had 2-choices each only. Importantly, in the 2-choice practice the stimulus-response mappings were the same as used in the 4-choice versions, so that they could learn the full version of the task slowly.

In session 1, the computerised experiment consisted of 6 blocks for practice rounds and 15 blocks for initial pre-testing. Specifically, in the auditory block, in the practice round, participants were presented with two tones (low tone 450 Hz and hight tone 600 Hz) and asked to press keys (S-ring finger and F-index finger) with their left hand respectively. And similarly, in the visual block, in the practice round, participants were presented with two numbers (4 and 1) and asked to press keys (H–index finger, J–middle finger) with their right hand respectively. Additionally, there were two practice blocks for MT condition, and the MT block included both auditory and visual tasks with 2 tones and 2 numbers. The next set of practice blocks was with 4 tones and 4 numbers in ST and MT conditions. After the practice rounds, all participants completed the pre-testing phase, which consisted of 15 blocks (Auditory ST mode with 4 tones, Visual ST mode with 4 numbers, MT mode with 4 tones and with 4 numbers) and were randomly divided into two - the Choice and the Fixed groups.

Following the first pre-testing session, the training phase of the experiment consisted of 3 sessions. The Choice group had to choose which conditions they would like to perform next in sets of 2 blocks (10 choices and 20 blocks in total), whereas the Forced group only trained in MT condition for all 20 blocks per session. Participants in the Choice group were offered following choices:

1. Auditory Task (ST) and Auditory Task (ST)
2. Visual Task (ST) and Visual Task (ST)
3. Auditory Task (ST) and Visual Task (ST)
4. Auditory Task (ST) and Dual-Task (MT)
5. Visual Task (ST) and Dual-Task (MT)
6. Dual-Task (MT) and Dual-Task (MT)

The duration of one session ranged from 30 to 45 minutes. Participants were presented with instructions, providing definitions of ST and MT learning modes, and asked to complete five sessions (pre-testing session, three training sessions, and post-testing session) within a period of three weeks maximum. They were not allowed to complete more than one session per day. The fifth and last session was identical for both groups and consisted of the

15 blocks (5 blocks auditory ST, 5 blocks visual ST and 5 blocks MT) like the first session but without the practice rounds. The recorded measures were reaction times (RTs) and error rates in all tasks. To induce some temporal uncertainty about the stimulus presentation times, two SOAs were used, 0ms and 100ms. Note that the difference between SOAs was too short to calculate a meaningful PRP effect, and therefore the effect of the SOA was not analysed.

Noteworthily, all participants were informed about the incentive scheme and the instructions around it. It was crucial to make sure that participants actually wanted to learn multitasking (and not get through the sessions as easily as possible). At the end of the data collection, the 30 participants with the best multitasking learning received bonus payments. The bonuses were 30$ for 1st and 2d places, 25$ for 3d and 4th places, 20$ for 5th and 6th places, 15$ for 7th and 8th places, 10$ for 9th to 15th places and 5$ for 16th to 30th places. For this, the learning effects were calculated to make sure that participants were rewarded for the most progress in MT learning and not the absolute MT performance.

3.3 Results

Raw Scores at the pre- and post-session

In this thesis, the main focus is MT learning; therefore, I will describe the values related to the MT performance, such as reaction times (RTs) and error rates, separately at pre- and post-sessions (Table 3.1). The raw values of the response times (RT1 for Auditory ST, Visual ST, and MT and RT2 for MT) and error rates (Auditory ST, Visual ST, and MT) were analysed at the pre- and post-session. In the MT mode, the auditory task was always presented first, and the visual task was always presented second: consequently, RT1 is always related to auditory task response and RT2 is related to the visual task response. Therefore, the absolute performance values are defined as raw scores produced by the participants.

To check for outliers, the raw values were z-transformed, separately for each group, and outliers were defined as z >= 3 (see Methods for details). The outliers were removed on an analysis-by-analysis basis. In the raw scores, two participants were removed completely from RT2 analysis, because RTs were more than 3SD above the mean.

To analyse whether there was a difference in the performance in both groups, first I conducted independent sample t-tests for each DV. Then, I analysed whether the errors in all tasks were different from 0, or in other words, whether participants made a statistically significant number of errors at the pre- and post-sessions. In all tasks, the same pattern was observed: both Choice and Fixed groups showed comparable error rates which were significantly above 0 at the pre- and post-sessions. Additionally, both groups showed comparable RTs in both, ST and MT conditions.

The overall MT learning pattern is illustrated in Table 3.1 and Figure 3.2. This figure shows the MT learning trajectory of the two groups, where participants in the Choice group (green line) have chosen to train in MT blocks. It is important to note that only the performance in MT blocks is illustrated in the scatterplots and Choice's performance in ST blocks is not reflected. The lines represent the learning progress in Choice and Fixed groups, showing how participants reduced the number of overall errors and RTs after MT training for 3 sessions (out of 5).

Next, I analyse the MT costs of each group, which is the difference of RTs and errors in the performance in MT mode minus the performance in the ST mode. This analysis should show how a free choice to pick a mode (ST, Mix or MT) of training may influence learning multitasking as compared to a purely MT training regime.

Table 3.1

Pre-session and post-session RTs and error rates. For the error rates, one sample t-tests versus 0 are presented, to test whether they had significant error rates within the groups. Right-most column shows independent sample t-tests between the groups.

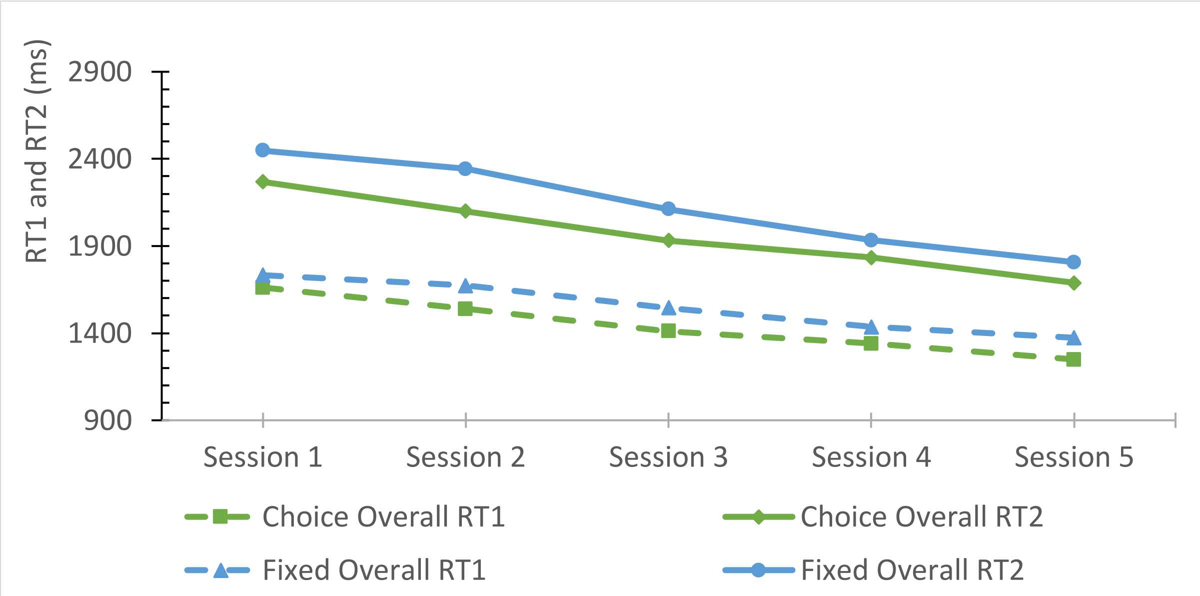
	CHOICE GROUP	**FIXED GROUP**	*t-tests C vs F groups*
	Auditory ST RT		
PRE	M=1125ms, SD=269ms,	M=1197ms, SD=332ms,	t(87)=1.02, p=.308, d=.252
POST	M=972ms, SD=223ms,	M=1050ms, SD=233ms,	t(87)=1.40, p=.164, d=.345
	Visual ST RT		
PRE	M=795ms, SD=177ms,	M=867ms, SD=174ms,	t(86)=1.66, p=.100, d=.410
POST	M=655ms, SD=147ms,	M=695ms, SD=101ms,	t(86)=1.17, p=.246, d=.288

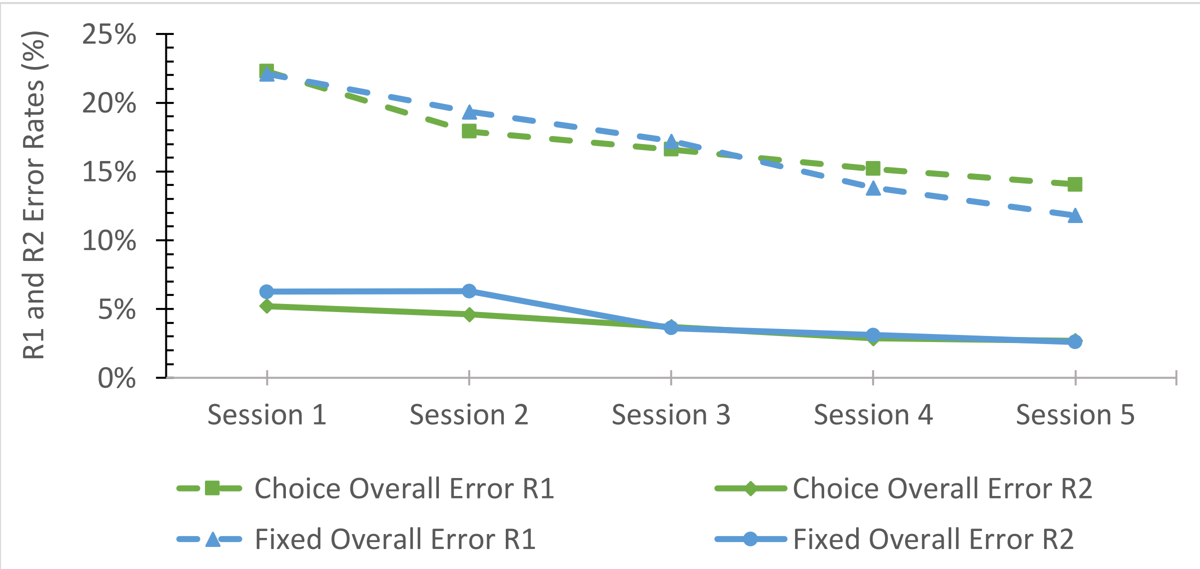
	CHOICE GROUP	**FIXED GROUP**	*t-tests C vs F groups*
		MT RT1	
PRE	M=1653ms, SD=461ms,	M=1732ms, SD=484ms,	t(86)=0.69, p=.490, d=.171
POST	M=1233ms, SD=286ms,	M=1373ms, SD=423ms,	t(86)=1.75, p=.083, d=.432
		MT RT2	
PRE	M=2226ms, SD=527ms,	M=2367ms, SD=597ms,	t(84)=1.03, p=.306, d=.258
POST	M=1645ms, SD=368ms,	M=1734ms, SD=336ms,	t(84)=0.99, p=.327, d=.248
		Auditory ST Error	
PRE	M=24.1%, SD=13.9%, t(66)=14.12, **p<.001,** d=1.725	M=23.0%, SD=12.4%, t(21)=8.68, **p<.001,** d=1.851	t(87)=0.33, p=.745, d=.080
POST	M=16.0%, SD=12.1%, t(66)=10.76, **p<.001**, d=1.315	M=14.7%, SD=10.5%, t(21)=6.56, **p<.001**, d=1.399	t(87)=0.43, p=.666, d=.106
		Visual ST Error	
PRE	M=3.6%, SD=2.05% t(66)=14.20, **p<.001,** d=1.735	M=3.5%, SD=01.92%, t(21)=8.52, **p<.001,** d=1.817	t(86)=0.14, p=.892, d=.033
POST	M=2.5%, SD=1.75% t(66)=11.63, **p<.001**, d=1.421	M=2.4%, SD=01.87%, t(21)=5.97, **p<.001,** d=1.273	t(86)=0.23, p=.820, d=.056
		MT Error R1	
PRE	M=21.8%, SD=13.3% t(65)=13.28, **p<.001,** d=1.635	M=22.1%, SD=12.2%, t(21)=8.47, **p<.001,** d=1.806	t(86)=0.10, p=.923, d=.024
POST	M=12.7%, SD=10.3%, t(64)=9.94, **p<.001,** d=1.233	M=11.8%, SD=10.8%, t(21)=5.14, **p<.001,** d=1.097	t(85)=0.34, p=.733, d=.084
		MT Error R2	
PRE	M=5.1%, SD=4.8% t(65)=8.60, **p<.001,** d=1.058	M=5.8%, SD=5.1%, t(20)=5.22, **p<.001,** d=1.139	t(85)=0.59, p=.558, d=.147
POST	M=2.5%, SD=2.0%, t(65)=10.08, **p<.001,** d=1.241	M=2.1%, SD=1.5%, t(20)=6.67, **p<.001,** d=1.455	t(85)=0.85, p=.400, d=.212

Note that participants were excluded from the analysis based on the z>3; therefore, in the analysis of the Visual ST RT at the pre- and post-sessions, one participant from the Choice group was excluded. In the analysis of the MT RT2 at the pre- and post-sessions, one participant from the Fixed group and two participants from the Choice group were excluded.

Figure 3.2

Raw scores of MT learning process in Overall RT1, RT2 (top panel) and Overall R1, R2 (bottom panel) presented throughout all 5 sessions. The overall RTs is the averaged values of responses with SOA of 0ms and SOA of 100ms. For the Choice group, this figure only shows data from the MT mode performances.





Costs at the pre- and post-sessions

The RT1 costs were calculated by subtracting the Auditory ST RT from the dual-task RT1, because in the MT condition the order was always Auditory Task first and Visual Task second. Respectively, the RT2 costs were calculated by subtracting the Visual ST RT from the dual-task RT2. The error costs were calculated in the same way; for example, the R1 error costs were calculated by subtracting the Auditory ST errors from the dual-task R1 errors. To simplify data presentation, the MT Error Costs were calculated by subtracting averaged auditory and visual tasks error rates from averaged MT R1 and R2 error rates (plus wrong order errors) (Table 3.2, Figure 3.3).

For the outlier analysis of the MT costs at the pre- and post-sessions, the results were z-transformed, separately for each group, and outliers were defined as $z >= 3$ (see Methods for details). The outliers were removed on an analysis-by-analysis basis. In the costs analyses, five people were removed from different DVs (4 participants in the Choice group and 1 participant in the Fixed group).

Table 3.2

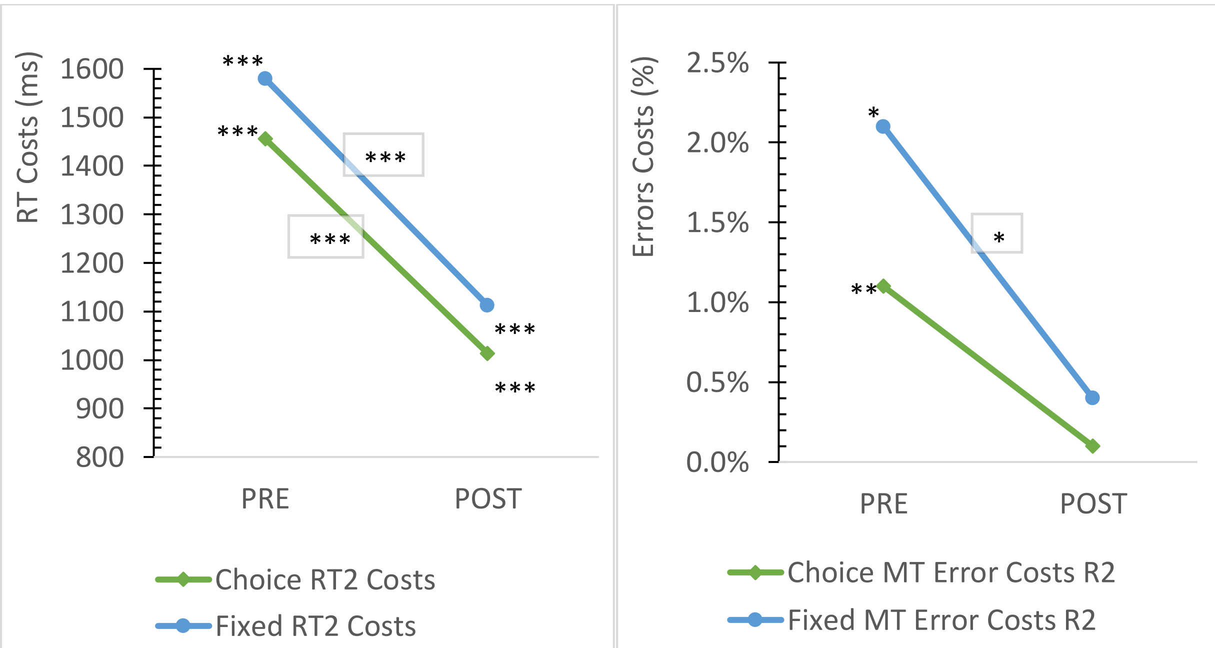
Pre-session and Post-session Costs, One Sample t-tests versus 0 within the groups and Independent Sample t-tests between the groups

	CHOICE GROUP	FIXED GROUP	*t-tests C vs F groups*
	RT1 Costs		
PRE	M=519ms, SD=279ms, t(65)=15.11, **p<.001,** d=1.860	M=536ms, SD=275ms, t(21)=9.15, **p<.001,** d=1.951	t(86)=0.25, p=.806, d=.061
POST	M=287ms, SD=144ms, t(64)=15.99, **p<.001,** d=1.984	M=280ms, SD=173ms, t(20)=7.40, **p<.001,** d=1.614	t(84)=0.17, p=.865, d=.043
	RT2 Costs		
PRE	M=1456ms, SD=447ms, t(66)=26.68, **p<.001,** d=3.259	M=1580ms, SD=548ms, t(21)=13.53, **p<.001,** d=2.884	t(87)=1.07, p=.289, d=.262
POST	M=1000ms, SD=280ms, t(65)=29.03, **p<.001,** d=3.574	M=1047ms, SD=263ms, t(20)=18.24, **p<.001,** d=3.981	t(85)=0.68, p=.499, d=.170
	R1 Error Costs		
PRE	M=-1.8%, SD=5.7% t(66)=2.56, **p=.013,** d=.313	M=-0.9%, SD=6.1% t(21)=0.67, p=.509, d=.143	t(87)=0.64, p=.525, d=.157
POST	M=-2.1%, SD=3.9% t(65)=5.00, **p<.001,** d=.615	M=-2.9%, SD=4.6% t(21)=2.97, **p=.007,** d=.632	t(86)=0.84, p=.401, d=.208
	R2 Error Costs		
PRE	M=1.1%, SD=3.7% t(64)=2.39, **p=.020,** d=.296	M=2.1%, SD=3.5% t(20)=2.74, **p=.006,** d=.597	t(84)=1.04, p=.303, d=.260
POST	M=0.1%, SD=2.0% t(65)=0.29, p=.775, d=.035	M=0.4%, SD=2.5% t(20)=0.68, p=.507, d=.147	t(85)=0.54, p=.591, d=.134
	MT Error Costs %		
PRE	M=11.4%, SD=8.7% t(66)=10.72, **p<.001,** d=1.310	M=12.5%, SD=8% t(21)=7.33, **p<.001,** d=1.563	t(87)=0.53, p=.596, d=.131
POST	M=4.8%, SD=8% t(66)=4.87, **p<.001,** d=.594	M=7.4%, SD=6% t(21)=5.82, **p<.001,** d=1.240	t(87)=1.42, p=.159, d=.349

Note that the R1 Error Costs are related to RT1 Costs and R2 Error Costs are related to RT2 Costs. The MT Error Costs are calculated by subtracting averaged Auditory and Visual error rates from MT error rates (which include additional errors such as wrong order of response) separately at pre- and post-sessions. Therefore, negative costs indicate that participants had more errors in the ST condition than in MT condition.

Figure 3.3

RT2 Costs and DT Costs Errors R2 presented in pre- and post-sessions. The asterisks (*<0.5; **<0.01; ***<0.001) at the ends of the lines show costs significantly different from 0., whereas the asterisk symbols in the box on the line show the significant difference of the costs between the pre- and post-sessions, respectively.



First, I have analysed the differences in the RT1 Costs and then separately in RT2-Costs (the Auditory Task and Visual Task, respectively) between the Choice and the Fixed groups. I calculated two 2 x 2 mixed ANOVAs (Table 3.3) with the within-subject factors

Time (Pre, Post) and the between-subject factor Group (Choice, Fixed). This analysis should help understand whether there was a difference between pre-session and post-session training as well as between the Choice and Fixed groups; and, whether the effect of training (pre- vs post-session) is different for Choice and Fixed groups.

Table 3.3

Pre-session and post-session RT1 and RT2 costs, 2x2 mixed ANOVA for all groups for RT1 and RT2, and one-way ANOVAs with factor time (pre- vs post-session).

RT1 Costs/ N	85	64	21
	All Groups	**CHOICE Group**	**FIXED Group**
Time (Pre, Post)	$F(1, 83)=119.16$, $\mathbf{p<.001}$, $\eta^2=.439$	$F(1, 61)=56.85$, $\mathbf{p<.001}$, $\eta^2=.474$	$F(1, 20)=40.20$, $\mathbf{p<.001}$, $\eta^2=.668$
Group (Choice, Fixed)	$F(1, 83)=0.002$, $p=.965$, $\eta^2=.000$		
Time * Group	$F(1, 83)=0.001$, $p=.970$, $\eta^2=.000$		
RT2 Costs/ N	87	66	21
Time (Pre, Post)	$F(1, 85)=137.91$, $\mathbf{p<.001}$, $\eta^2=.592$	$F(1, 65)=135.69$, $\mathbf{p<.001}$, $\eta^2=.676$	$F(1, 20)=48.05$, $\mathbf{p<.001}$, $\eta^2=.706$
Group (Choice, Fixed)	$F(1, 85)=0.463$, $p=.498$, $\eta^2=.005$		
Time * Group	$F(1, 85)=0.080$, $p=.778$, $\eta^2=.619$		

In the RT1-Costs, averaged across groups, performance was significantly better at post-session as compared to pre-session (main effect of time, $F(1, 83)=119.16$, $p<.001$, $\eta^2=.439$). The main effect of Group was not significant ($F(1, 83)=0.002$, $p=.965$, $\eta^2=.000$); nor was the interaction between Time and Group ($F(1, 83)=0.001$, $p=.970$, $\eta^2=.000$).

Therefore, with respect to RT1 costs, Choice and Fixed did not differ in the amount of MT learning.

In greater detail, before the training took place, at the pre-session, both Fixed and Choice groups showed significant RT1 costs, which did not differ significantly between each other (Table 3.2). At the post-session both groups showed a significant reduction in RT1 Costs in the auditory task; however, there was no significant difference between the groups. The reduction of RT1 Costs in the Fixed group (from 536ms at the pre-session to 280ms at the post-session a significant reduction of on average of 256ms, paired sample t-test, $t(20)=4.41$; $p<.001$; $d=.961$) was numerically higher by 24ms ($t(87)=0.72$; $p=.474$; $d=.177$, independent sample Choice vs Fixed) than in the Choice group (from 519ms at pre- to 287ms at post-session a significant reduction of on average of 232ms, paired sample t-test, $t(63)=5.76$; $p<.001$; $d=.720$). This means that after the training, both Fixed and Choice groups had a statistically significant reduction in RT1 costs; there was no statistically significant differences between the learning effects of the Fixed group and the Choice group.

For the RT2 costs averaged across groups, performance was also significantly better at post-session as compared to pre-session (main effect of time, $F(1, 85)=137.91$, $p<.001$, $\eta^2=.592$). The main effect of Group ($F(1, 85)=0.463$, $p=.498$, $\eta^2=.005$) and the interaction between Time and Group ($F(1, 85)=0.080$, $p=.778$, $\eta^2=.619$) were not significant.

At the pre-session, both Fixed and Choice groups showed significant RT2 Costs, which did not differ significantly from each other (Table 3.2, Figure 3.3). At the post-session, both groups showed a significant reduction in RT2 Costs in the visual task; however, there was no significant difference between the groups. The reduction of RT2 Costs in the Fixed group (from 1580ms at the pre-session to 1047ms at the post-session a significant reduction of on average of 553ms, paired sample t-test $t(20)=6.93$, $p<.001$, $d=1.513$) was numerically higher by 97ms ($t(83)=0.43$, $p=.666$, $d=.109$, two-sample t-test) than in the Choice group (from 1456ms at pre- to 1000ms at post-session a significant reduction of on average of 456ms, paired sample t-test $t(65)=11.65$, $p<.001$, $d=1.434$). This means that after the training both Fixed and Choice groups had a comparable statistically significant reduction in RT2 Costs.

Next, the R1 and R2 error costs were analysed in the same way as RT1 and RT2 Costs (Table 3.3.1). It should be remembered that the R1 and R2 error costs were calculated by subtracting Auditory ST errors from the dual-task R1 errors and Visual ST errors from the dual-task R2 errors; therefore, negative costs indicate that participants had more errors in the ST condition than in the MT condition. In the R1 error costs averaged across groups, performance was not significantly better at post-session as compared to pre-session (main effect of time, $F(1, 86)=1.99$, $p=.161$, $\eta^2=.023$). The main effect of Group was not significant ($F(1, 86)=0.005$, $p=.944$, $\eta^2<.001$) as well as the interaction Time and Group ($F(1, 86)=1.003$, $p=.319$, $\eta^2=.012$).

Table 3.3.1

Pre- and Post-session MT R1 and R2 error costs, between subjects and within subject ANOVA.

Error R1 Costs/N	88	66	22
	All Groups	**CHOICE Group**	**FIXED Group**
Time(Pre, Post)	$F(1, 86)=1.99$, $p=.161$, $\eta^2=.023$	$F(1, 65)=0.16$, $p=.693$, $\eta^2=.002$	$F(1, 21)=2.50$, $p=.129$, $\eta^2=.106$
Group (Choice, Fixed)	$F(1, 86)=0.005$, $p=.944$, $\eta^2<.001$		
Time * Group	$F(1, 86)=1.003$, $p=.319$, $\eta^2=.012$		
Error R2 Costs/N	84	64	20
Time(Pre, Post)	$F(1, 82)=7.00$, $\mathbf{p=.010}$, $\eta^2=.079$	$F(1, 63)=3.86$, $p=.054$, $\eta^2=.058$	$F(1, 19)= 5.13$, $\mathbf{p=.035}$, $\eta^2=.213$
Group (Choice, Fixed)	$F(1, 82)=1.04$, $p=.311$, $\eta^2=.013$		
Time * Group	$F(1, 82)=0.41$, $p=.524$, $\eta^2=.005$		

Before the training took place, at the pre-session both Fixed and Choice groups showed significant R1 error costs, which did not differ significantly between each other (Table 3.2.2). At the post-session, both groups showed a non-significant reduction in R1 error costs in the auditory MT task; however, there was no significant difference between the groups. The reduction of R1 error costs in the Fixed group (from -0.9% at the pre-session to -2.9% at the post-session a non-significant change of on average of -2% error costs, paired sample t-test $t(21)=1.58$, $p=.129$, $d=.337$) was numerically higher by 1.7% ($t(87)=1.36$, $p=.178$, $d=.333$) than in the Choice group (from -1.8% at pre- to -2.1% at post-session a significant change of on average of -0.3 error costs, paired sample t-test $t(65)=0.40$, $p=.693$, $d=.049$). This means that after the training both Fixed and Choice groups had a non-significant comparable change in R1 error costs, meaning that the Fixed group was as accurate as the Choice group ($t(87)=1.36$; $p=.178$; $d=.333$) after the training.

In the R2 error costs averaged across groups, performance was significantly better at post-session as compared to pre-session (main effect of time, $F(1, 82)=7.00$, $p=.010$, $\eta^2=.079$). The main effect of Group was not significant ($F(1, 82)=1.04$, $p=.311$, $\eta^2=.013$) as well as the interaction Time and Group ($F(1, 82)=0.41$, $p=.524$, $\eta^2=.005$).

At the pre-session, both Fixed and Choice groups showed significant R2 error costs, which did not differ significantly between each other (Table 3.2, Figure 3.3). At the post-session, both groups showed a non-significant reduction in R2 error costs in the visual task; however, there was no significant difference between the groups. The reduction in the Fixed group (from 2.1% at pre- to 0.4% at post-session reduction of on average of 1.7% error costs, paired sample t-test pre vs post, $t(19)=2.27$; $p=.035$, $d=.507$) was marginally higher than in the Choice group (from 1.6% at pre- to 0.2% at post-session a reduction of on average of 1.4% error costs, paired sample t-test pre vs post, $t(63)=2.36$; $p=.054$, $d=.246$). This shows that, although only Fixed group showed a significant reduction in R2 error costs after the training, both groups had comparable costs reduction. However, the Choice group has almost reached the floor effect (at post-session 0.2% R2 error costs) which means they could not improve any further.

Finally, the MT error costs (calculated MT errors minus averaged Auditory and Visual tasks errors) produced by the Choice and the Fixed groups were significant at the pre-session and there was no significant difference between the groups (Table 3.2). Similarly, at the post-session participants in both groups also produced significant numbers of errors, which did not differ significantly between the groups. The MT error costs averaged across groups, performance was significantly better at post-session as compared to pre-session

(Table 3.3.2, main effect of time, $F(1, 87)=42.79$, $p<.001$, $\eta^2=.330$). The main effect of Group was not significant ($F(1, 87)=0.015$, $p=.903$, $\eta^2<.001$) as well as the interaction Time and Group ($F(1, 87)=2.02$, $p=.159$, $\eta^2=.023$). This shows that although there was a significant effect of time from pre- to post-session, both groups achieved similar reductions of MT costs.

Table 3.3.2

Pre- and Post-session MT error costs, between subjects and within subject ANOVA.

MT Error Costs/N	89	67	22
	All Groups	**CHOICE Group**	**FIXED Group**
Time (Pre, Post)	$F(1, 87)=42.79$, **$p<.001$**, $\eta^2=.330$	$F(1, 66)=23.68$, **$p<.001$**, $\eta^2=.264$	$F(1, 21)=33.83$, **$p<.001$,** $\eta^2=.617$
Group (Choice, Fixed)	$F(1, 87)=0.015$, $p=.903$, $\eta^2<.001$		
Time * Group	$F(1, 87)=2.02$, $p=.159$, $\eta^2=.023$		

Note that the R1 Error Costs are related to RT1 Costs and R2 Error Costs are related to RT2 Costs. The MT Error Costs are calculated by subtracting averaged Auditory and Visual error rates from MT error rates (which include additional errors such as wrong order of response) separately at pre- and post-sessions.

The reduction in MT error costs in the Choice group (from 11.4% at pre- to 4.8% at post-session a reduction of on average of 6.6% MT error costs, paired sample t-test pre vs post $t(66)=7.15$; $p<.001$, $d=.874$) was numerically higher than in the Fixed group ($t(87)=1.42$, $p=.159$, $d=.349$, in Fixed group the reduction of costs from 12.5% at pre- to 7.4% at post-session of on average of 5.1% MT errors costs, paired sample t-test pre vs post $t(21)=3.58$;

p<.001, d=.764). This shows that after the training both Choice and Fixed groups had a significant reduction in MT error costs.

Learning Effects

The learning effect is a central aim of this study and is analysed in detail. As mentioned previously, the learning effect is the difference of the MT costs from the pre- to post-session. The first question of this study was to assess whether the number of blocks the participants spent in MT-training (expressed in % of all blocks) would show a correlation with the learning effect. Secondly, exploring whether the participants in the Choice group with varied overall MT training percentage would show any interesting behaviour in learning MT activity, since the choice group involved more participants by the design and the Fixed group was a control group with 100% MT regime. The interest also lies in the possible patterns in the choices made by the participants, and whether there are any possible indicators which could be correlating with the decision-making process in the choice of training.

For this, I calculated, separately for each group, the *learning effects* (Table 3.4, Figure 3.4), which is the MT costs in the pre-session minus the MT costs in the post-session. This analysis is based on the previous analysis (see section Costs at pre- and post-sessions), and the MT costs are the RTs and error rates in the MT mode minus the error rates in the ST mode. Therefore, larger learning effects reflect a stronger reduction in MT costs from the pre- to the post-session. This allows targeting specifically the MT learning, because learning in ST would not be captured by this, and also allows evaluation of the results of the two learning regimes in more detail.

The learning effect is key to this analysis, and before calculating the statistical tests, I first checked the data for outliers. For this, the learning effect values were z-transformed, separate for each group, and outliers were defined as z >= 3 (see Methods for details). The outliers were removed on an analysis-by-analysis basis. In the learning effects analysis, eight participants were removed from the Choice group and one participant from the Fixed group.

Table 3.4

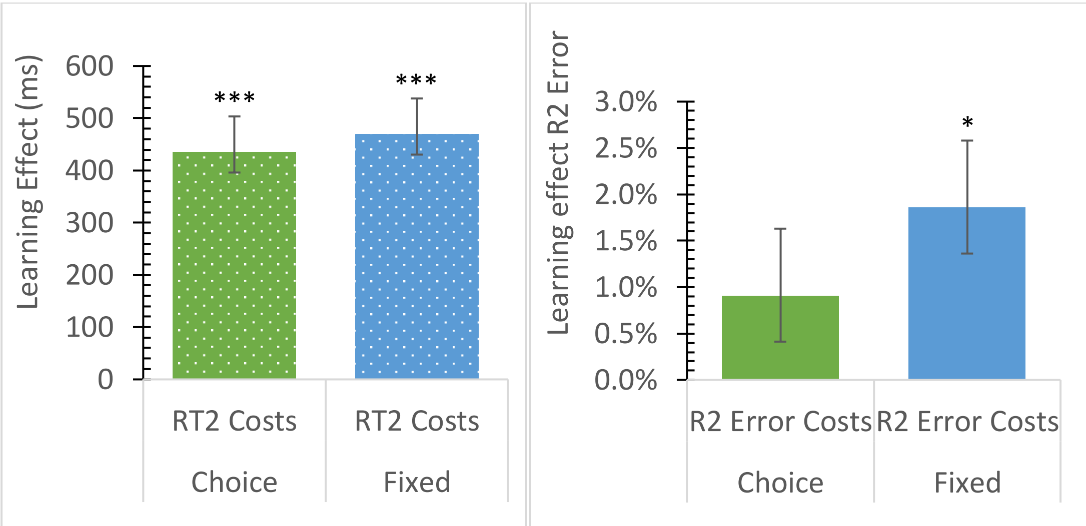
Learning effects in MT Costs, calculated as pre-costs minus post-costs in RT1, RT2 and error R1, R2. One sample t-tests vs 0

CHOICE GROUP	**FIXED GROUP**	*t-tests C vs F groups*
	RT1 Costs	
M=260ms, SD=283ms, t(66)=7.53, **p<.001**, d=.919	M=213ms, SD=216ms, t(21)=4.62, **p<.001**, d=.986	t(87)=0.72, p=.474, d=.177
	RT2 Costs	
M=436ms, SD=317ms, t(63)=11.00, **p<.001**, d=1.375	M=467ms, SD=311ms, t(20)=6.93, **p<.001**, d=1.513	t(83)=0.43, p=.666, d=.109
	MT R1 Error Costs	
M=3.6%, SD=6.1%, t(66)=4.75, **p<.001**, d=.581	M=5.7%, SD=7.1%, t(21)=3.76, **p<.001**, d=.802	t(87)=1.36, p=.178, d=.333
	MT R2 Error Costs	
M=0.9%, SD=4.0%, t(64)=1.83, p=.072, d=.227	M=1.9%, SD=3.3%, t(20)=2.58, **p=.018**, d=.563	t(84)=0.98, p=.329, d=.246
	MT Error Costs	
M=4.8%, SD=8.0% t(66)=4.87, **p<.001,** d=.594	M=7.4%, SD=6.0% t(21)=5.82, **p<.001,** d=1.240	t(87)=1.42, p=.159, d=.349

Note. MT learning effect is calculated by subtracting averaged Auditory and Visual error rates from MT error rates separately at pre- and post-sessions, then the MT error costs at post-session subtracted from MT Error Costs at pre-session. Therefore, a higher number represents a higher learning effect.

Figure 3.4

Learning Effect in RT2 Costs and MT Costs in R2 Error presented in bars for Choice and Fixed groups. The asterisk symbols (*<0.05; ***<0.001) at the top of a bar chart show the significance of the learning effect, i.e., significant difference of the MT costs between the pre-session and post-session. The error bars denote SEM.



Since RT2 and Error R2 costs are the most sensitive and show MT learning best, these two aspects are addressed more closely. The learning effect in RT2 costs was analysed separately for the Fixed and Choice groups. The Fixed group reduced the RT2 costs from pre-session to post-session on average by 467ms, and this MT learning effect was significantly larger than 0 (one-sample t-test vs 0, $t(20)=6.93$, $p<.001$, $d=1.513$). The Choice group reduced the RT2 costs from pre-session to post-session by on average 442ms, and this MT learning effect was also significantly different from 0 (one-sample t-test vs 0, $t(63)=11.00$, $p<.001$, $d=1.375$). Although the Fixed group achieved a numerically higher learning effect by 25ms, an independent sample t-test showed no significant difference between the groups ($t(83)=0.43$, $p=.666$, $d=.109$). This means, both groups achieved comparable learning effects in RT2 costs for the second task (which was always the visual task).

The learning effect in R2 error costs just failed to reach significance in the Choice group (t(64)=1.83, p=.072, d=.227, Table 3.4, Figure 3.4) but it was significant in the Fixed group (t(20)=2.58, p=.018, d=.563). However the two groups did not differ significantly (t(83)=1.134, p=.260, d=.290). Thus, the two groups showed comparable learning effects in R2 error rates.

The learning effect in the RT1-costs was significant in both Fixed and Choice groups (Table 3). An independent sample t-test showed no significance difference between the groups (t(87)=0.72, p=.474, d=.177). This means that the learning effect in reaction time (RT1 costs) for the first task (which was always the auditory task) was also comparable between the groups. A similar pattern was observed in auditory task R1 error rates, which were also comparable between the groups.

Usually, the previous (PRP) literature suggests that in the dual task condition the R2 response and RT2 is prolonged and has more errors as compared to R1 response and RT1 (Otermans et al., 2022). In line with that, in the Choice group, the RT2-costs learning effect (M=436ms) was significantly higher (by 166ms) than in the RT1-costs learning effect (M=270ms, paired sample t-test, t(63)=5.76, p<.001, d=.720). Similarly, in the Fixed group, the learning effect in the RT2 costs (M=470ms) was significantly higher (by 229ms) than in the RT1-costs learning effect (M=241ms, paired sample t-test, t(20)=4.41, p<.001, d=.961). The significant difference between the learning effects in RT1costs and RT2 costs may indicate that, during the training, the participant learns processing such as bottleneck scheduling and coordination, which mostly affects RT2. In other words, since the RT2 costs reflect MT performance, the reduction of RT2 costs evidently demonstrated MT learning.

Learning Effects in Auditory Task and Visual Task in ST mode

In this section, I will briefly present the learning effects in RTs and error rates separately for the auditory and visual single tasks (ST) (Table 3.5). As expected, in both tasks, and for RTs and error rates, the same pattern was observed. Specifically, participants showed statistically significant learning effects (i.e., improved their performance) from the pre- to the post-session, and the size of the learning effects never significantly differed between the two groups. This means that although numerically there are some differences, statistically the two groups had comparable learning outcomes in ST mode.

Table 3.5

Learning effects in Auditory and Visual Tasks in ST mode, calculated as pre-costs minus post-costs RT and error values. Thus, the higher the number, the higher the learning effect. One sample t-tests reflect whether the learning effect is significantly different from 0.

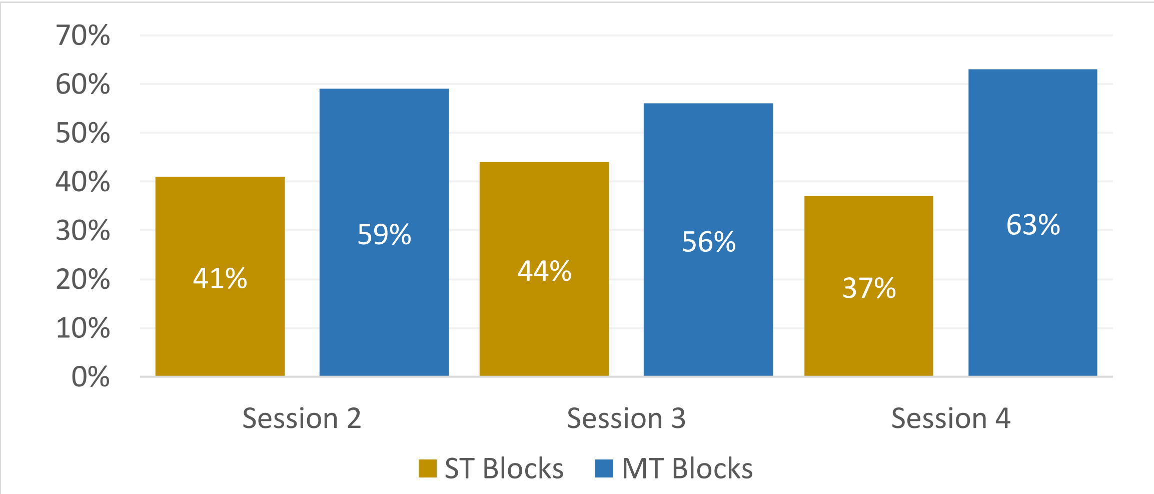
CHOICE GROUP	**FIXED GROUP**	*t-tests C vs F groups*
	Audio ST RT	
M=152ms, SD=183ms, t(66)=6.80, **p<.001**, d=.831	M=146ms, SD=184ms, t(21)=3.74, **p=.001**, d=.797	t(87)=0.13, p=.896, d=.032
	Visual ST RT	
M=137ms, SD=142ms t(66)=7.92; **p<.001**; d=.967	M=172ms, SD=146ms, t(21)=5.54; **p<.001**, d=1.182	t(87)=0.99, p=.323, d=.244
	Audio ST Error	
M=8.1%, SD=10.2% t(66)=6.47, **p<.001**, d=.790	M=8.3%, SD=7.5% t(21)=5.19, **p<.001**, d=1.107	t(87)=0.07, p=.946, d=.017
	Visual ST Error	
M=1.1%, SD=2.3% t(66)=3.86, **p<.001**, d=.472	M=1.1%, SD=2.0% t(20)=2.59, **p=.017**, d=.552	t(87)=0.06, p=.953, d=.015

The correlation between the MT Training Percentages and the Learning Effect in RT2 Costs

As mentioned previously, the Choice group had an option to pick the ST or MT condition in which they could train the MT activity (Figure 3.5). The number of MT blocks were averaged across the three training sessions and transformed into percentages for illustration purposes. In this instance, when discussion a group of participants which trained 20-40% in the MT mode also means that this group trained for 80-60% in the ST mode. This analysis was performed to find out whether there is a significant connection between the pure MT training and the size of the learning effect: this connection would be direct evidence of the DTPA phenomenon illustrated in learning complex MT activity. In this section, I will describe the correlation analysis between the learning (in RT2 costs and R2 error costs) and the percentage of the MT training (Figure 3.6). It should be noted that while the Fixed group had 100% MT training, participants from the Choice group chose on average 59% MT training. In this scatterplot the Fixed group was presented only for comparison; the blue dots were added artificially for visual representation.

Figure 3.5

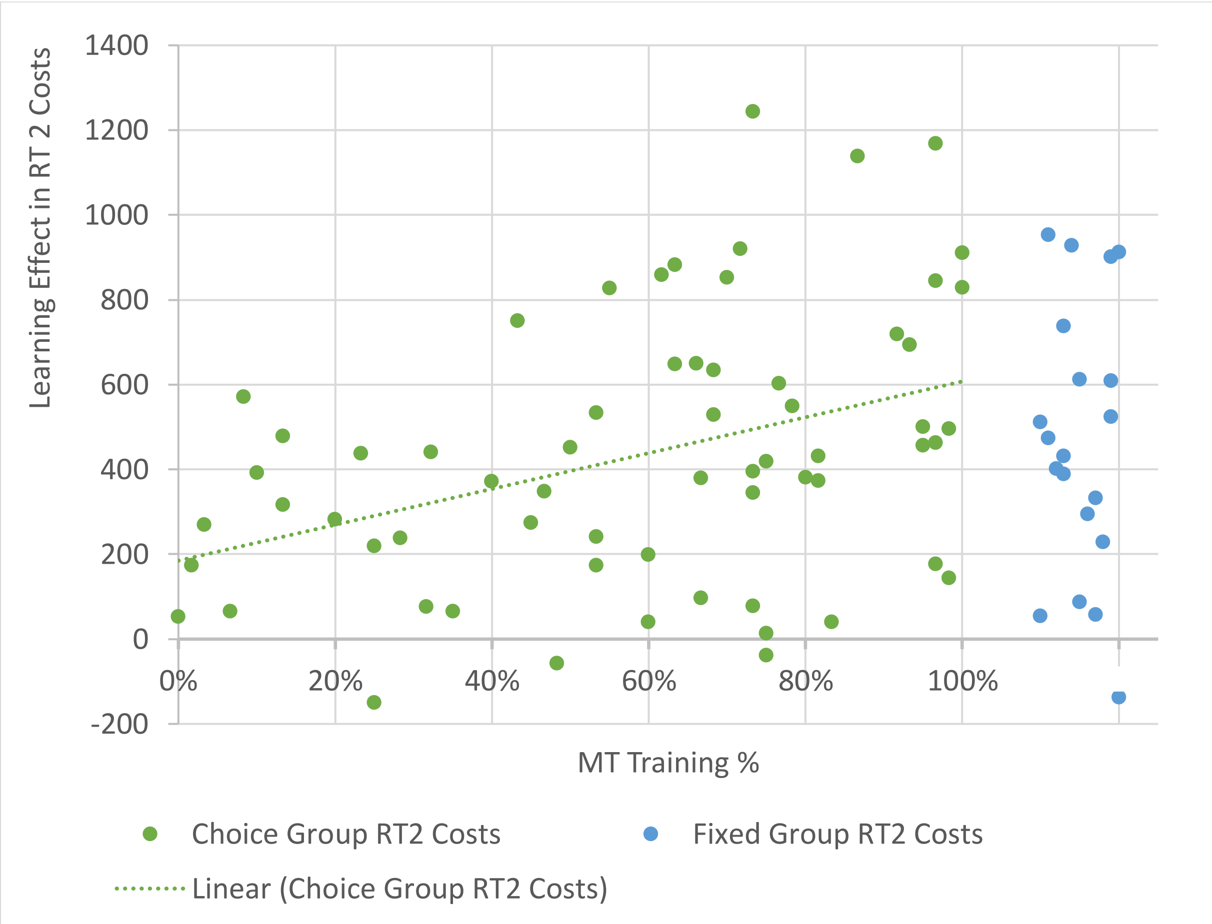
The MT and ST blocks in three training sessions in the Choice group were converted into percentages. On average, participants in the Choice group chose 59.3% of MT blocks.



A positive correlation (r = .31; p =.012; N = 64) was found between the percentages of the MT training (across all 3 sessions) and the learning effect in RT2 costs of the Choice group (Figure 5). This suggests a link between the time spent in MT training and the MT learning effect. Interestingly, while there was a significant positive correlation between the MT training and RT2 costs learning effects, the Fixed group and the Choice group did not differ significantly in their overall MT learning. Noteworthily, these results show that participants in the Choice group overall learned MT as well as the Fixed group, although the Choice group had on average only 59% MT training compared to the 100% in the Fixed group.

Figure 3.6

The scatterplot demonstrating the correlation between the amount of MT Training in percent of blocks and the Learning Effect in RT2 Costs for Choice group (N=64) and Fixed group (N=20). Dotted line is the line of best fit for the Choice group. All the participants in the Fixed group had 100% DT Training; for better visualisation, the Fixed group data points were separated from the Choice group and scattered artificially.



Additionally, Figure 5 demonstrates that in the Choice group there was not a single person among participants with learning effects above 600ms in the range of participants who only completed less than 40% of MT training; while some participants with MT training below 20% also showed notable RT2 learning effects in comparison to the Fixed group with 100% DT training. This is noteworthy because this indicates that additional factors may influence the MT learning process besides the sheer number of trials or training hours in pure MT mode.

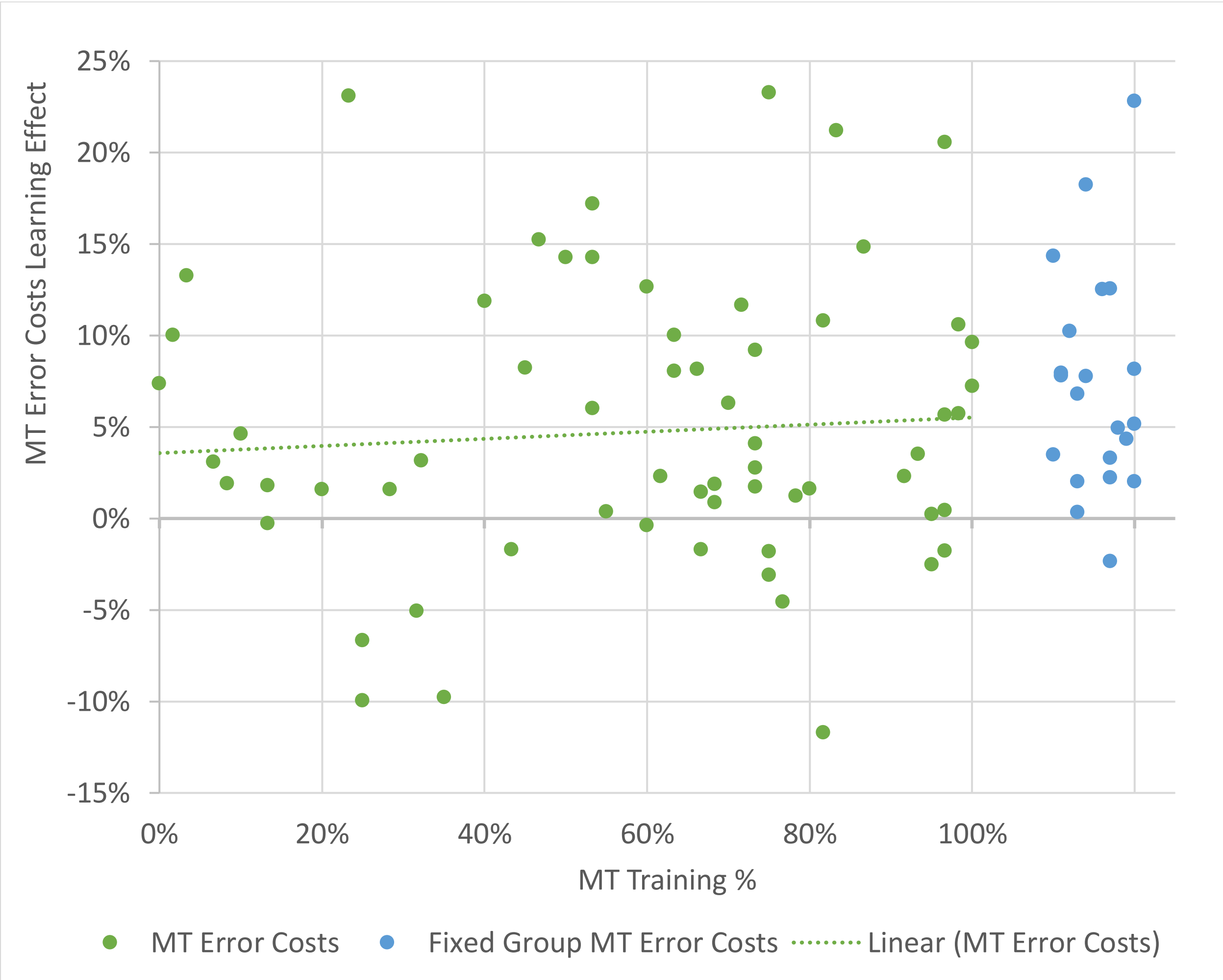
Notably, the Figure 5 showed that some participants with relatively high percentage of MT training (>60%) had relatively little learning (<200ms) in RT2. One possible explanation to this could be that they showed already small costs in the beginning at pre-session and, thus, could not reduce their MT costs anymore (floor effect). To test for this possibility, first I selected the two subgroups from the choice group participants with MT training of 60% to 100%, into the subgroup CH<200 (N=9) with learning effects below 200ms in RT2 costs, and the subgroup CH>200 (N=21) with learning effects above 200ms in RT2 costs. The CH<200 group showed MT costs in RT2 of on average M=1125ms at pre-session and M=1057ms at post-session. The CH>200 showed MT costs in RT2 of on average M=1655ms at pre-session and M=1025ms at post-session. The paired sample t-tests showed that from pre-session to post-session there was a significant reduction in RT2 costs in the CH>200 group (t(20)=12.11, p<.001, d=2.643) and in the CH<200 group (t(8)=3.11, p=.007, d=1.038). As expected both groups had a significant reduction in RT2 costs, and the learning effect in CH>200 group (M=629ms, SD=238) was significantly larger than the learning effect in CH<200 group (M=67ms, SD=65, t(28)=6.90, p<.001, independent sample t-test). This analysis was done to examine the performances at the pre- and post-sessions to exclude effects such as floor effect.

Then, I analysed the performance of the two subgroups separately at pre- and post-sessions. At the pre-session in the CH>200 group the RT2 costs (M=1655ms, SD=442) were significantly larger than in the CH<200 group (M=1125ms, SD=406, independent sample t-test, t(28)=3.08, p=.005, d=1.226). However, at the post-session there was no significant difference between the CH>200 (M=1025ms, SD=289) and CH<200 groups (M=1057ms, SD=403, independent t-test, t(28)=0.24, p=.810, d=.097). This analysis showed that at least some of the 9 participants in the 60-100% MT training and less than 200ms (Figure 4) had already shown lower costs at the pre-session, which could indicate that these participants (or most of them) already had a better performance at the beginning and couldn't achieve as much progress as the CH>200 subgroup. Having said that, they still showed costs of above 1000ms which showed potential for further improvement.

A similar correlation of MT% with the MT error costs was not significant (*r* =0.083; p=.439). The learning effect in MT error costs showed numercially the same trend, i.e., the more MT practice the more learning, which was not significant (Figure 3.7).

Figure 3.7

The scatter plot demonstrating the correlation between the amount of MT Training in percent of all blocks and the Learning Effect in MT Error Costs for Choice and Fixed groups. The dotted line represents the line of best fit. All the participants in the Fixed group had 100% DT Training. For better visualisation the Fixed group data points were scattered artificially.



Overall, this correlation analysis indicates that having a choice in which mode (ST or MT) they learned, the demanding MT might not have a strong effect on the overall MT learning success, even if that meant spending time on practising the tasks in ST mode.

High and Low Achievers in the Choice group and in the Fixed group

For illustration purposes, I have divided each group by the range of learning effects (LE) achieved in RT2. The low achievers were participants with an LE of below 200ms; in the middle range (middle achievers), from 200ms to 600ms; and high achievers with learning effects above 600ms. The range of learning effects to assign the "achievers" was made on a rough estimate that everything above approximately half a second (i.e., 600ms) is considered as high improvement, whereas anything below 0.2 of a second is considered as low improvement. This analysis was done for illustration purposes, and there might be alternative ways of splitting the Choice group. While the average MT training percentages varied in the Choice group (Table 3.6, Figure 3.8), all participants in the Fixed group had 100% of MT training.

Table 3.6

The participants in each group were divided by learning effects in RT2 Costs.

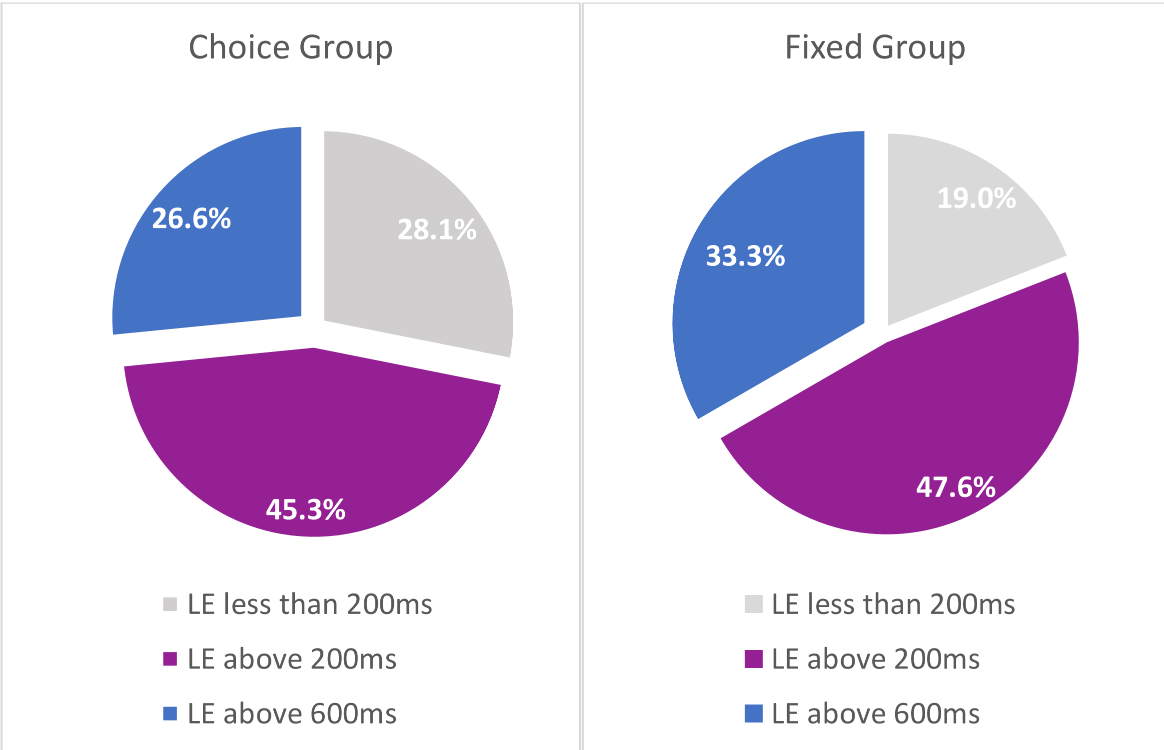
	CHOICE GROUP		**FIXED GROUP**
Learning effect	**N=64**	**AVR MT training**	**N=21**
LE < 200	28.1% (N=18)	0 – 98%	19% (N=4)
LE 200 – 600	45.3% (N=29)	3% - 98%	47.6% (N=10)
LE > 600	26.6% (N=17)	43%-100%	33.3% (N=7)

Note, the percentages in brackets represent the percentages of the participants in each category relative to the group, and since the groups have different N, the percentages are much easier to compare. So, the percentages are presented as "main" data and the N in parentheses.

Average MT training is the averages percentages of MT blocks across 3 training sessions only for the Choice group, because the Fixed group had 100% MT training.

Figure 3.8

LE stands for Learning Effect in RT2 Costs and the percentages of participants in each category.



The Pearson's chi-square analysis showed no significant difference between the number of high achieving (LE above 600ms) participants in the Choice group and in the Fixed group (X2(1, N=24) = 2.42, p=.119). Similarly, there was no significant difference between the number of mid-achieving (LE from 200-600ms) participants in the Choice and Fixed groups (X2(1, N=39) = 0.39, p=.534). However, the same results were not observed in low-achieving (LE below 200ms) participants, because the Choice group had a significantly higher number of the "low achievers" as compared to the Fixed group (X2(1, N=22) = 7.16, p=.001). This may indicate that training in a pure MT regime leads to a lower number of participants with the lowest learning effects.

The scatterplot of the Choice group illustrated how the leaning effects were distributed among people with different choices in training. The aim of the current section was to present the distribution of high- and low-achievers in the Choice and the Fixed groups. For this the Choice group was divided into subgroups based on the total percentage of MT training.

To remove outliers, the learning effect values of the subgroups were z-transformed separately for each group, and outliers were defined as z >= 3. The outliers were removed on an analysis-by-analysis basis. In the current analysis two data points were removed (two participants).

First, I examined participants with a relatively high percentage of MT training above 80% (from 80% to 100% of MT training in the Choice group). These participants were analysed as the Choice80 subgroup (N=17, M=92% of MT training, SD=7%, Table 3.7) and can be considered as the MT group (choosing to MT). The range from 80 to 100 % MT training was selected because there were not enough participants with 100% MT training in the Choice group. The Fixed group played the role of a control group with no choice regarding the training modes (100% forced MT). This was done to determine whether there is a significant difference in learning MT between the participants did not have a choice and trained only in MT mode, and the participants who chose to train in the highest range of MT training. Results showed that there was no significant difference between the learning effect in RT2 Costs obtained by the Fixed group and the Choice80 subgroup (t(35)=0.75, p=.459, d=.249). These results were expected because the Choice80 subgroup did MT training above 80%. However, the Choice subgroup showed a larger learning effect by 84ms, although this was not significant. This could potentially indicate that some level of ST training might not be detrimental to the MT learning effects.

The learning effect in MT R2 errors costs (MT R2 minus ST R2 errors, pre minus post) was significant only in the Fixed group (M=1.9%, t-test vs 0, $t(20)=2.58$, $p=.018$, $d=.563$), while the Choice80 (M=0%, Table 3.7, Figure 3.9) subgroup did not obtain a significant learning effect in MT R2 error costs. These results show that, although only the Fixed group exhibited a significant reduction in MT R2 error costs, the reduction was numerically relatively moderate. This might be caused by the fact that this analysis is based on R2 error costs only, i.e., the visual task, which was comparatively easy. Therefore, it is possible that the participants quickly learned it and already had low error rates at the pre-session (Choice80 M=1% and Fixed=3% MT R2 error costs at pre-session). Thus, there potentially was no more room for improvement in R2 error costs for all groups, because they achieved the 'floor effect'.

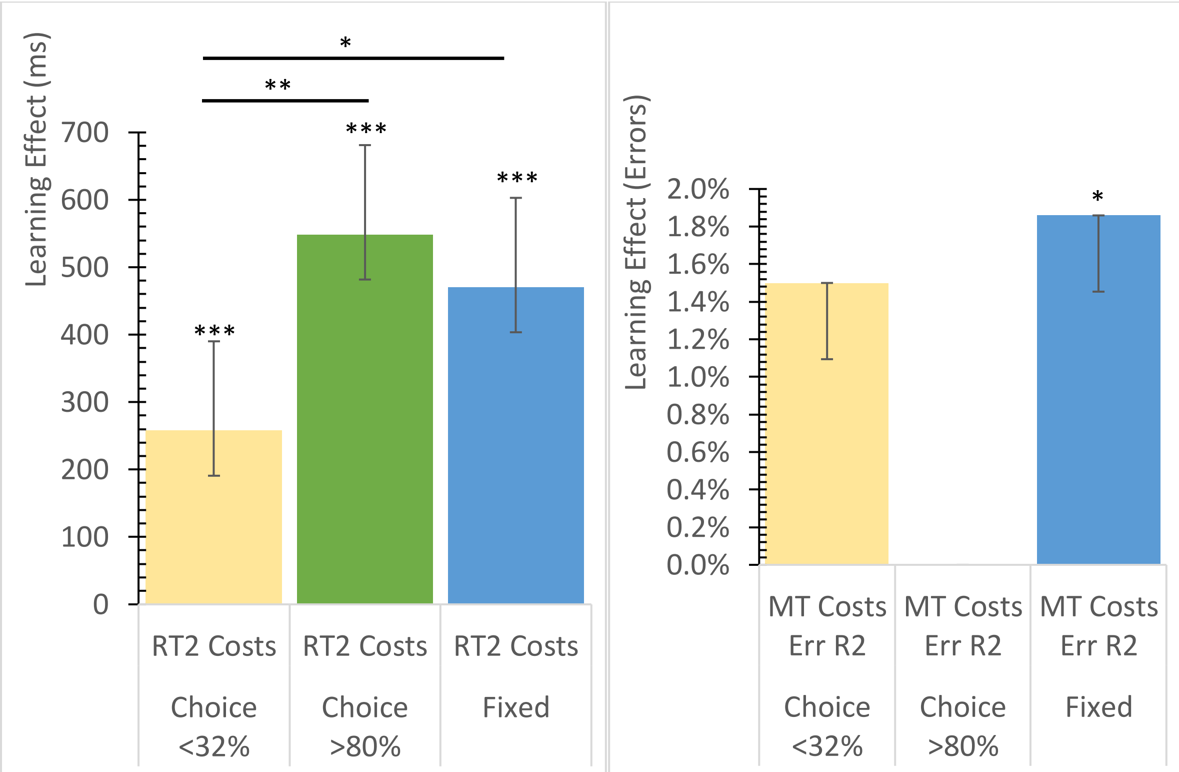
Table 3.7

Learning effect in RT2 Costs and MT R2 Error Costs, calculated as pre-costs minus post-costs. The Fixed Group data have already been presented in Table 3.

Choice ≤32		**CHOICE >80**		**FIXED GROUP**	
N=16		**N=17**		**N=21**	
MT training M=17%		**MT training M=92%**		**MT training M=100%**	
Learning Effect (LE)					
LE RT2 Costs	**LE MT R2 Error Costs**	**LE RT2 Costs**	**LE MT R2 Error Costs**	**LE RT2 Costs**	**LE MT R2 Error Costs**
M=257ms, SD=193 t(14)=5.16, **p<.001,** d=1.333	M=1.5%, SD=0.04, t(15)=1.35, p=.198, d=1.260	M=554ms, SD=371, t(16)=6.28, **p<.001,** d=1.523	M=0.0%, SD=0.03, t(16)=0.00, p=1.0, d=0.0	M=470ms, SD=311, t(20)=6.93, **p<.001,** d=1.513	M=1.9%, SD=0.03, t(20)=2.58, **p=.018,** d=.563

Figure 3.9

Learning Effect in RT2 Costs and MT R2 Error Costs presented in bars. The asterisk symbols (*<0.050; **<0.010; ***<0.001) at the top of a bar chart show the learning effect, i.e., significant difference of MT costs between pre-session and post-session. The error bars denote SEM.



Secondly, I examined participants with a relatively low percentage of MT training below 10%, but I found only 8 from 69 participants, which is why the parameters were widened to 32% of MT training, which resulted in a total of 16 participants. These participants were analysed as the Choice32 subgroup, with the MT% of training less than 32% (N=16, M=17% of MT training, SD=11%). The Choice32 subgroup can be potentially considered as an approximation of the ST training with a minimal MT training, because this 17% are equivalent to performing on average 3.4 blocks out of the 20 blocks as MT training per session, whereas earlier I compared Choice80 to the MT group. As expected the Choice32 subgroup with the least training showed significantly smaller learning effects as compared to the Choice80 subgroup (by 297ms in RT2 LE, $t(29)=2.78$, $p=.010$, $d=.994$) and to the Fixed group (by 213ms RT2 LE, $t(34)=2.34$, $p=.025$, $d=.792$). A similar pattern was observed in the R2 error rates, for which the Choice32 subgroup did not show significant learning effect($M=1.5\%$, t-test vs 0, $t(15)=1.35$, $p=.198$, $d=1.260$, Figure 3.9).

Additionally, it should be noted that in the Choice32 group, some participants achieved relatively high learning effects in RT2 costs (minimum learning effect of 52ms and maximum of 571ms). For example, the highest learning effect in the Choice32 group (571ms) was achieved by a participant with MT training of only 8% (on average 1.6 blocks). Out of 16 people in the Choice32 group 10 participants achieved learning effects above 200ms. This may indicate that for some participants it is beneficial to rely on their own preference of training regimes and regulate modes even if they choose mostly ST training for very complex MT tasks.

The Choice32 subgroup showed significantly lower learning effects as compared to the Choice80 subgroup and Fixed group. While all three groups obtained significant learning effects in reaction times, the Fixed group alone showed a significant reduction of MT R2 error costs, although only numerically (and not significantly) larger than in the two Choice subgroups.

The transitions in the Choice group

Finally, the last analysis I will describe in this section is the types and frequencies of choices made by the participants during the training phase of the experiment. Specifically, what could potentially be a marker of the decision for the next choice of training modes (which includes changing and remaining in the same training condition). The participants in the Choice group had an option to choose in what mode (ST, MT, or Mix) they wanted to train each out of the 10 sets of blocks (with each set comprised of 2 blocks; therefore, they had 20 blocks in total, and 10 choices per session). The choices could be classified as ST-ST (1,2 and 3), ST-MT (Mix, 4,5), or MT-MT (6) and included six training options:

1. Auditory Task (ST) and Auditory Task (ST)
2. Visual Task (ST) and Visual Task (ST)
3. Auditory Task (ST) and Visual Task (ST)
4. Auditory Task (ST) and Dual-Task (MT)
5. Visual Task (ST) and Dual-Task (MT)
6. Dual-Task (MT) and Dual-Task (MT)

The RT and error data was collated for auditory and visual STs and MT modes to target specifically the MT performance right before the decision for the next training mode was made. These choices of modes (e.g., from ST=>ST to ST=>MT or remaining on the same mode of training) are defined as transitions.

The transitions were analysed in two dependent variables, error rates and reaction times. For example, in RT analyses a transition from ST-MT represented the average RTs produced by participants during the ST mode before deciding to change to MT mode (Table 6). For example, when a participant switches from ST (in block N-1) to MT (in block N), then this would be indicated as “ST => MT”. Importantly, the reported performance data (error rates, RTs) refer to block N-1, i.e., in this example to the performance in the ST blocks. This analysis allowed me to test whether performance in block N-1 (ST) is associated with the next choice (block N). It might be speculated that if participants were performing well in ST in block N-1, then they were more likely to switch to MT in block N (i.e., “ST => MT” when ST has comparatively fast RTs and low error rates). On the other hand, if participants were not performing well in ST in block N-1, they may have been more likely to continue with ST in block N (i.e., “ST => ST” when ST has comparatively slow RTs and high error rates). Therefore, the values reflected performance right before the decision was made whether to change the training mode or remain on the same mode.

It should be noted that the times that each transition occurred within a participant hugely varied; some might have 9 transitions in a session for one transition only (e.g., MT => MT). The maximum number of transitions within 10 choice-blocks was 9 transitions, since the first choice-block could not be analysed, because there was no preceding block. Therefore, the mean of a participant may be based on any number between 1 and 9 scores.

Additionally, some transitions may have never been done by a participant, therefore there is potentially missing data, and the overall group mean of one particular transition (e.g. “MT => MT”) may be based on 100% of the sample, while the mean of another transition (e.g. “MT => Mix”) may be based on 20% of the sample (for the number of the transitions see column NT in Table 6).

1. *Error Rates*

Participants always chose a set of two blocks, which could be ST, MT or mixed (Mix, one block in ST and one block in MT). To calculate the values for the Mix blocks, first the average error rate for each block was calculated (i.e., the mean of 30 ST trials, and then the mean of the 15 MT trials). Then the average of ST mean and MT mean was calculated, so that the ST and MT blocks had the same weight. According to my hypothesis, I would expect lower error rates in block N-1 when switching to MT in block N, and higher error rates in block N-1 when switching to ST in block N.

Average error rates for the different transitions (ST, MT and Mix) of the Choice group were analysed (Table 3.8, Figure 3.10). The comparison of the error rates between different transitions presented in Table 7 showed that the only significant difference between the mode transitions were shown in three instances.

Table 3.8

Raw error rates for all possible transitions, averaged across sessions 2-4.

Transitions	N	NT	Error rates	SD	t-tests of error rates vs 0
MT => MT	55	145	**18%**	0.11	t(144)=19.05; **p<.001 ,** d=1.582
MT => Mix	18	27	**22%**	0.13	t(26)=8.65; **p<.001 ,** d=1.574
MT => ST	36	65	**27%**	0.16	t(64)=13.31; **p<.001 ,** d=1.651
Mix => MT	48	96	**15%**	0.11	t(95)=13.17; **p<.001 ,** d=1.344
Mix => Mix	36	75	**20%**	0.15	t(74)=11.61; **p<.001 ,** d=1.340
Mix => ST	18	21	**22%**	0.13	t(20)=7.54; **p<.001 ,** d=1.644
ST => MT	35	67	**11%**	0.12	t(66)=7.52; **p<.001 ,** d=.919
ST => Mix	40	79	**13%**	0.10	t(78)=11.18; **p<.001 ,** d=1.258
ST => ST	50	118	**13%**	0.10	t(117)=13.50; **p<.001 ,** d=1.242

Note. In the Transition column first conditions are in bold to illustrate that the shown Error rates come from the bold blocks. N represents the number of participants contributing to calculating the mean error rates of the transitions (i.e., which did the transitions at least once in any of the 3 training sessions). NT is the total number of transitions per change from one mode to another throughout all 3 training sessions, given that each participant may contribute between 1 and 9 transitions.

Figure 3.10

Average error rates in blocks N-1 for the different transitions. The 3 panels are grouped by the condition in block N-1 (From MT, From Mix, From ST), and the 3 bars in each panel reflect the condition switched to in block N (=>MT, =>MX, =>ST). Each condition identified with its own colour (MT blue etc), and that the "From" condition determines the colour on top, and the "To" condition the colour at bottom of the bar. All the transitions in error percentages (from mode to mode) made among the participants were significant against 0. The asterisk symbols (**<0.010; ***<0.001) on the top lines represent the statistically significant differences between the transitions, e.g., MT to MT transition vs MT to ST transition. The error bars denote SEM.

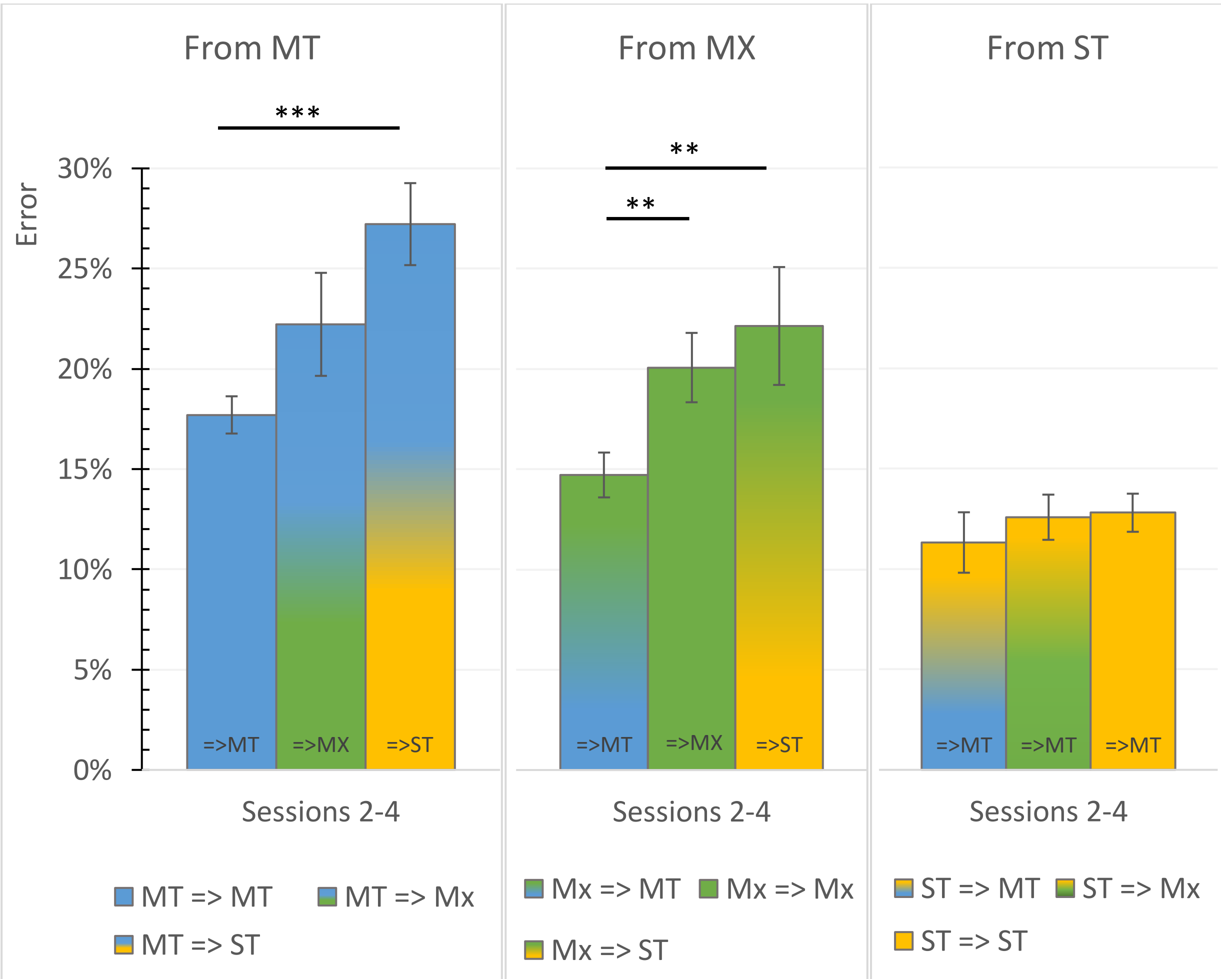


Table 3.9

Comparisons of between transition error scores independent sample t-tests

Choices of transitions	Independent sample t-test
From **MT** => **MT** vs From **MT** => **MX**	t(170)=1.87, p=.064, d=.391
From **MT** => **MT** vs From **MT** => **ST**	t(208)=4.88, **p<.001,** d=.729
From **MT** => **MX** vs From **MT** => **ST**	t(90)=1.39, p=.166, d=.319
From **MX** => **MT** vs From **MX** => **MX**	t(169)=2.70, **p=.008**, d=.416
From **MX** => **MT** vs From **MX** => **ST**	t(115)=2.70, **p=.008**, d=.650
From **MX** => **MX** vs **MX** => **ST**	t(94)=0.57, p=.568, d=.625
From **ST** => **MT** vs From **ST** => **MX**	t(143)=0.99, p=.322, d=.113
From **ST** => **MT** vs From **ST** => **ST**	t(183)=0.87, p=.383, d=.134
From **ST** => **ST** vs From **ST** => **MX**	t(195)=0.15, p=.880, d=.022

Note, that the times each transition occurred within a participant hugely varied; some may be based on any number between 1 and 9 scores. For this reason, independent sample t-tests instead of paired sample t-tests were used.

I hypothesised that errors were low in block N-1 when choosing MT next (in block N), and high when switching to ST. For the situation where participants did MT in block N-1 (left-most panel in Figure 3.10, “From MT”), this was numerically the case: In those cases, where participants chose to continue with MT (From MT => MT), the error rates in the N-1 MT block were lowest (18%) while they were highest (27%), when they switched to ST (From MT =>ST). Numerically, error rates fell in-between these two extremes when they switched to Mx training (22%). The results showed that the error rates were indeed significantly lower when they decided to stay with MT (From MT =>MT) than when switching to ST (From MT =>ST, $t(208)=4.88$, $p<.001$, $d=.729$). The difference between MT-MT and MT-MX just failed to reach significance ($t(170)=1.87$, $p=.064$, $d=.391$) and the difference between MT=>MX and MT=>ST was not significant ($t(90)=1.39$, $p=.166$, $d=.319$).

For the situation where participants did Mix in block N-1 (middle panel in Figure 3.10, "From MX"), a similar pattern was observed, participants had comparatively low error rates (15%) in the Mix mode when they decided to switch to the MT mode, but comparatively higher error rates (20%) when they decided to stay in the Mix mode ($t(169)=2.70$, $p=.008$, $d=.416$). Similarly, participants had comparatively high error rates (22%) in the Mix mode when they decided to switch to the ST mode, and comparatively lower error rates (20%) when they decided to stay in the Mix mode ($t(115)=2.70$, $p=.008$, $d=.650$).

Finally, for the situation where participants did ST in block N-1 the same pattern was observed numerically, but not significantly (right panel in Figure 3.10, "From ST"). The lowest error rates (11%) were observed in the ST mode when they decided to switch to the MT mode, and comparatively higher error rates (13%) when they decided to stay in the ST mode or switch to Mix mode.

Overall, this pattern of results is as predicted by the hypothesis that participants chose MT practice for the next mode when the performance in the current block was comparatively good, chose ST practice when the performance in the current block was comparatively poor and might choose Mix practice if the performance was somewhere in the middle. Therefore, the error rates might be one of the possible indicators of the decision which condition to train next.

1. RT1 and RT2

Next, I performed the same analysis for the response times as reported above for the error rates. The descriptive data of the average RTs of the possible transitions between different training modes is presented in Table 3.10 and Figure 3.11. As mentioned before, one of the aims of this explorative study is to determine what could potentially be a marker of the next choice. In this analysis, the expected pattern would be similar to the error-rates analysis, participants choose training in ST mode over the MT mode with relatively high RTs and transition to MT mode with lower RTs.

The RT analyses numerically showed similar patterns as for the error rates, where comparatively slower RTs in block N-1 result in transitions to ST modes in block N, whereas comparatively faster RTs result in transitions to MT mode. Whereas the analysis of the RTs of transitions from the Mix condition showed different pattern. As shown in the Figure 3.11, in all bars except for the “from Mix” the RTs are numerically higher in transitions from MT to Mix and ST to Mix, although this difference was not significant.

Table 3.10

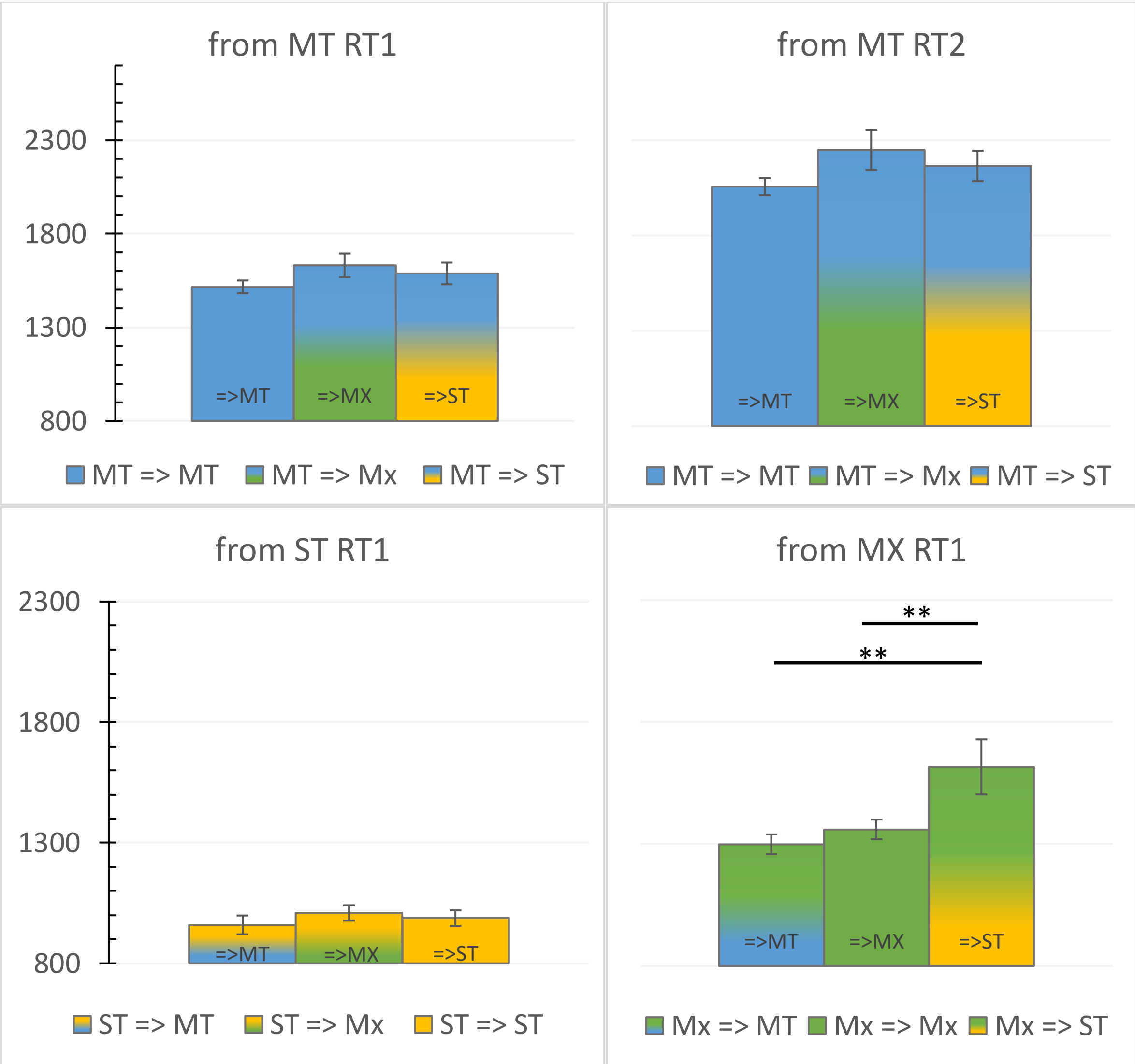
Raw RT1s and RT2s of the transitions in sessions 2-4. The "from MT" conditions include RT1s and RT2s, while the "from ST" and "from Mix" conditions only included RT1s.

RT	Transitions	N	NT	RT (ms)	SD
	MT => MT	55	146	**1517**	411.1
RT1	**MT => Mix**	18	27	**1631**	330.9
	MT => ST	36	65	**1588**	466.7
	MT => MT	55	146	**2056**	539.5
RT2	**MT => Mix**	18	27	**2248**	541.2
	MT => ST	36	65	**2164**	638.9
	Mix => MT	48	96	**1299**	398.8
RT1	**Mix => Mix**	36	74	**1360**	346.0
	Mix => ST	18	21	**1616**	517.4
	ST => MT	35	67	**959**	320.0
RT1	**ST => Mix**	40	78	**1009**	282.5
	ST => ST	50	117	**987**	348.6

Note. In the Transition column first conditions are in bold to illustrate that the shown RTs come from the bold blocks. N represents the number of participants contributing to calculating the RTs mean of the transitions (i.e., which did the transitions at least once in any of the 3 training sessions). NT is the total number of transitions per change from one mode to another throughout all 3 training sessions, given that each participant may contribute between 1 and 9 transitions.

Figure 3.11

Averaged transitions in RT1 and RT2. The top two charts show RT1 and RT2 in MT condition, and the bottom two charts show RT1 for ST and Mix conditions. All the transitions in RTs (from mode to mode) made among the participants were significant against 0. The asterisk symbols (**<0.010) on the top lines represent the statistically significant differences between the transitions, e.g., MX to MT transition vs MX to ST transition. The error bars denote SEM.



The comparison of the transitions presented in Table 3.11 shows that the only significant differences between the mode transitions were shown in two instances. First, the reaction time in the Mix mode were significantly lower in the transition from Mix to MT than in the transition from Mix to Mix ($t(115)=3.12$, $p=.002$, $d=.752$). This finding is aligned with the finding in error rates and shows that participants remained in the Mix mode (from Mix to Mix) when the RT1 was on average 1360ms, whereas the change was made from Mix mode to MT mode when the RT1 was on average of 1299ms. Second, the reaction time in the Mix mode were significantly slower in the transition from Mix to ST than in the transition from Mix to Mix ($t(93)=2.66$, $p=.009$, $d=.657$). This shows that participants remained in the Mix mode (from MX to MX) when the RT1 was comparatively faster (1360ms), while the change was made from Mix mode to ST mode when the RT1 was comparatively slower (1616ms). Therefore, the reaction times also might be one of the possible indicators of the decision-making processes involved in deciding the mode of the training.

Table 3.11

Between transition RTs t-tests

RT	Choices of transitions	Paired sample t-test
	From **MT to MT** vs From **MT to MX**	t(171)=1.37, p=.174, d=.286
RT1	From **MT to MT** vs From **MT to ST**	t(209)=1.11, p=.267, d=.166
	From **MT to ST** vs From **MT to MX**	t(90)=0.44, p=.663, d=.100
	From **MT to MT** vs From **MT to MX**	t(171)=1.70, p=.091, d=.356
RT2	From **MT to MT** vs From **MT to ST**	t(209)=1.27, p=.205, d=.190
	From **MT to ST** vs From **MT to MX**	t(90)=0.60, p=.551, d=.137
	From **MX to MT** vs From **MX to MX**	t(168)=1.05, p=.294, d=.163
RT1	From **MX to MT** vs From **MX to ST**	t(115)=3.12, **p=.002**, d=.752
	From **MX to MX** vs From **MX to ST**	t(93)=2.66, **p=.009**, d=.657
	From **ST to MT** vs From **ST to MX**	t(143)=0.99, p=.322, d=.165
RT1	From **ST to MT** vs From **ST to ST**	t(182)=0.54, p=.589, d=.083
	From **ST to ST** vs From **ST to MX**	t(193)=0.46, p=.648, d=.067

Taken together, the results from Choice group transition error-rates and RTs illustrate that if participants showed on average good performance, then they were more likely to decide for Mix or MT modes, and if participants showed on average poor performance, then they were more likely to decide for simpler ST or Mix modes. This pattern indicates that indeed the decision-making process related to choosing a mode may be influenced by performance (error-rates, possibly also reaction times).

3.3.1 Discussion

This online computerised PRP learning study examined the MT learning effect in a Choice group and in a Fixed group. While the Fixed group had 100% MT training, the Choice group were able to choose the mode of training (ST, MT, or Mix) for each set of two blocks (total of 20 blocks per session) and had an average of 59% MT training. In this learning study, the tasks were Auditory Tone and Visual Number tasks, either in ST mode (performed separately) or in MT mode (performed at the same time, where participants had to *respond* to the auditory task first). The auditory and visual tasks were relatively demanding and complex, mimicking the demands of real-life MT situations.

In the auditory task, participants were asked to press four different keys with four different tones (low tone 450 Hz to hight tone 600 Hz) with their left hand. And in visual blocks, participants were presented with four numbers (1-4) and asked to press keys with their right hand. In the MT condition, the MT block included both auditory and visual tasks with 4 tones and 4 numbers. As predicted, both groups reduced MT costs after the training and gained MT learning effects. Since the focus of this study is learning MT, and the RT2 Costs are the most liable to pick up MT costs and learning effects (De Jong, 1995; Logan & Gordon, 2001), the discussion will mostly focus on RT2 Costs (the second, visual task in MT condition).

MT Learning Effects between the Choice group and the Fixed group

The learning effects were calculated by subtracting the MT costs at the post-session from the MT costs at the pre-session. The results showed that, although numerically the Fixed group achieved more MT learning, there was no significant difference between the two groups in the learning effect for RT2 Costs, and no significant difference in the learning effect of MT Error

Costs. Thus, MT training resulted in significant learning effects in RT2 Costs in both groups; this pattern of learning was in line with the DTPA where MT training leads to effective MT learning (Strobach, 2020) and PRP studies which described less MT learning in ST groups in comparison to MT groups (P. A. Allen et al., 2009; Karbach & Strobach, 2022; Lawlor-Savage & Goghari, 2016; Lien et al., 2003; Oberauer & Kliegl, 2004).

An intriguing finding is that while there was no significant difference between the Choice and the Fixed groups, the correlation between the amount of MT training and the learning effect for RT2 was positive. One potential explanation for these seemingly contradictory findings is a combination of two factors. Firstly, participants in the Fixed group (100% MT training) were potentially “dragging down” the value of the learning effect mean, because participants may have needed some more ST practice; and since this was lacking, they may have never learned MT properly. In other words, the potential learning effect could have been hampered by lack of flexibility during the training phase. This can potentially explain the data in the scatterplot (Figure 3.6) that in the Fixed group there were quite a few participants who showed very little MT learning. Secondly, the participants in the Choice group (average 60% MT training) could be potentially “pulling up” the value of the learning effect mean, because they had a chance to adjust the training to their optimal learning strategy. Since the amount of MT practice correlated with MT learning, this then would create the expectation that the 60% choice group would show on average lower MT learning. This then could mean that at least some participants had a good idea of their skill levels and were able to adjust their training to maximise the MT learning, even if this required ST training as well.

This argument would be supported by the analysis of the distribution of participants with high and low learning effects in the Fixed and the Choice groups (Figure 3.8). To analyse how high and low learners were distributed in each group, both groups were evenly split in the range of the best and the worst learners based on the learning effects in RT2. The low achievers were classified with learning effects of below 200ms, the middle achievers between 200ms and 600ms, and high achievers above 600ms (Figure 3.8). The analysis showed that in the Fixed group with 100% of MT training there were 19% (N=4 out of 21) low achievers, 47.6% (N=10 out of 21) middle achievers and 33.3% (N=7 out of 21) high achievers; while in the Choice group there were 28.1% (N=18 out of 64) low achievers with the range of MT training from 0 to 98%, and 45.3% (N=29 out of 64) middle achievers with the range of MT training from 3% to 98%. Of high achievers ,26.6% (N=17 out of 64) were within the range of MT training from 43% to 100%, showing that there were no high achievers in MT learning with the MT training effect below 43%. This is in line with the main hypothesis that more MT training (amount of hours, sessions, lessons) results in higher MT learning effects.

If the argument above about participants in the Choice group being able to maximise MT learning by employing ST learning is correct, then the Choice group would have fewer “low achievers” with learning effects below 200ms than the Fixed group, but that was not the case. In fact, the only significant results in the Chi-square analysis showed that the Choice group had significantly more “low achievers” in contrast to the Fixed group. One possible interpretation of this finding may be that pure MT practice is the most efficient approach; however, additional variables such as previous experience and individual differences, including differences in learning speed, may produce some “noise” in the data. This shows that there is a need for further studies of MT learning to investigate additional variables associated with learning complex activities and MT activities.

Another potential interpretation of the data in this context is that the correlation (Figure 3.6) was produced by the study, where participants were by design not assigned a certain percentage of MT training. It might simply be that the interpretation of the correlation as showing that "MT training is associated with MT learning" is not applicable, i.e., there is no causal relationship in that direction. Perhaps, for at least for some participants, it was the other way round (those who learn MT better picked a greater MT%). Or maybe there was a third unknown underlying variable which may link both together. Since there was a gap in the literature on learning MT at the time of writing, it is difficult to determine which interpretation is the most applicable. However, I would suggest that the causal relationship might indeed be the other way around; specifically, poor learners choose more ST training (because they might struggle more during learning) and even if these poor learners had done pure MT training, they would still not learn as much MT as the high learners did. Otherwise, the Fixed group would perform profoundly better. In other words, there might be some hidden variables which may affect MT learning, but these could not be tested in this experiment. Potential examples could be individual differences in learning and undiagnosed attentional deficits. In addition, there may be a further alternative; simply that the Fixed group on average did learn better (numerical differences pointed in that direction), but not to a statistically significant degree.

Overall, the correlation analysis might support the idea that for demanding tasks, having a choice in which mode (ST or MT) participants decide to learn, and spending time on practising the tasks in ST mode, may not be detrimental to the success of learning the MT activity. However, it may not necessarily be beneficial for the overall MT training outcome either, because the Choice group also did not show signs of greater MT learning or avoiding low-achieving learning. This study was designed with a larger number of participants in the

Choice group specifically for the purposes of investigating choices of MT learning regimes. Therefore, I will next discuss the Choice group performance in greater detail.

Choice group MT learning

It was interesting initially to examine whether there was a difference in performance of people who did 100% MT training without choice (Fixed group) in comparison to a group of participants who voluntarily chose virtually only MT training (80% to 100% MT training). The Choice80 subgroup showed MT learning effect on average 84ms higher than the Fixed group, but that difference was not statistically significant. And as expected, the Choice32 subgroup with the least MT training showed the lowest learning effect in RT2 costs, which is in line with the formula "MT training associated with high MT learning effects".

Furthermore, this was the first study to capture the potential indicators of decisions to learn in ST mode or MT mode. The ensuing analysis was conducted to examine the choices participants made during the training phase of the experiment.

Transitions in the Choice group

As described previously, in the Choice group participants were offered a choice of training mode (ST-ST, or MT-MT, or ST-MT) for 10 sets of two blocks (20 blocks in total, and 10 choices). In this manner, the choice of modes would show transitions from one mode to another as well as maintaining the same mode. The results showed that both error rates and RTs can be identified as potential markers of the choices made by participants to change training mode. The markers showed that the participants with relatively fast and accurate performance tended to choose more demanding Mix/MT modes; whereas participants with poorer performance would more likely choose ST modes.

Finally, the transitions which were defined as the choices of learning modes, (from MT to ST, Mix or MT) could show the overall trend in the decision-making processes in choosing the best approach to learning MT in different training modes. For example, the growing amount of MT training from the first to the third training session among Choice group (Figure 3.8, 63% of MT training by the third session) may indicate that as participants learned tasks in ST mode and obtained more confidence in their performance, they were more likely to move on to the MT mode with higher cognitive demands.

3.3.2 Conclusions

This study analysed the MT learning effects, specifically the MT learning processes of participants with an option to choose the training condition of each block. The results showed that there is a significant overall trend in choices (better performance leads to choosing more challenging tasks), and the MT learning effect between participants with 100% of MT training (Fixed) and from 80% to 100% of MT training (Choice) was not significantly different. This could potentially mean that some level of ST training might not cause any drawbacks in overall MT learning.

4 Driving Simulator Laboratory Study

4.1 Introduction

As has been shown in previous studies, the majority of people have learned MT activities in Mix regimes, as well as showing preference towards learning in Mix regimes. The second study also showed that, when given the choice of training mode, participants also mostly chose the Mix regimes. These findings were in line with the DTPA phenomenon, in which most of the studies also showed that the MT (also referred as dual-task DT) regimes of MT training resulted in better MT learning than training in ST regimes (Strobach, 2020). However, there is virtually no research to investigate whether the DTPA phenomenon would still hold for learning applied complex MT activities. Additionally, the main question remains which training regime (MT, ST or Mix) is the most effective approach to learn complex MT activities.

To investigate these questions, a driving simulator was used to mimic real-life multitasking situations and provide valuable insight into learning especially demanding MT activities. While driving itself was not the focus of the study, it was chosen because driving was already a demanding activity on its own, and with the additional tasks, could create a highly challenging environment, very different to the basic computerised tasks used in most previous research.

Multitasking (MT) in the context of driving has attracted the attention of multiple researchers (R. W. Allen et al., 2007; Jokinen et al., 2021; Levy et al., 2006; Nijboer et al., 2016). This interest is certainly justified since driving can be considered as one of the most common real-life MT activities. Furthermore, many occupations such as police and ambulance drivers, require additional skills to be able to drive in extremely demanding and sometimes even dangerous environments (Loukopoulos et al., 2016b).

Previous research on driving training with different simulators suggested that there was evidence of improved driving performance after the training (Alonso et al., 2023). For example, Allen et al. (2007) found that training driving on a simulator with wide screens closely mimicking real-life driving resulted in a better learning effect compared to two other more basic forms of driving simulator. They compared performances of the three groups of participants after training on simulators from a very simplistic narrow-field screen simulator to a wide-angle projected screens simulator with software adjusted to real-life driving conditions. (Allen et al.'s study was focused on comparing different simulators rather than investigating MT learning.). In line with these findings, Madigan & Romano (2020) also reported that the best training results were obtained on a simulator with the highest video quality. This study supports the previous research that training on a driving simulator improves performance.

There is a distinct lack of applied studies that focus precisely on applied learning MT, whether driving activities or other disciplines. There are some studies examining different aspects of learning MT in driving; for example, in PRP studies (Levy & Pashler, 2008), attentional demands (Patoine et al., 2021; Trick et al., 2004) and working memory (Broadbent et al., 2023). However, such learning studies were based on relatively straightforward driving simulations without additional demands (e.g., following navigation instructions and making operations on the dashboard) and did not compare different learning regimes.

To the best of my knowledge, one of the studies most nearly focused on the applied MT learning in the context of driving was conducted by Anguera et al. (2013) using a video race game. In this study the first task consisted of tracking a car on a simulated road with left/right turns as well as downhill/uphill movements, while the second task was a detection task (go/no-go task) with green and red signs representing a traffic light. The training duration was for a month with 3 one-hour sessions scheduled each week (12 sessions in total). The study found that, following the training, participants had improved their multitasking performance, and emphasised improvements in cognitive control abilities, such as sustained attention and working memory. Anguera et al. (2013) suggested that driving simulators could provide useful training for cognitive abilities in MT contexts.

In addition, there is still a gap in literature regarding the training of specific cognitive abilities as well as the exact mechanisms of the executive functions involved in MT learning (Karbach & Strobach, 2022). Although not in the focus of this study, knowledge and understanding of these cognitive mechanisms behind the learning would be useful, but the lack of a theoretical basis remains. This was also addressed by Jokinen et al. (2021), suggesting that multitasking strategies can be considered as optimal adaptation to demanding continuous activities such as driving. Authors stated that cognitive mechanisms of such adaptation were not well known and discussed multitasking in the context of developing safe and unsafe behaviours while adapting to changing circumstances. In their empirical non-learning study, Jokinen et al. (2021) found that multitasking strategies play a crucial role in adapting to uncertain, changing environments, in this case driving, with attentional demands of ongoing tasks. They measured lane deviations and visual attention to investigate how participants adapted to the cognitive constraints and the task uncertainties, concluding that safe and unsafe behaviours were developed because drivers had to manage conflicting demands while driving and make quick decisions in concurrent subtasks.

As mentioned in the general introduction (1.3.2 MT Learning Regimes), the current study addresses three main learning regimes: the ST regime (i.e., performing each task separately), the MT regime (i.e., performing all tasks in parallel) and the Mix regime (a combination of MT and ST conditions during each training session). The benefits of learning MT in Mix and MT regimes was emphasised by Strobach (2020) in the DTPA review paper. In line with the dual-task advantages and current research on MT training, Karbach & Strobach (2022) highlighted the need for additional research to evaluate MT learning. The current study aims to fulfil this need, specifically by identifying the most effective MT learning regime.

Therefore, the hypothesis of this study is that the training of complex MT activities in the MT learning regime is more effective than learning in ST and Mix regimes.

4.2 Methods

Participants

Initially, 71 participants were recruited. However, 23 participants did not complete all sessions and could not be analysed, leaving 48 participants for the final analysis.

These 48 participants, 30 men (M=25.97 years; SD=4.18; 20– 38 years) and 18 women (M=26.89 years; SD=5.27; 18 – 37 years), with drivers' licences, were recruited via posters on campus and social media (e.g., WhatsApp). The study was approved by the Department of Life Sciences Ethics Committee at Brunel University London, and all participants gave informed written consent and received a total of £63 for participation in all seven sessions. Participants were randomly divided into three equal groups (Table 4.1.).

Table 4.1

Descriptive values of participants. Each group included 10 male and 6 female participants.

		N	ST GROUP	MIX GROUP	MT GROUP
Years	**M**	16	26.25	25.50	27.19
	SD		4.17	3.90	5.64

Materials

The study was conducted in the Simulator Laboratory (Sim-Lab) at Brunel University, which was equipped with a driving simulator. This setup consisted of a computer running City Car Driving 1.5 driving simulator software (***https://citycardriving.com***), which is used for real-driving training, on three screens to create a horizontally wide view, including the side rear-mirrors and scenery to the left and right of the car, similar to the road with a real car. A steering wheel and pedals (Logitech G29 Driving force Racing) were installed to mimic the driving environment. Additionally, two 14-inch computer screens were installed on the front-left side and the rear-right side of the participant (see Figure 4.1 and 4.2). While the front screen was easy to see while driving, participants had to properly turn around to see the rear screen, mimicking a shoulder-look when turning or changing lanes. A 10-inch Android tablet was installed on the left-hand side of the table to mimic the screen/dashboard in the car.

Figure 4.1

The simulator laboratory schematic set up.

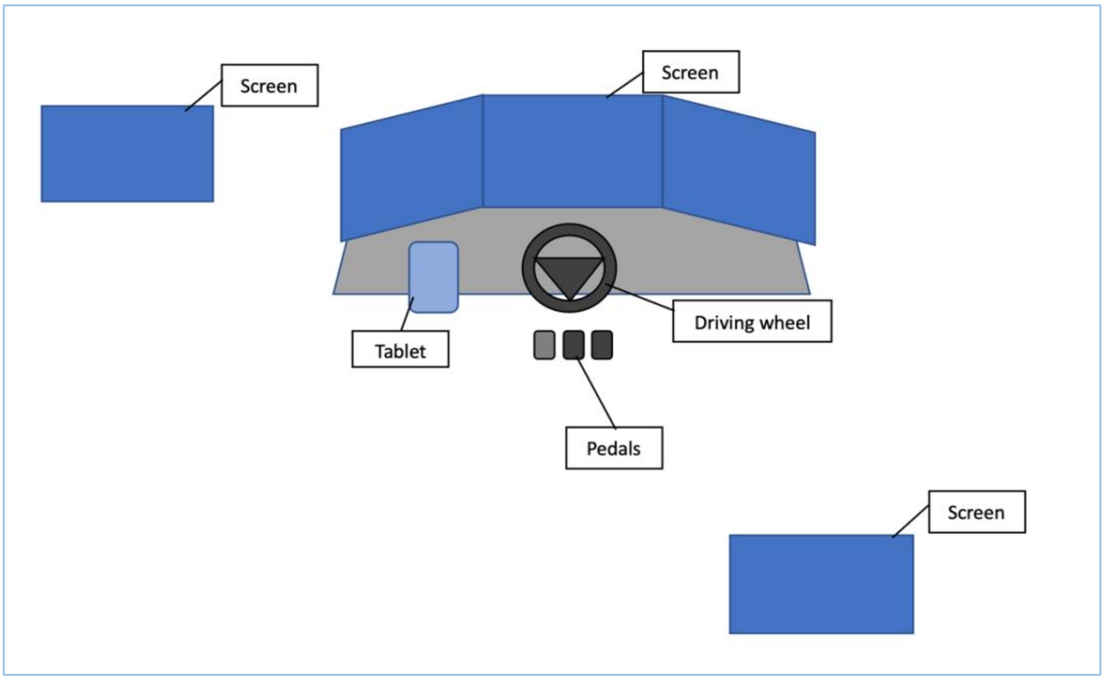


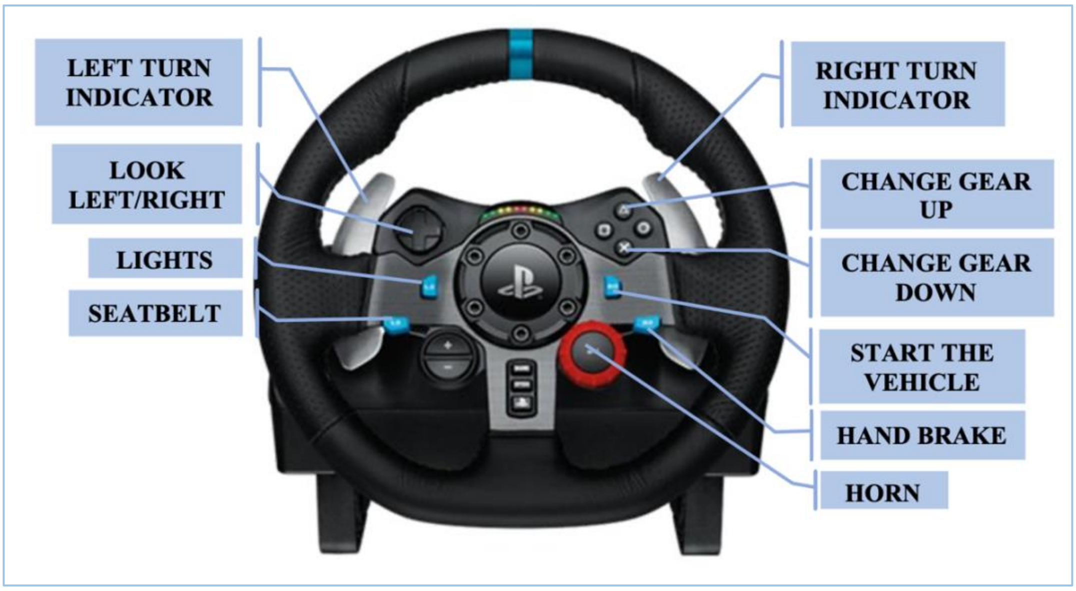
Figure 4.2

The simulator laboratory setup demonstration. The microphone on the right side was replaced with a smaller version, which would be attached to the collar of the shirt of the participant. The instructions for the steering wheel were attached below the middle screen to help memorising which buttons to press.

The setting of the car gear was automatic, and instead of the gear stick, participants were instructed to use the steering wheel to change only between forward driving and reversing. The steering wheel instructions (see Figure 4.3) also included switching on indicators (left and right), using the horn, and switching on the headlights.

Figure 4.3

The simulator steering wheel instructions. The buttons indicated changed the gear down for driving forward and up for reverse.



Experimental Tasks

In this training study four different tasks were employed: Driving Task, Monitoring Task, Math Task and Memory Game Task.

Driving Task

In the driving task, participants were required to use the pedals and the steering wheel to operate the virtual car. The driving was on the left side of the road (i.e., UK driving) and the steering wheel on the right side of the virtual car. Similar to real-world driving, participants were required to follow road rules, such as indicating when turning/changing lanes, speed control, stopping for pedestrians to cross the road.

In the driving task, participants had to follow the navigation route provided by the researcher and had to keep the number of penalties as low as possible. The route instructions were given verbally by the experimenter and when the participants missed the turn, they were instructed to either make a U-turn or take a loop around the block to get back on the route. If the participant had an accident, the virtual car in front would stop and switch on hazard lights. In this case, for the purposes of continuing the trial, participants were instructed to reverse for a couple of metres (or car length) and the virtual car in front would usually start moving. Or in rare cases when the virtual car involved in the accident wasn't moving, participants were instructed to take over the virtual car blocking the way.

The driving weather conditions were always set for clear sunny midday. The driving areas comprised of single and multiple lane roads, and road structures such as roundabouts, bridges, and tunnels. The setting of the traffic density was 20%, which represents other cars on the road and makes the simulation more realistic. There were no traffic jams, and the traffic density was set up to mimic a moderately busy road. The setting for erratic and dangerous drivers on the road was enabled, which created some unpredictable situations such as a lead car suddenly changing the lane in front of the participant's car and accidents occurring on the road. The population of pedestrians was set to 20% and generated pedestrians walking on pavements and crossing the road on zebra crossings, as well as suddenly running across the road in random places and creating distractions.

During the driving task, the software recorded a list of Penalties. "Penalties" represent the count of penalties produced by the participants during the driving task. Examples of Penalties:

1. Driving through a red traffic light
2. Driving in the wrong lane (i.e., toward oncoming traffic)
3. Driving over the speed limit
4. Having an accident
5. Not using indicators to make turns
6. Being a hindrance to other vehicles
7. Driving off the road
8. Not following the researcher's direction instructions

When a participant increased speed above 5km/h the software indicated a violation and recorded the exceeding speed every 10 seconds of driving for a continuous measurement. While the software did not record when participants missed the turn, or did not follow navigation instructions, I was recording missed turns/navigation manually.

Math Task

The math task was an audio recording comprised of 24 simple equations (adding and subtracting numbers between 1 and 9; interim results could be larger than 10) occurring in a sequence (e.g., 3+2; +6; -2; -5; +4). This task was added to mimic typical cognitive processes involved in driving, such as calculating the mileage or choosing optimal routes. The participants were asked to remember the result calculated from the first equation (e.g., 3+2=5, remember 5) and sum/subtract the new number from the previous result as quickly and accurately as possible. For example, the sequence may start with "3 + 2" and the participant had to say out loud "3 plus 2 equals 5" and remember the result of 5. Then the next equation would be presented, e.g., as "plus 6". The participant had to remember the 5 from the previous equation and add 6 to it and say "5 plus 6 equals 11" and remember 11 as the last result. If the next equation would, e.g., have been "minus 2", then they would have to say out loud "11 minus 2 equals 9", and so forth.

For MT training mode, the 24 equations occurred every 15 seconds during the 6-minute trial (where all the four tasks were performed together) and for ST regime the 24 equations occurred every 5 seconds for 2.5 minute trials (where only the math task was performed on its own). This was done to minimise the time participants would spend in the lab; without this adjustment each task would take 6 minutes, adding up to a two-hour session with very slow and simple tasks (when performed separately).

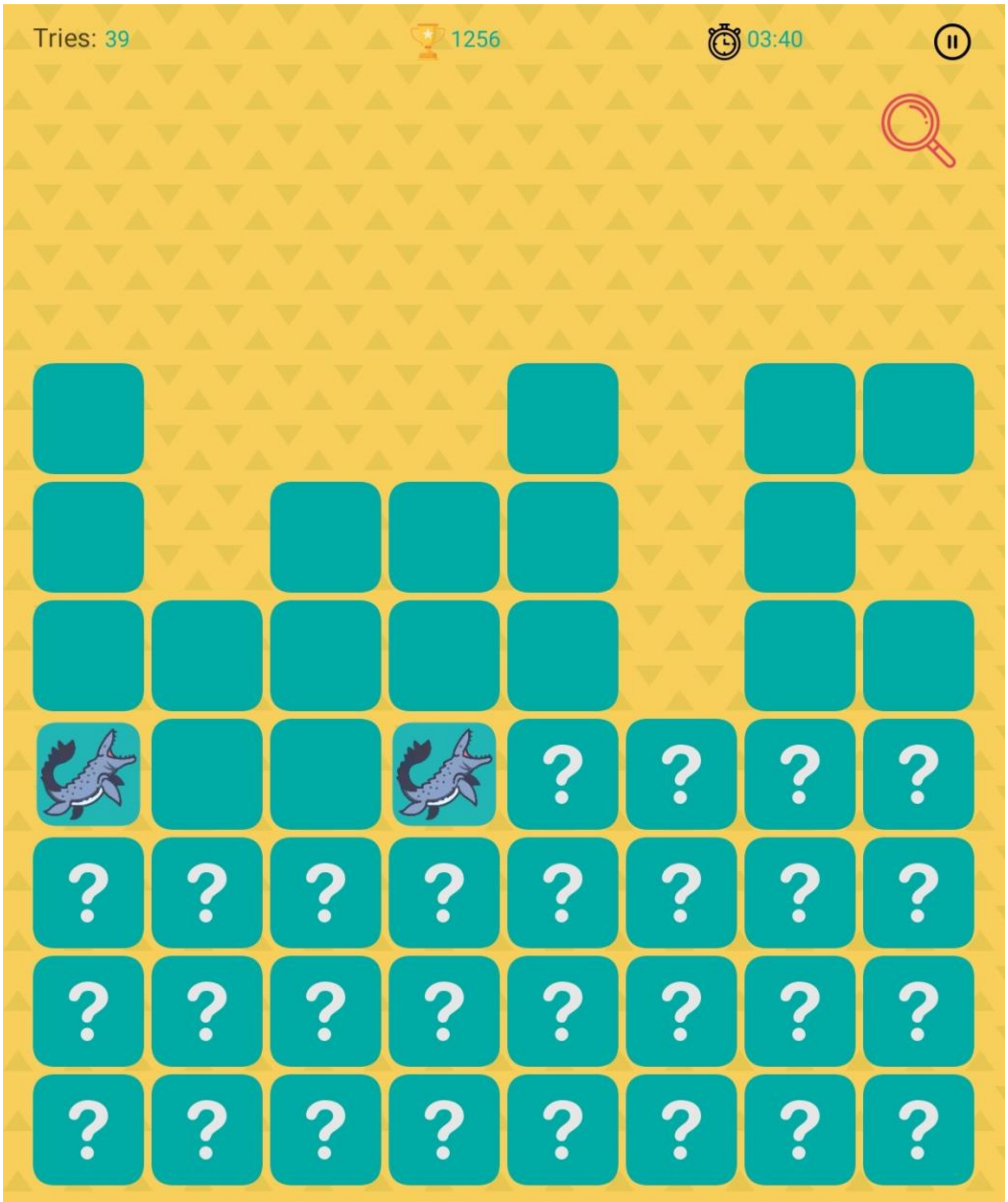
An error could be caused when a participant made a mathematical mistake (Math error), when a participant forgot the previous number (Memory error) and when a participant did not provide an answer at all (Missed error). In the occasion where participants forgot the number, or miscalculated, if the next equation was calculated correctly, I would record only one error and continue with the 'wrong' sequence as long as the equations were correct. In the Results section, the Math Task errors were collated together as one error measure separately for the ST and MT modes. In fact, the memory errors specifically contributed the largest part of the overall Math Task errors (the percentages of all memory errors in Math task (of the learning effect): in the ST group 94% of Memory errors, in the Mix group 96% of Memory errors and in the MT group 81% of Memory errors).

Memory Game Task

The Memory Game Task was presented on a tablet mounted on the left-hand side of the table next to the steering wheel, mimicking the panel with a screen or radio on the dashboard of the car. This task used the free Android game "Matching Pairs" developed by Milaan Games ,downloaded from the Google Play Store on 27 October 2021. The app was a simple "find a pair" game for children, where participants were required to flip two cards at a time on the touchscreen to find identical pairs of objects. Objects belonged to different categories, and per game (trial) all objects belonged to that category, e.g., cars, animals, fruit and vegetables, car signs/ flags, and dinosaurs. If the two flipped-over cards were not a matching pair, they flipped back to show their back cover. Once a pair was found, these cards disappeared from the screen, leaving empty spaces, and participants picked from the remaining cards (see Figure 4.3).

Figure 4.3

The memory game interface on a tablet.



To make sure the game was challenging and would not easily be finished before the trial was over, a version which started with 56 cards (28 pairs), arranged in a 7 x 8 matrix was used. For ST regime the trial was 3 minutes in duration (MT regime trials were 6 minutes of multitasking all four tasks together). In this task, the successfully found pairs were subtracted from 28 pairs in total, showing the missed number of pairs, which I used for a measure as a dependent variable.

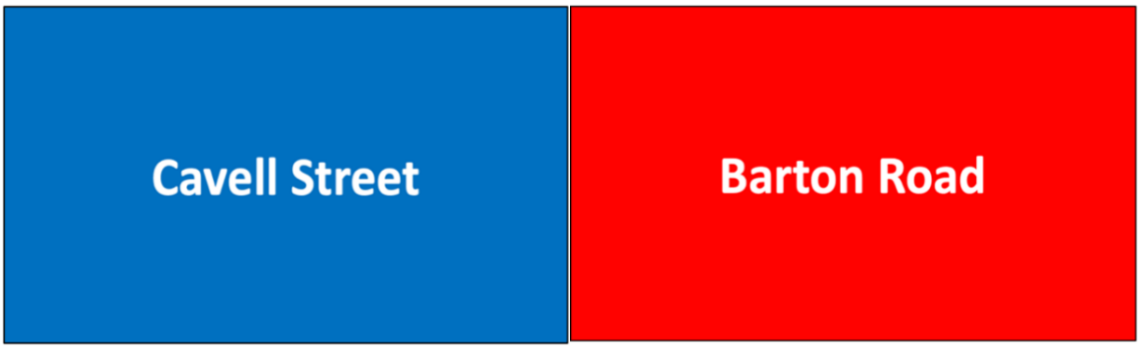
In the MT mode trials, where all 4 tasks were performed simultaneously, the participants were instructed not to touch the tablet and not to do the Memory Task when they were standing still on the red traffic light and waiting for the green light before moving on. This was done to ensure that the tablet task created multitasking demands concurrent to the driving.

Monitoring Task

The monitoring task involved two 14-inch monitors (one in front and one behind the participants), each showing a different slide show. This task was included to mimic the traffic lights, road signs and the blind spot in the car. The slideshow consisted of road / location names printed in large font on differently coloured backgrounds (blue, red, yellow, green, Figure 4.4).

Figure 4.4

The illustration of Monitoring Task screens examples.



Participants had to read out loud the location names only if they were presented on a red background, and could ignore them if presented on any other background colour. For MT mode the screens were changing every 24 seconds (6-minute trial) and in ST mode the screens changed every 12 seconds (3-minute trials). Five red screens were presented on each screen per trial (total of 10 red screens per trial) and each trial had different presentation randomisations.

Values reflecting Costs of each task variables.

The MT costs represented difference of the number of errors produced by participants in MT mode versus the ST mode. The costs of each dependent variable, for example Penalties, Math or Monitoring, were calculated by subtracting the number of values of performance in ST mode from the values in MT mode in pre-session and then in post-session. This was done to calculate the difference (or costs) of errors between ST mode and MT mode. For these MT cost measures, higher values always reflected the worse performance in MT mode as compared to ST mode. Then, the MT costs of the post-session were subtracted from the costs the of pre-session. This was done to measure the difference of MT costs in errors produced at pre-session versus post- session which represents the Learning Effect (LE). In the learning effects higher values reflect more learning (i.e. more reduction in costs from pre to post).

Procedure

This training study consisted of seven sessions in total, first session for pre-testing, last session for post-testing and five training sessions in the middle. Each session consisted of four trials, each trial lasting six minutes. In the pre- and post-sessions, the trials were identical, i.e., the first and second trials were in ST mode, and the third and fourth trials were in MT mode. The five training sessions differed depending on the training group, where the ST group trained only in ST mode in all four trials per training session. The MT group trained only in MT mode in all four trials per training session, and the Mix group had two trials in ST mode and two trials in MT mode per training session. The duration of the pre- and post-sessions was approximately 45 minutes each across all three groups. The duration of the training sessions ranged from 30 to 60 minutes depending on the training group, with the ST group taking approximately 60 minutes per training session, the Mix group 45 minutes and the MT group 30 minutes per training session.

In MT mode trials, all tasks were performed at the same time for 6 minutes per trial. In ST mode, trials consisted of 3 minutes Monitoring Task, 2.5 minutes Math Task, 3 minutes Memory Game Task, and 6 minutes Driving Task. While the duration of the tasks differed in ST and MT modes of training to cut down time spent in the lab by the participants performing the tasks in ST mode, the number of stimuli in both modes were identical. In the Monitoring Task, both ST and MT modes included 10 red screens; in ST mode the slides were timed to change every 12 seconds, whereas in MT mode the slides were changing every 24 seconds. In the Math Task, both modes involved 24 basic mathematical equations, but the timing of the audio instructions differed for ST mode (every 6 seconds) and MT mode (every 12 seconds). The Memory Task included 28 identical pairs of cards; in ST mode the participants were given 3 minutes for this task, while in MT mode participants were performing Memory Task in addition to all the remaining tasks for 6 minutes. The duration of the Driving Task was equally 6 minutes for both modes of training.

The different session durations are explained by the fact that it takes longer to do the tasks after the others in the ST regime than concurrently in the MT regime, and while the MT session lasts about 30 minutes (6 minutes x 4 trials), the ST session would have lasted about 2 hours (6 minutes x 4 tasks x 4 trials per task). The aim of this timing was to maintain the number of trials and stimulus contacts consistently across all the groups, instead of focusing on overall learning time.

At the beginning of the first session, participants were presented with an information sheet and the consent form. Next, participants were given a questionnaire about demographics, including age, gender, driving experience and whether they played videogames. Then they were provided with instructions and a short practice run of each task separately for about 2-3 minutes each, and then all tasks together in MT mode (also 2-3 minutes). At the end of the first and the last session (pre- and post-session), participants were asked to provide feedback about their performance experience in ST and MT trials (data not presented in this thesis). Additionally, participants were asked to fill out the adjusted NASA Task Load Index (NASA, 2006), which includes visual-analogue-scale questions, e.g., "how mentally demanding was the task?", "How insecure, discouraged, stressed did you feel during the task?" (data not presented).

4.3 Results

4.3.1 Driving Task

The learning effect is key to this analysis, and before calculating the statistical tests, I first checked the data for outliers. For this, the learning effect values were z-transformed, separate for each group, and outliers were defined as z >= 3 (see Methods for details). One outlier was identified in the Mix group and excluded from all following analyses of the Penalties scores.

Raw scores. The raw scores of participants directly reflecting the raw number of penalties produced in the driving task were analysed (Tab 4.2, Fig 4.5).

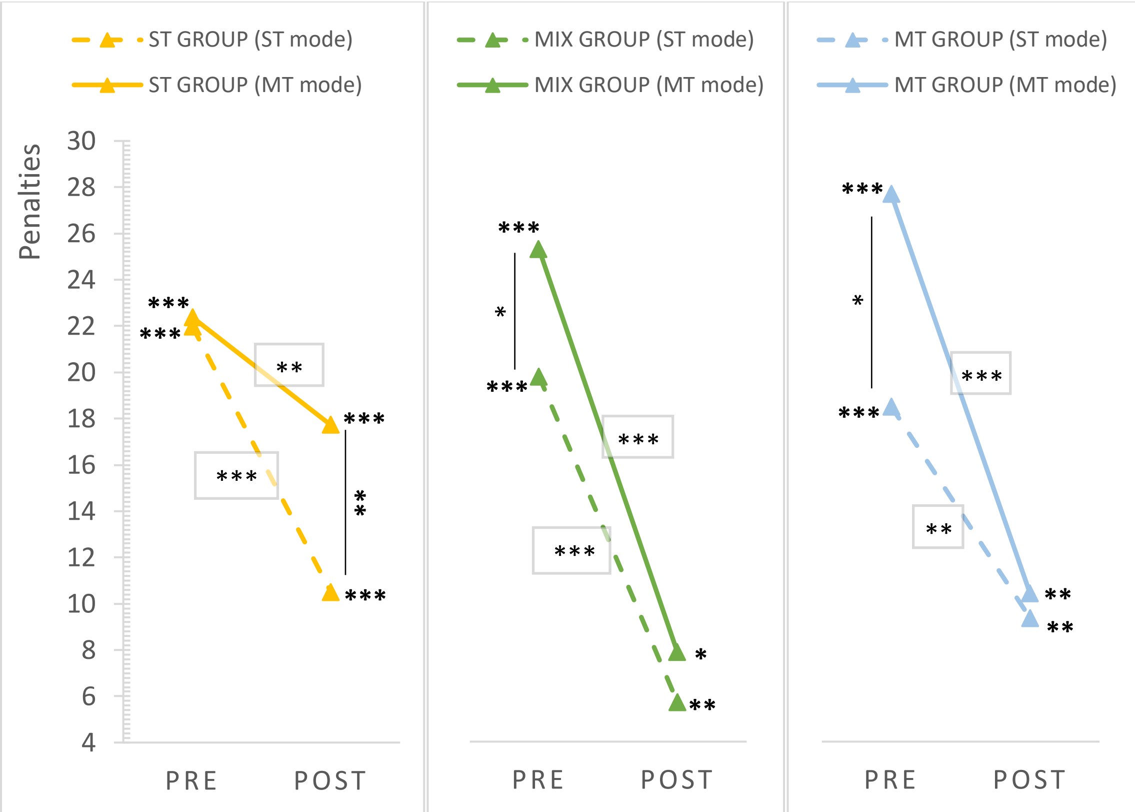
Table 4.2

Penalty raw scores. Higher scores reflect worse performance.

Session		**ST GROUP**		**MIX GROUP**		**MT GROUP**	
		ST mode	**MT mode**	**ST mode**	**MT mode**	**ST mode**	**MT mode**
PRE	**M**	21.97	22.38	19.80	25.27	18.50	27.69
	SD	13.53	15.52	12.77	19.18	17.61	24.43
POST	**M**	10.50	17.72	5.70	7.87	9.34	10.41
	SD	10.00	15.44	4.48	6.21	8.15	12.07

Figure 4.5

Penalty raw scores. The asterisks (*<0.05; **<0.01) next to the vertical lines indicate statistically significant differences between ST and MT modes at pre- and post-sessions, respectively, whereas the asterisk symbols in the boxes show significant differences of the raw scores between the pre- and post-sessions for ST mode and MT mode, respectively.



To test for differences in the penalty raw scores, first I calculated a 2 x 2 x 3 mixed ANOVA (Table 4.3) with the within-subject factors Time (Pre, Post) and Mode (ST, MT), and the between-subject factor Group (ST, Mix, MT). Averaged across groups and modes, performance was significantly better at post-session as compared to pre-session (main effect of time, $F(1, 44)=65.79$, $p<.001$, $\eta^2=.599$). The effect of Mode is the difference between ST mode and MT mode averaged across groups and averaged across Time (Pre, Post) was significant (ME of mode, $F(1, 44)=13.47$, $p=.001$, $\eta^2=.234$). Overall, there were more penalties in the MT mode as compared to the ST mode. The main effect of Group was not significant ($F(2, 44)=0.305$, $p=.739$, $\eta^2=.014$).

Table 4.3.

Penalty raw scores. Results of four mixed ANOVAs (one overall and three separate for each group).

N	47	16	15	16
	All Groups	**ST Group**	**Mix Group**	**MT Group**
		Main Effects		
Time (Pre, Post)	F(1, 44)=65.79, **p<.001**, η²=.599	F(1, 15)=19.22, **p=.001**, η²=.562	F(1, 14)=31.78, **p<.001**, η²=.694	F(1, 15)=17.96, **p=.001**, η²=.545
Mode (ST, MT)	F(1, 44)=13.47, **p=.001**, η²=.234	F(1, 15)=3.24, p=.092, η²=.177	F(1, 14)=7.81, **p=.014**, η²=.358	F(1, 15)=4.84, **p=.044**, η²=.244
Group (ST, Mix, MT)	F(2, 44)=0.305, p=.739, η²=.014			
		Interactions		
Time * Mode	F(1, 44)=1.04, p=.313, η²=.023	F(1, 15)=7.41, **p=.016**, η²=.331	F(1, 14)=2.68, **p=.124**, η²=.161	F(1, 15)=6.80, **p=.020**, η²=.312
Time * Group	F(2, 44)=2.20, p=.122, η²=.091			
Mode * Group	F(2, 44)=1.14, p=.866, η²=.006			
Time * Mode * Group	F(2, 44)=8.72, **p=.001**, η²=.284			

Whereas the three 2-way interactions of time*mode ($F(1, 44)=1.043$, $p=.313$, $\eta^2=.023$), time*group ($F(1, 44)=2.204$, $p=.122$, $\eta^2= .091$) and mode*group ($F(1, 44)=0.144$, p=.866, η^2=.006) were not significant, the 3-way interaction time*mode*group showed significance (F(2, 44)=8.718, p=.001, η^2=.284). To further investigate the significant 3-way interaction (time*mode*group), I analysed the results of three training groups one by one.

MT Group

Participants exhibited a significant number of penalties in the pre-session (Fig 4.4), during MT mode (M=27.69 penalties, one-sample t-test vs 0, t(15)=4.53, p<.001) as well as ST mode (M=18.50 penalties, one-sample t-test vs 0, t(15)=4.61, p<.001). Therefore, at pre-session the MT group showed statistically significant MT costs, i.e. MT mode penalties (27.69) minus ST mode penalties (18.50) of 9.19 penalties (one-sample t-test vs 0, t(15)2.45, p=.027).

Table 4.4

Penalty raw scores. T-tests within the training groups.

Comparison	ST Group	Mix Group	MT Group
ST Mode (Pre) vs MT Mode (Pre)	t(15)=.136, p=.894, d=.028	t(14)=2.442, **p=.028**, d=.336	t(15)=2.448, **p=.027**, d=.444
ST Mode (Post) vs MT Mode (Post)	t(15)=4.032, **p=.001**, d=.555	t(14)=2.503, **p=.025**, d=.484	t(15)=.836, p=.416, d=.103
ST Mode (Pre) vs ST Mode (Post)	t(15)=4.871, **p<.001**, d=.965	t(14)=6.130, **p<.001**, d=1.473	t(15)=3.450, **p=.004**, d=.719
MT Mode (Pre) vs MT Mode (Post)	t(15)=2.232, **p=.041**, d=.299	t(14)=4.952, **p<.001**, d=1.221	t(15)=4.159, **p=.001**, d=.897

After training in MT regime, in the post-session, the MT group produced a significant number of penalties in MT mode (M=10.41, one-sample t-test vs 0, t(15)=3.45, p=.004) and in ST mode (M=9.34, one-sample t-test vs 0, t(15)=4.59, p<.001). The MT costs of 1.06 at post-session were not statistically significant from zero (one-sample t-test, t(15)=0.84, p=.416) (see Tab 4.5).

Table 4.5

Penalty Costs. One-sample t-tests versus 0 within the groups

Penalty Costs	ST Group	Mix Group	MT Group
Pre-session	t(15)=0.14, p=.894 d=.034	t(14)=2.44, **p=.028**, d=.631	t(15)=2.45, **p=.027**, d=.612.
Post-session	t(15)=4.03, **p=.001**, d= 1.001	t(14)=2.50, **p=.025**, d=.646	t(15)=0.84, p=.416, d=.209 .

Notably, the reduction in penalties was more pronounced in the MT mode (from 27.69 at pre-session to 10.41 at post, a reduction by 17.28 penalties on average, t(15)=4.16, p=.001, paired-sample t-test pre vs post) as compared to the ST mode (from 18.50 at pre to 9.19 at post, reduction by 9.31 penalties on average, t(15)=3.45, p=.004, paired-sample t-test pre vs post), illustrating a significant interaction between Time and Mode (F(1,15)=6.80, p=.020, η^2=.312, interaction in a 2 x 2 ANOVA with Time and Mode; ME time F(1,15)=17.96, p=.001, η^2=.545; ME mode F(1,15)=4.84, p=.044, η^2=.244). Consequently, the MT costs, i.e., the difference between MT mode and ST mode, were higher at pre-session (M=9.19) than at post-session (M=1.06), resulting in a significant MT learning effect of on average 8.13 penalty points (paired two-sample t-test of costs pre vs post t(15)=2.61, p=.020).

This shows that participants did not simply improve their overall performance but in particular learned how to multitask, with the MT costs virtually abolished in the penalties after practice.

Mix Group

Before the training took place, in the pre-session (Fig 4.5), the Mix group produced a significant number of penalties during MT mode (M=25.27 penalties, $t(14)=5.10$, $p<.001$, one-sample t-test vs 0) and in ST mode (M=19.80 penalties, $t(14)=6.01$, $p<.001$, one-sample t-test vs 0). This suggests that the Mix group showed significant MT costs of on average 5.47 penalties (one-sample t-test, $t(14)=2.44$, $p=.028$) (Tab 4.4).

After training in the Mix regime, in the post-session, the Mix group produced a significant number of penalties in MT mode (M=7.87, $t(14)=4.91$, $p<.001$, one-sample t-test vs 0) as well as in ST mode (M=5.70, $t(14)=4.56$, $p<.001$, one-sample t-test vs 0). This shows that the training of Mix regime participants produced MT costs of on average 2.17 penalties (one-sample t-test, $t(14)=2.50$, $p=.025$) (see Tab 4.5).

Notably, the reduction in penalties was numerically more pronounced in the MT mode (from 25.27 at pre- to 7.87 at post-session, a reduction by 17.40 points on average, $t(14)=4.95$, $p<.001$, paired-sample t-test pre vs post) as compared to the ST mode (from 19.80 at pre to 5.70 at post-session, a reduction by 14.10 points, $t(14)=6.13$, $p<.001$, paired-sample t-test pre vs post). However, the Mix group did not show a significant interaction between Time and Mode ($F(1, 14)=2.68$, $p=.124$, $\eta^2=.161$, interaction in a 2 x 2 ANOVA with Time and Mode; ME time $F(1, 14)=31.78$, $p<.001$, $\eta^2=.694$, ME mode $F(1, 14)=7.81$, $p=.014$, $\eta^2=.358$). Consequently, the MT costs, i.e., the difference between MT mode and ST mode, were not significantly lower at post-session (M=2.17) than at pre-session (M=5.47), resulting in a non-significant MT learning effect of on average 3.30 penalty points ($t(14)=1.64$, $p=.124$, paired sample t-test of costs pre vs post). This shows that although the Mix Group improved overall performance in ST and MT modes ($F(1, 14)=31.78$, $p<.001$, $\eta^2=.694$), the Mix training regime resulted in only a moderate improvement in MT learning.

ST group

Before the training took place, in the pre-session, the ST group produced a significant number of penalties in ST mode ($M=21.97$, $t(15)=6.49$, $p<.001$, one-sample t-test vs 0) and in MT mode ($M=22.38$, $t(15)=5.695$, $p<.001$, one-sample t-test vs 0). However, the ST group did not produce significant MT costs (average 0.41 penalties, $t(15)=0.14$, $p=.894$, one-sample t-test vs 0). Since the lack of MT costs at the pre-session is very unusual, further analyses were conducted to understand this pattern in more detail (see Tab 4.4).

First, I aimed at answering the question of whether MT costs were absent because the ST group produced an unexpected high number of penalties in ST mode, or whether in the pre-session the ST group produced an unexpectedly low number of penalties in MT mode, or a combination of both. For this, I first compared the ST mode performance across groups. Three independent sample t-tests showed that the ST mode performance did not differ significantly between the groups (two-sample t-tests, ST group vs Mix ($t(30)=0.31$, $p=.759$), ST group vs MT group ($t(30)=0.66$, $p=.514$), Mix group vs MT group ($t(30)=0.40$, $p=.694$). Therefore, it appears that the performance of the ST group in the ST mode was comparable to the performance of the Mix and MT groups in ST mode (see Tab 4.5).

Secondly, I compared the MT mode performance across groups. Three further independent t-tests showed that the ST group did not produce significantly less penalties than the Mix group (two-sample t-tests, ST group vs Mix $t(30)=0.72$, $p=.479$) and the MT group (two-sample t-tests, ST group vs MT, $t(30)=0.73$, $p=.470$). In addition, the MT and Mix groups did not differ significantly from each other (two-sample t-test, Mix group vs MT, ($t(30)=0.10$, $p=.918$).

Therefore, it appears that the absence of MT costs might be explained by a combination of two sources. First, the ST group had numerically (but statistically non-significant) slightly more penalties during ST mode than expected from the performance of the Mix and MT groups. Second, the ST group had numerically (but statistically non-significant) markedly less penalties during MT mode than expected from the Mix and MT groups.

After training in the ST regime, in the post-session the ST group produced a significant number of penalties in the ST mode ($M=10.50$, one-sample t-test vs 0, $t(15)=4.20$, $p=.001$) and in the MT mode ($M=17.72$, one-sample t-test vs 0, $t(15)=4.59$, $p<.001$). This shows that the training in the ST regime resulted in significant MT costs at post-session ($M=7.22$, paired t-test post ST mode vs post MT mode, $t(15)=4.03$, $p=.001$).

Notably, the reduction in penalties was more pronounced in the ST mode (from 21.97 at pre-session to 10.50 at post-session, a reduction by 11.47 points on average, $t(15)=4.87$, $p<.001$, paired-sample t-test pre vs post) as compared to the MT mode (from 22.37 at pre to 17.72 at post, reduction by 4.65 points, $t(15)=2.23$, $p=.041$, paired-sample t-test pre vs post), illustrating a significant interaction between Time and Mode ($F(1, 15)=7.41$, $p=.016$, $\eta^2=.331$, interaction in a 2 x 2 ANOVA with Time and Mode; ME time $F(1, 15)=19.22$, $p=.001$, $\eta^2=.562$, ME mode $F(1, 15)=3.24$, $p=.092$, $\eta^2=.177$). Consequently, the MT costs, i.e., the difference between MT mode and ST mode, were significantly higher at post- ($M=7.22$) than at pre-session ($M=0.41$). The MT costs were higher in post compared to pre-session, because while the ST group improved performance in ST mode, they improved much less in MT mode, resulting in a significant increase of MT costs, by on average 4.25 penalty points (paired sample t-test of costs pre vs post, $t(15)=2.72$, $p=.015$). This finding is unexpected and most likely caused by the unusual performance in the pre-session: see the Discussion section for a thorough evaluation. Nevertheless, it shows that, although training in the ST regime resulted in significant improvement of overall performance of individual tasks, there was no MT learning effect, which indicates that ST training regime did not result in specifically learning multitasking, i.e., the coordination between tasks. To support the notion that there was no or only minimal MT learning in the ST group, it is noteworthy that the MT mode performance (in form of raw penalty scores at post-session) of the ST group ($M=17.72$ penalties) was statistically worse than the Mix group ($M=7.9$ penalties) , two-sample t-test Mix vs ST, $t(29)=2.49$, $p=.029$) and numerically worse than the MT group ($M=10.41$ penalties, two-sample t-test MT vs ST, $t(30)=1.49$, $p=.146$).

Comparison of Learning Effects in MT costs across groups

The central question of this study was to assess whether the three different groups showed differences in multitasking learning. For this, I calculated, separately for each group, the *learning effect*, which is the MT costs in the pre-session minus the MT costs in the post-session (and the MT costs are the raw scores in the MT mode minus the raw scores in the ST mode). Therefore, larger learning effects reflect a stronger reduction in MT costs from the pre- to the post-session, i.e., more MT learning (Table 4.6, Figure 4.6)

Table 4.6

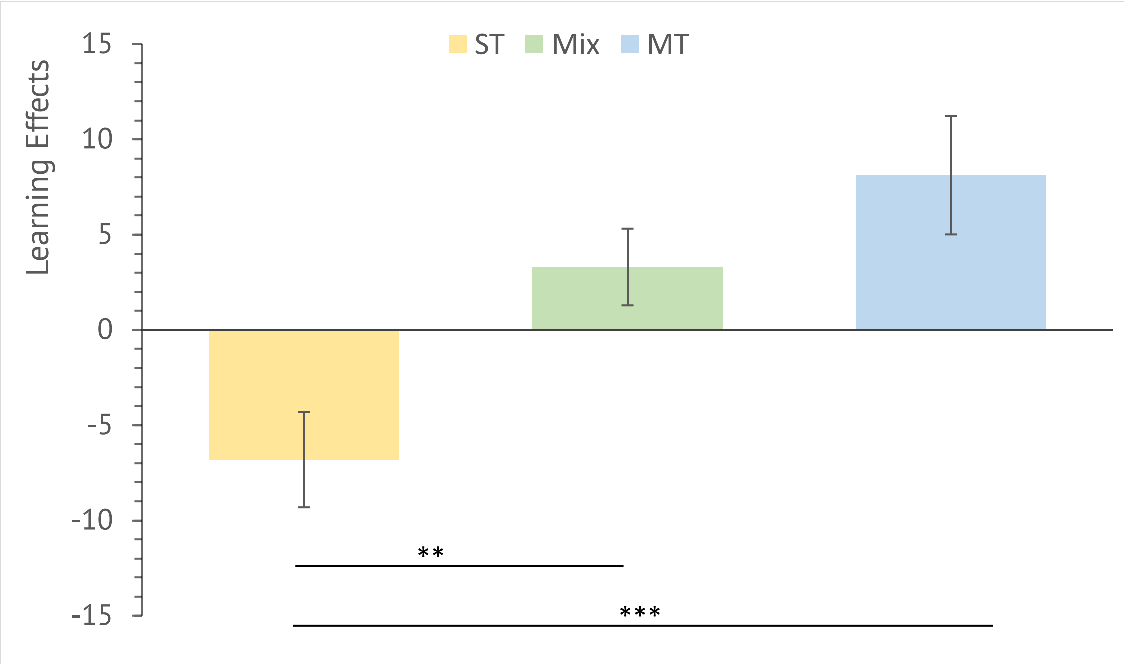
Learning effect in MT Costs, calculated as pre-costs minus post-costs penalty values.

	ST GROUP	MIX GROUP	MT GROUP
N	16	15	16
M	-6.81	3.30	8.13
SD	10.01	7.80	12.46

Descriptive results showed the largest learning effect in the MT group (M=8.13, SD=12.46, t-test vs 0, t(15)=0.90, p=.383), followed by the Mix group (M=3.30, SD=7.80, t-test vs 0, t(14)=0.58, p=.569), and the smallest learning effect in the ST group (M=-6.81, SD=10.01, t-test vs 0, t(15)=0.94, p=.363). For the ST group, the learning effect is negative (not significantly), which means that technically participants declined in their multitasking performance from the pre- to the post-session. However, as described above and discussed further below, this is most likely caused by the unusual finding of no MT costs in the pre-session.

Figure 4.6

Learning effect (MT costs pre minus MT costs post) in Penalties for the ST, Mix and MT groups. The asterisk symbols (**<0.01; ***<0.001) at the top of the bar chart indicate whether the size of the learning effect was significantly different from 0. The asterisk symbols on the bottom lines represent the statistically significant differences between the groups, e.g., ST group vs Mix group.



To test whether the size of the learning effects differ between groups, a one-way ANOVA with the factor group (ST, Mix, MT) was calculated, which was significant ($F(2, 44)=8.72$, $p=.001$, $\eta^2=.284$). To understand which groups differed from each other, three two-sample t-tests were calculated. These tests showed that the learning effect in the MT group ($M=8.12$) did not differ significantly from the learning effect in the Mix group ($M = 3.30$; $t(29)=1.28$, $p=.210$, $d=.460$). The learning effect in the MT group ($M=8.12$) was, however, significantly higher than in the ST group ($M=-6.81$; $t(30)=3.74$, $p=.001$, $d=1.320$). Finally, the learning effect in the Mix group (M=3.30) was significantly higher than in the ST group (M=-6.81; t(29)=3.12, p=.004, d=.39).

Overall, the largest reduction of MT costs from pre- to post-session (i.e., MT learning), occurred after learning in the MT training regime. In fact, in the post-session, the MT group produced a similar number of penalties in ST mode and MT mode, resulting in no significant MT costs after the training. The smallest reduction of MT costs was observed after training in ST regime and resulted in a non-significant learning effect. The Mix training numerically stands in between the learning effects of the ST and MT regimes, which may explain why it did not differ significantly from either of them.

4.3.2 Math Task

Raw scores. The raw scores of participants directly demonstrating the errors and missed equations in the math task were analysed (Tab 4.7, Fig 4.7).

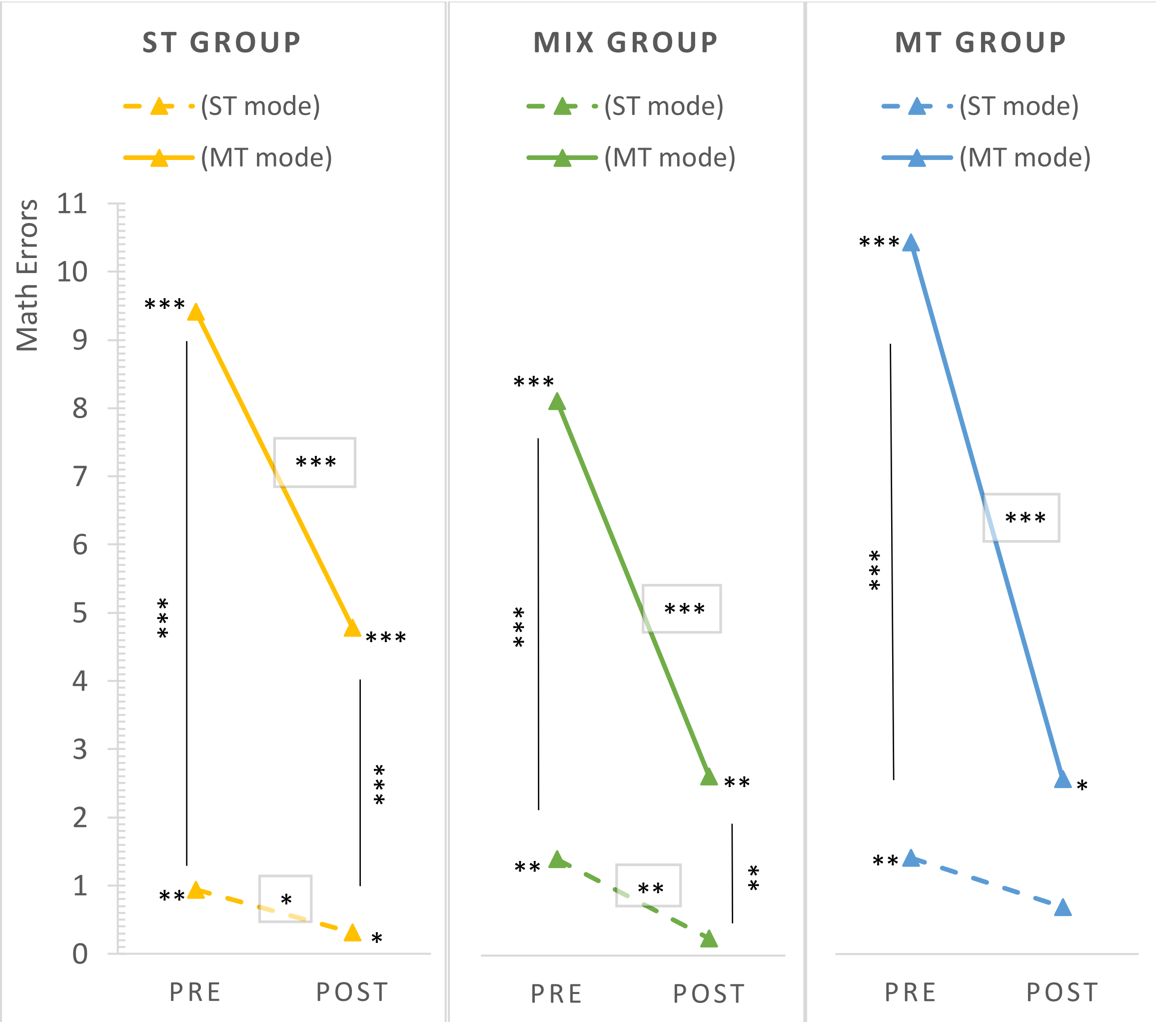
Table 4.7

Math raw errors

Session		**ST GROUP**		**MIX GROUP**		**MT GROUP**	
		ST mode	**MT mode**	**ST mode**	**MT mode**	**ST mode**	**MT mode**
PRE	**M**	0.94	9.41	1.41	8.13	1.41	10.44
	SD	1.21	3.10	1.67	3.40	1.69	4.07
POST	**M**	0.31	4.78	0.25	2.63	0.69	2.56
	SD	0.48	3.38	0.48	2.67	1.93	4.15

Figure 4.7

Math raw scores. The asterisks (*<0.5; **<0.01) on the lines demonstrate the statistically significant difference between ST and MT modes at pre- and post-sessions, respectively, whereas the asterisk symbols in the box on the line show the significant difference of the raw scores between the pre- and post-sessions for ST mode and MT mode, respectively.



To test for differences in the math error raw scores, first I calculated a 2 x 2 x 3 mixed ANOVA (Table 4.8) with the within-subject factors Time (Pre, Post) and Mode (ST, MT), and the between-subject factor Group (ST, Mix, MT). Averaged across groups and mode, performance was significantly better at post-session as compared to pre-session (main effect of time, $F(1, 45)=121.23$, $p<.001$, $\eta^2=.729$). The effect of training modes showed significantly higher number of math errors in MT mode, than in ST mode (ME of mode, $F(1, 45)=203.07$, $p<.001$, $\eta^2=.819$). The effect of the groups was not significant (ME of group, $F(2, 45)=0.79$, $p=.459$, $\eta^2=.034$).

Table 4.8

Math raw scores. Between subjects and within subject ANOVAs.

N	48	16	16	16
	All Groups	**ST Group**	**Mix Group**	**MT Group**
		Main Effects		
Time (Pre, Post)	$F(1, 45)=121.23$, **$p<.001$**, $\eta^2=.729$	$F(1, 15)=57.02$, **$p<.001$**, $\eta^2=.792$	$F(1, 15)=25.06$, **$p<.001$**, $\eta^2=.626$	$F(1, 15)=60.78$, **$p<.001$**, $\eta^2=.802$
Mode (ST, MT)	$F(1, 45)=203.07$, **$p<.001$**, $\eta^2=.819$	$F(1, 15)=92.57$, **$p<.001$**, $\eta^2=.861$	$F(1, 15)=80.32$, **$p<.001$**, $\eta^2=.843$	$F(1, 15)=47.49$, **$p<.001$**, $\eta^2=.760$
Group (ST, Mix, MT)	$F(2, 45)=0.79$, $p=.459$, $\eta^2=.034$			
		Interactions		
Time * Mode	$F(1, 45)=122.89$, **$p<.001$**, $\eta^2=.732$	$F(1, 15)=29.54$, **$p<.001$**, $\eta^2= .663$	$F(1, 15)=23.30$, **$p<.001$**, $\eta^2=.608$	$F(1, 15)=84.85$, **$p<.001$**, $\eta^2=.850$
Time * Group	$F(2, 45)=2.44$, $p=.099$, $\eta^2=.098$			
Mode * Group	$F(2, 45)=2.08$, $p=.137$, $\eta^2=.084$			
Time * Mode * Group	$F(2, 45)=4.60$, **$p=.015$**, $\eta^2=.170$			

Whereas the 2-way interactions of time*mode ($F(1, 45)=122.89$, $p<.001$, $\eta^2=.732$), time*group ($F(2, 45)=2.44$, $p=.099$, $\eta^2=.098$) were significant, and interaction mode*group ($F(2, 45)=2.08$, $p=.137$, $\eta^2=.084$) was not significant, the 3-way interaction time*mode*group showed significance ($F(2, 45)=4.60$, $p=.015$, $\eta^2=.170$). To further investigate the significant

3-way interaction time*mode*group, I analysed the results of three training groups one by one.

MT Group

Before the training took place, in the pre-session (Fig 4.7), MT group produced a significant number of math errors during MT mode (M=10.44 math errors, one-sample t-test vs 0, t(15)=10.26, p<.001) and in ST mode (M=1.41 math errors, one-sample t-test vs 0, t(15)=3.34, p=.004). This suggests that the MT group showed significant MT costs of on average 9.03 math errors (one-sample t-test, t(15)=10.32, p<.001) (see Tab 4.9).

Table 4.9

Math raw error scores. T-tests within the training groups.

Comparison	ST Group	Mix Group	MT Group
ST Mode (Pre) vs MT Mode (Pre)	t(15)=12.70, **p<.001**, d=3.599	t(15)= 8.89, **p<.001**, d=2.20	t(15)=10.32, **p<.001**, d=2.899
ST Mode (Post) vs MT Mode (Post)	t(15)= 5.23, **p<.001**, d=1.853	t(15)= 4.02, **p=.001**, d=1.239	t(15)=2.111, p=.052, d=.579
ST Mode (Pre) vs ST Mode (Post)	t(15)= 2.18, **p=.046**, d=.679	t(15)= 2.77, **p=.014**, d=.943	t(15)=1.84, p=.085, d=.396
MT Mode (Pre) vs MT Mode (Post)	t(15)= 7.05, **p<.001**, d=1.427	t(15)= 5.21, **p<.001**, d=1.80	t(15)=9.05, **p<.001**, d=1.915

After training in MT regime, in the post-session, the MT group produced a significant number of math errors in MT mode (M=2.56, one-sample t-test vs 0, t(15)=2.48, p=.026) but not a significant number of math errors in ST mode (M=0.69, one-sample t-test vs 0, t(15)=1.42, p=.175). This shows that the training in MT regime resulted in MT costs on average 1.87 math errors (one-sample t-test, t(15)=2.11, p=.052) (see Tab 4.10).

Table 4.10

Math Error Costs, One-sample t-tests within the groups

Math Costs	ST Group	Mix Group	MT Group
Pre-session	t(15)=12.70, **p<.001,** d=3.175	t(15)=8.89, **p<.001,** d=2.223	t(15)=10.32, **p<.001**, d=2.580
Post-session	t(15)=5.23, **p=.001**, d= 1.307	t(15)=4.02, **p=.001**, d=1.005	t(15)=2.11, p=.052, d=.528

Notably, the reduction in math errors was more pronounced in the MT mode (from 10.44 at pre-session to 2.56 at post, a reduction by 7.88 math errors on average, t(15)=9.05, p<.001, paired-sample t-test pre vs post) as compared to the ST mode (from 1.41 at pre to 0.69 at post, reduction by 0.72 math errors on average, t(15)=1.84, p=.085, paired-sample t-test pre vs post), illustrating a significant interaction between Time and Mode (F(1, 15)=84.85, p<.001, η^2=.850, interaction in a 2 x 2 ANOVA with Time and Mode; ME time F(1, 15)=60.78, p<.001, η^2=.802; ME mode F(1, 15)=47.49, p<.001, η^2=.760). Consequently, the MT costs, i.e., the difference between MT mode and ST mode, were higher at pre-session (M =9.03) than at post-session (M=1.87), resulting in a significant MT learning effect of on average 7.16 math error points (paired two-sample t-test of costs pre vs post t(15)=4.83, p<.001). This shows that participants did not simply improve their overall performance but in particular learned how to multitask.

Mix Group

Before the training took place, in the pre-session (Fig 4.3.2.1), the Mix group produced more math errors during MT mode (M=8.13 math errors, t(15)=9.56, p<.001, one-sample t-test vs 0) as compared to ST mode (M=1.41 math errors, t(15)=3.78, p=.004, one-sample t-test vs 0). This suggests that the Mix group showed significant MT costs of on average 6.72 math errors (one-sample t-test, t(15)=1.93, p=.072) (Tab 4.9).

After training in the Mix regime, in the post-session, the Mix group produced significant number of math errors in MT mode (M=2.63, t(15)=3.94, p=.001, one-sample t-test vs 0) and approaching significance number of math errors in ST mode (M=0.25, t(15)=2.07, p=.056, one-sample t-test vs 0). This shows that the training in the Mix regime improved performance in the math task, as assessed by math errors with MT costs of on average 2.38 math errors (one-sample t-test, t(15)=4.02, p=.001, (see Tab 4.10).

Notably, the reduction in math errors was more pronounced in the MT mode (from 8.13 at pre- to 2.63 at post-session, a reduction by 5.5 points on average, t(15)=5.21, p<.001, paired-sample t-test pre vs post) as compared to the ST mode (from 1.41 at pre to 0.25 at post-session, a reduction by 1.16 points, t(15)=2.77, p=.014, paired-sample t-test pre vs post). Consequently, the Mix group showed a significant interaction between Time and Mode (F(1, 15)=23.30, p<.001, η^2=.608, interaction in a 2 x 2 ANOVA with Time and Mode; ME time F(1, 15)=25.06, p<.001, η^2=.626, ME mode F(1, 15)=80.32, p<.001, η^2=.843). Consequently, the MT costs, i.e., the difference between MT mode and ST mode, were lower at post-session (M=2.38) than at pre-session (M=6.72), resulting in a significant MT learning effect of on average 4.34 math errors points (t(15)=9.21, p< .001, paired sample t-test of costs pre vs post). This shows that the Mix group did not simply improve their overall performance, but specifically learned how to multitask.

ST group

Before the training took place, in the pre-session, the ST group produced more math errors in MT mode (M= 9.41 math errors, one-sample t-test vs 0, $t(15)=12.14$, $p<.001$, one-sample t-test vs 0) as compared to ST mode (M=0.94 math errors, one-sample t-test vs 0, $t(15)=3.10$, $p=.007$), suggesting that the ST group produced significant MT costs of an average 8.47 math errors ($t(15)=12.70$ $p<.001$, one-sample t-test vs 0) (see Tab 4.9).

After training in the ST regime, in the post-session the ST group produced a significant number of math errors in the MT mode (M=4.78, one-sample t-test vs 0, $t(15)=5.66$, $p<.001$) and in ST mode (M=0.31, one-sample t-test vs 0, $t(15)=2.61$, $p=.020$). This shows that the training in the ST regime improved performance in the math task, as assessed by math errors with MT costs on average 4.47 math errors (one-sample t-test, $t(15)=0.84$, $p=.416$) (see Tab 4.10).

Noteworthily, the reduction in math errors was more pronounced in the MT mode (from 9.41 at pre to 4.78 at post, reduction by 4.65 points, $t(15)=7.05$, $p<.001$, paired-sample t-test pre vs post) as compared to the ST mode (from 0.94 at pre-session to 0.31 at post-session, a reduction by 11.47 points on average, $t(15)=2.18$, $p=.046$, paired-sample t-test pre vs post), illustrating a significant interaction between Time and Mode ($F(1, 15)=29.54$, $p<.001$, $\eta^2=.663$, interaction in a 2 x 2 ANOVA with Time and Mode; ME time $F(1, 15)=57.02$, $p<.001$, $\eta^2=.792$, ME mode $F(1, 15)=92.57$, $p<.001$, $\eta^2=.861$). Consequently, the MT costs, i.e., the difference between MT mode and ST mode, were lower at post-session (M=4.47) than at pre-session (M=8.47), resulting in a significant MT learning effect of on average 4.0 math errors points ($t(15)=5.44$, $p<.001$, paired sample t-test of costs pre vs post).

Comparison of Learning Effects in MT costs across groups

The central question of this study was to assess whether the three different groups showed differences in multitasking learning. For this, I calculated, separately for each group, the *learning effect*, which is the MT costs in the pre-session minus the MT costs in the post-session (and the MT costs are the raw scores in the MT mode minus the raw scores in the ST mode). Therefore, larger learning effects reflect a stronger reduction in MT costs from the pre- to the post-session, i.e., more MT learning (Table 4.11, Figure 4.8).

Table 4.11

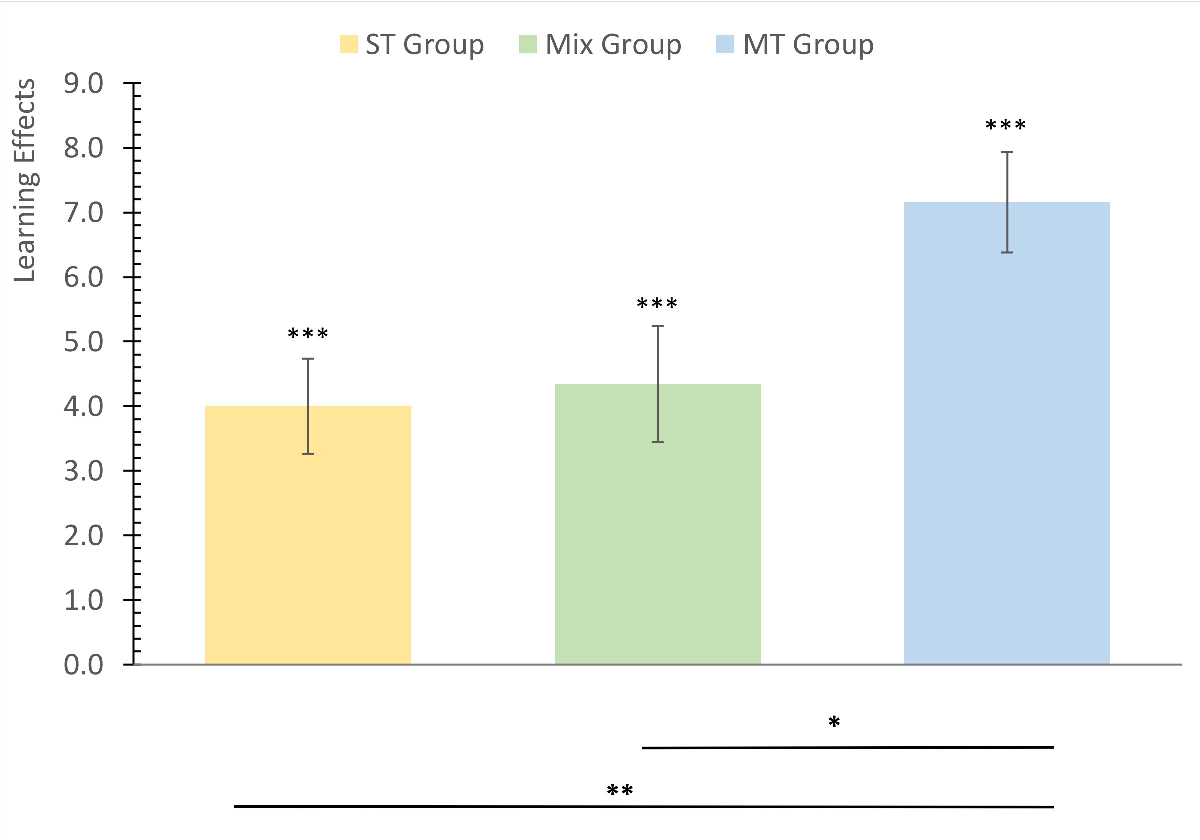
Learning effect in MT Costs, calculated as pre- minus post-session math values.

	ST GROUP	**MIX GROUP**	**MT GROUP**
N	16	16	16
M	4.0	4.34	7.16
SD	8.67	12.96	9.66

Descriptive results showed the largest learning effect in the MT group (M=7.16, t(16)=9.21, p<.001 one-sample t-test vs 0:), followed by the Mix group (M=4.34, t(16)=4.83, p<.001), and the smallest learning effect in the ST group (M=4.0, t(16)=4.43, p<.001).

Figure 4.8

The learning effect in Math MT Costs for ST, Mix and MT groups. The asterisk symbols (*<0.5; **<0.01; ***<0.001) at the top of the bar chart shows the learning effect, i.e., significant difference of the MT costs between the pre-test and post-test. The asterisk symbols on the bottom lines represent the statistically significant differences between the groups, e.g., ST group vs Mix group.



To test whether the size of the learning effects differed between groups, a one-way ANOVA with the factor group (ST, Mix, MT) was calculated, which was significant ($F(2, 45)=4.60$, $p=.015$, $\eta^2=.284$). To understand which groups differed from each other, three two-sample t-tests were calculated. These tests showed that the learning effect in the MT group ($M = 7.16$) was significantly higher than in the Mix group ($M=4.34$; $t(30)=2.37$, $p=.025$, $d=.246$) and in the ST group ($M=4.0$; $t(30)=2.95$, $p=.006$, $d=.344$). Finally, the learning effect in the Mix group (M=4.34) was not significantly higher than in the ST group (M=4.0; t(30)=0.29, p=.770, d=.031).

Overall, the largest reduction of MT costs from pre- to post-session (i.e., MT learning), occurred after learning in the MT training regime and the smallest reduction of MT costs was observed after training in the ST regime. Although there is no significant difference in the ST and Mix learning effects, numerically the Mix regime stands in between the learning effects of the ST and MT regimes.

4.3.3 Monitoring Task

Raw scores. The raw scores of participants directly reflecting the raw number of missed or wrongly identified locations on the screens in monitoring task were analysed (Tab 4.12, Fig 4.9).

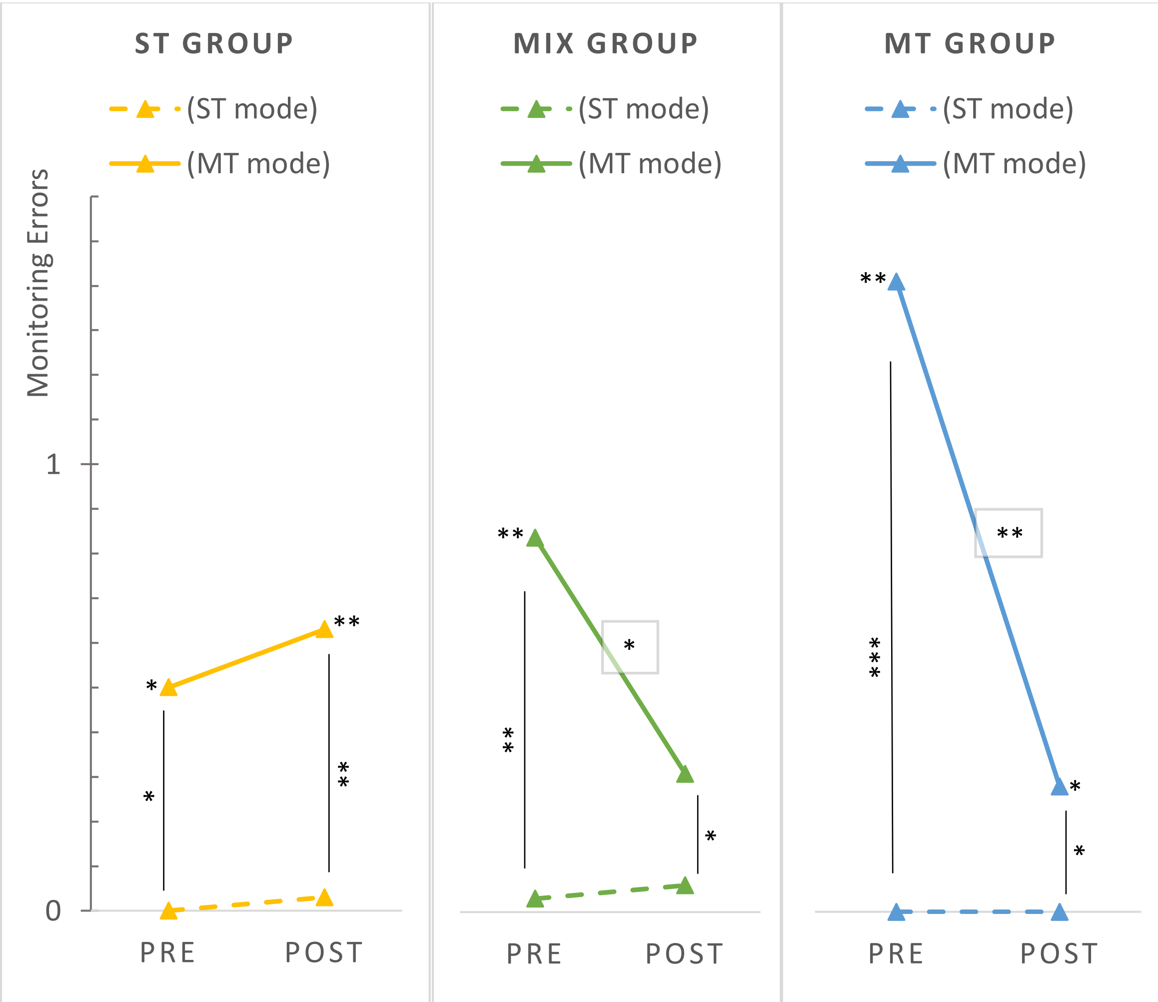
Table 4.12

Monitoring error raw scores.

Session		**ST GROUP**		**MIX GROUP**		**MT GROUP**	
		ST mode	**MT mode**	**ST mode**	**MT mode**	**ST mode**	**MT mode**
PRE	**M**	0	0.50	0.03	0.84	0	1.41
	SD	0	0.68	0.13	0.96	0	1.33
POST	**M**	0.03	0.63	0.63	0.31	0	0.28
	SD	0.13	0.69	0.17	0.36	0	0.45

Figure 4.9

Monitoring error raw scores. The asterisks (*<0.5; **<0.01) on the lines demonstrate the statistically significant difference between ST and MT modes at pre- and post-sessions, respectively, whereas the asterisk symbols in the box on the line show the significant difference of the raw scores between the pre- and post-sessions for ST mode and MT mode, respectively.



To test for differences in the monitoring raw scores, first I calculated a 2 x 2 x 3 mixed ANOVA (Table 4.13) with the within-subject factors Time (Pre, Post) and Mode (ST, MT), and the between-subject factor Group (ST, Mix, MT). Averaged across groups and modes, performance was significantly better at post-session as compared to pre-session (main effect of time, F(1, 45)=10.99, p=.002, η^2=.196). The effect of training modes (ST and MT) showed significantly higher number of monitoring errors in MT mode, than in ST mode (ME of mode, F(1, 45)=49.95, p<.001, η^2=.526). The effect of the groups was not significant (ME of group, F(2, 45)=0.78, p=.463, η^2=.034).

Table 4.13

Monitoring raw scores. Between subjects and within subject ANOVA.

N	48	16	16	16
	All Groups	**ST Group**	**Mix Group**	**MT Group**
		Main Effects		
Time (Pre, Post)	F(1, 45)=10.99, **p=.002**, η^2=.196	F(1, 15)=0.66, p=.429, η^2=.042	F(1, 15)=4.14, **p=.060**, η^2=.216	F(1, 15)=12.79, **p=.003**, η^2=.460
Mode (ST, MT)	F(1, 45)=49.95, **p<.001**, η^2=.526	F(1, 15)=17.82; **p=.001**, η^2=.543	F(1, 15)=13.93, **p=.002**, η^2=.482	F(1, 15)=19.29, **p=.001**, η^2=.563
Group (ST, Mix, MT)	F(2, 45)=0.78, p=.463, η^2=.034			
		Interactions		
Time * Mode	F(1, 45)=12.12, **p=.001**, η^2=.212	F(1, 15)=0.17, p=.682, η^2=.011	F(1, 15)=5.26, **p=.037**, η^2=.260	F(1, 15)=12.79, **p=.003**, η^2=.460
Time * Group	F(2, 45)=6.27, **p=.004**, η^2=.218			
Mode * Group	F(2, 45)=1.26, p=.294, η^2=.053			
Time * Mode * Group	F(2, 45)=5.33, **p=.008**, η^2=.191			

Whereas the 2-way interactions of time*mode (F(1, 45)=12.12, p=.001, η^2=.212), time*group (F(2, 45)=6.27, p=.004, η^2=.218) were significant, the interaction mode*group (F(2, 45)=1.26, p=.294, η^2=.053) was not significant, and the 3-way interaction time*mode*group was significant (F(2, 45)=5.33, p=.008, η^2=.191). To further investigate the significant 3-way interaction time*mode*group, I analysed the results of three training groups one by one.

MT Group

Before the training took place, in the pre-session (Fig 4.12), the MT group produced a significant number of monitoring errors during MT mode (M=1.41 monitoring errors, one-sample t-test vs 0, t(15)=2.93, p=.010) as compared to ST mode (M=0 monitoring errors, participants reported all 10 red screens correctly. This suggests that MT group showed significant MT costs of on average 1.41 monitoring errors (one-sample t-test, t(15)=4.22, p=.001) (see Tab 4.14).

Table 4.14

Monitoring error raw scores. T-tests within the training groups.

Comparison	ST Group	Mix Group	MT Group
ST Mode (Pre) vs MT Mode (Pre)	t(15)=2.93, **p=.010**, d=.031	t(15)=3.26, **p=.005,** d=2.20	t(15)=4.22, **p=.001,** d=2.899
ST Mode (Post) vs MT Mode (Post)	t(15)=3.45, **p=.004,** d=1.853	t(15)=2.74, **p=.015**, d=1.239	t(15)=2.52, **p=.023**, d=.579
ST Mode (Pre) vs ST Mode (Post)	t(15)=1.0, p=.333, d=.679	t(15)=0.57, p=.580, d=.943	**N/A**
MT Mode (Pre) vs MT Mode (Post)	t(15)=0.61, p=.554, d=1.427	t(15)=2.22, **p=.042**, d=1.80	t(15)=3.58, **p=.003**, d=1.915

N/A refers to not applicable, because there were 0 errors in both ST modes at pre- and post-sessions.

After training in the MT regime, in the post-session, the MT group produced a significant number of monitoring errors in the MT mode (M=0.28, one-sample t-test vs 0, t(15)=2.52, p=.023) but in ST mode (M=0), while participants showed a floor effect. Note that this task was mostly included to make the MT situation more demanding and that, if performed as a ST, it was an extremely easy task. This shows that the training in the MT regime resulted in MT costs of on average 0.28 monitoring errors (one-sample t-test vs 0, t(15)=2.52, p=.023) (see Tab 4.15).

Table 4.15

Monitoring Costs, SPSS One-sample t-tests within the groups

Monitoring Costs	**ST Group**	**Mix Group**	**MT Group**
Pre-session	t(15)=2.93, **p=.010,** d=.732	t(15)=3.26, **p=.005**, d=.815	t(15)=4.22, **p=.001**, d=1.059
Post-session	t(15)=3.45, **p=.004**, d= .863	t(15)=2.74, **p=.015**, d=.685	t(15)=2.52, **p=.023**, d=.630

In ST mode, participants showed perfect performance at pre- and post-sessions (0 monitoring errors, consequently no t-test was calculated). In MT mode there was a reduction in monitoring errors from 1.41 at pre- to 0.28 at post- session, a significant reduction by 1.19 monitoring errors on average (t(15)=3.58, p=.003, paired-sample t-test pre vs post). This illustrates a significant interaction between Time and Mode (F(1, 15)=12.79, p=.003, η^2=.460, interaction in a 2 x 2 ANOVA with Time and Mode; ME time F(1, 15)=12.79, p=.003, η^2=.460; ME mode F(1, 15)=19.29, p=.001, η^2=.563). Consequently, the MT costs, i.e., the difference between MT mode and ST mode, were higher at pre-session (=1.41) than at post-session (M=0.28), resulting in a significant MT learning effect of on average 1.13 monitoring errors points (paired two-sample t-test of costs pre vs post t(15)=3.58, p=.003). This shows that participants did not simply improve their overall performance but specifically learned how to multitask. This interaction potentially may be also explained by a floor effect in the ST mode and will be discussed in more detail in the discussion section.

Mix Group

Before the training took place, in the pre-session (Fig 4.9), the Mix group produced more monitoring errors during MT mode (M=0.84 monitoring errors, t(15)=3.51, p=.003, one-sample t-test vs 0) as compared to ST mode (M=0.31 monitoring errors, t(15)=1.0, p=.333, one-sample t-test vs 0). This suggests that the Mix group showed significant MT costs of on average 0.53 monitoring errors (one-sample t-test, t(15)=3.26, p=.005) (Tab 4.14).

After training in the Mix regime, in the post-session, the Mix group produced a significant number of monitoring errors in MT mode (M=0.31, t(15)=3.48, p=.003, one-sample t-test vs 0) and non-significance number of monitoring errors in ST mode (M=0.06, t(15)=1.46, p=.164, one-sample t-test vs 0). This shows that the training in the Mix regime improved performance in the monitoring task, as assessed by monitoring errors with MT costs of on average 0.25 monitoring errors (one-sample t-test, t(15)=2.74, p=.015) (see Tab 4.15).

Notably, the reduction in monitoring errors was more pronounced in the MT mode (from 0.84 at pre- to 0.31 at post-session, a reduction by 0.53 points on average, t(15)=2.22, p=.042, paired-sample t-test pre vs post) as compared to the ST mode (from 0.31 at pre to 0.06 at post-session, a reduction by 0.25 points, t(15)=0.57, p=.580, paired-sample t-test pre vs post). It is important to note the floor effect potentially caused by lower starting point at the pre-session, where in ST mode participants produced M=0.31 monitoring errors and there was no possibility to improve by 0.53 points as in the MT mode. Consequently, the Mix group showed a significant interaction between Time and Mode ($F(1, 15)=5.26$, $p=.037$, $\eta^2=.260$, interaction in a 2 x 2 ANOVA with Time and Mode; ME time $F(1, 15)=4.14$, $p=.060$, $\eta^2=.216$, ME mode $F(1, 15)=13.93$, $p=.002$, $\eta^2=.482$). Furthermore, the MT costs were lower at post-session (M=0.25) than at pre-session (M=0.53), resulting in a significant MT learning effect of on average 0.28 monitoring errors points ($t(15)=2.93$, $p=.037$, paired sample t-test of costs pre vs post). This shows that the Mix Group did not simply improve their overall performance but specifically learned how to multitask.

ST group

Before the training took place, in the pre-session, the ST group produced a significant number of monitoring errors in MT mode (M=0.5 monitoring errors, one-sample t-test vs 0, $t(15)=2.93$ $p=.010$, one-sample t-test vs 0) as compared to ST mode (M=0, participants performed without errors), suggesting that the ST group produced significant MT costs of an average 0.5 monitoring errors ($t(15)=2.93$ $p=.010$, one-sample t-test vs 0) (see Tab 4.14).

After training in ST regime, in the post-session the ST group produced a significant number of monitoring errors in the MT mode (M=0.63, one-sample t-test vs 0, $t(15)=3.60$, $p=.003$) but not in ST mode (M=0.03, one-sample t-test vs 0, $t(15)=1.0$, $p=.333$), suggesting that ST group produced significant MT costs of an average 0.6 monitoring errors ($t(15)=3.45$, $p=.004$, one-sample t-test vs 0). This shows that the training in ST regime did not improve performance in the monitoring task, in fact the performance slightly deteriorated from pre-session by MT costs increase of on average 0.1 monitoring errors (one-sample t-test, $t(15)=0.42$, $p=.682$) (see Tab 4.15).

There was an unexpected slight numerical, but statistically non-significant, increase in monitoring errors in the MT mode (from 0.5 at pre to 0.63 at post, $t(15)=0.61$, $p=.554$, paired-sample t-test pre vs post) and in the ST mode (from 0 at pre-session to 0.03 at post-session, an insignificant increase by 0.03 points on average, $t(15)=1.0$, $p=.333$, paired-sample t-test pre vs post). Therefore, the ST group did not illustrate a significant interaction between Time and Mode ($F(1, 15)=0.17$, $p=.682$, $\eta^2=.011$, interaction in a 2 x 2 ANOVA with Time and Mode; ME time $F(1, 15)=0.66$, $p=.429$, $\eta^2= .042$, ME mode $F(1, 15)=17.82$, $p=.001$, $\eta^2=.543$). The MT costs were numerically slightly higher at post-session (M=0.5) than at pre-session (M=0.6), and did not result in a significant MT learning effect (average 0.1 monitoring errors ($t(15)=0.42$, $p=.682$). This shows that the ST Group did not in particular learn how to perform the monitoring task while multitasking.

Comparison of Learning Effects in MT costs across groups

The central question of this study is to assess whether the three different groups showed differences in multitasking learning. For this, I calculated, separate for each group, the *learning effect*, which is the MT costs in the pre-session minus the MT costs in the post-session. Therefore, larger learning effects reflect a stronger reduction in MT costs from the pre- to the post-session, i.e., more MT learning (Table 4.16, Figure 4.10).

Table 4.16

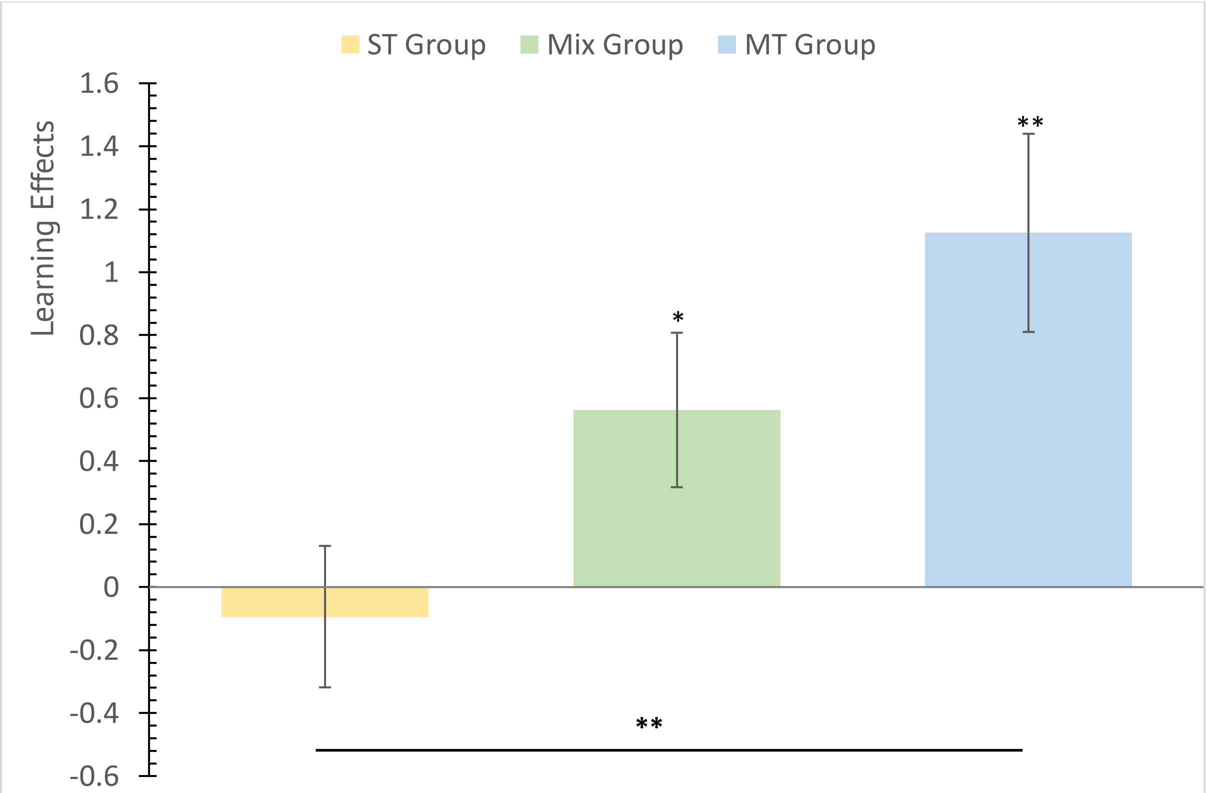
Learning effect in MT Costs, calculated as pre- minus post-session monitoring values.

	ST GROUP	MIX GROUP	MT GROUP
N	16	16	16
M	-0.09	0.56	1.13
SD	0.90	0.98	1.26

Descriptive results showed the largest learning effect in the MT group (M=1.13), followed by the Mix group (M=0.56), and the smallest learning effect in the ST group (M=0.09).

Figure 4.10

The learning effect in Monitoring MT Costs for ST, Mix and MT groups. The asterisk symbols (*<0.5; **<0.01) at the top of the bar chart shows the learning effect, i.e., significant difference of the MT costs between the pre-test and post-test. The asterisk symbols on the bottom lines represent the statistically significant differences between the groups, e.g., ST group vs Mix group.



To test whether the size of the learning effects differed between groups, a one-way ANOVA with the factor group (ST, Mix, MT) was calculated, which was significant ($F(2, 45)=5.33$, $p=.008$, $\eta^2=.209$). To understand which groups differed from each other, three two-sample t-tests were calculated. These tests showed that the learning effect in the MT group ($M=1.13$) was significantly higher than in the ST group ($M=-0.09$; $t(30)=3.15$, $p=.004$, $d=.821$), but not significantly higher than in the Mix group ($M=0.56$; $t(30)=1.41$, $p=.169$, d=.429). Finally, the learning effect in the Mix group (M=0.56) was just failed to reach significance compared to the ST group (M=-0.09; t(30)=1.97, p=.058, d=.528).

Overall, the largest reduction of MT costs from pre- to post-session (i.e., MT learning), occurred after learning in the MT training regime, and the smallest reduction of MT costs was observed after training in the ST regime. Although there is no significant difference in ST and Mix learning effects, numerically the Mix regime stands in between the learning effects of the ST and MT regimes.

4.3.4 Memory Game Task

Raw scores. The raw scores of participants directly reflecting the memory errors, which are missed pairs in the memory task were analysed (Tab 4.17, Fig 4.11). Because there were 56 cards, i.e., 28 pairs to be found, an error score of 15 implies that 13 pairs have been found. Errors were used instead of found pairs because this way the nature of the data (e.g., in graphs) is comparable to the other DVs (i.e., higher values reflect worse performance).

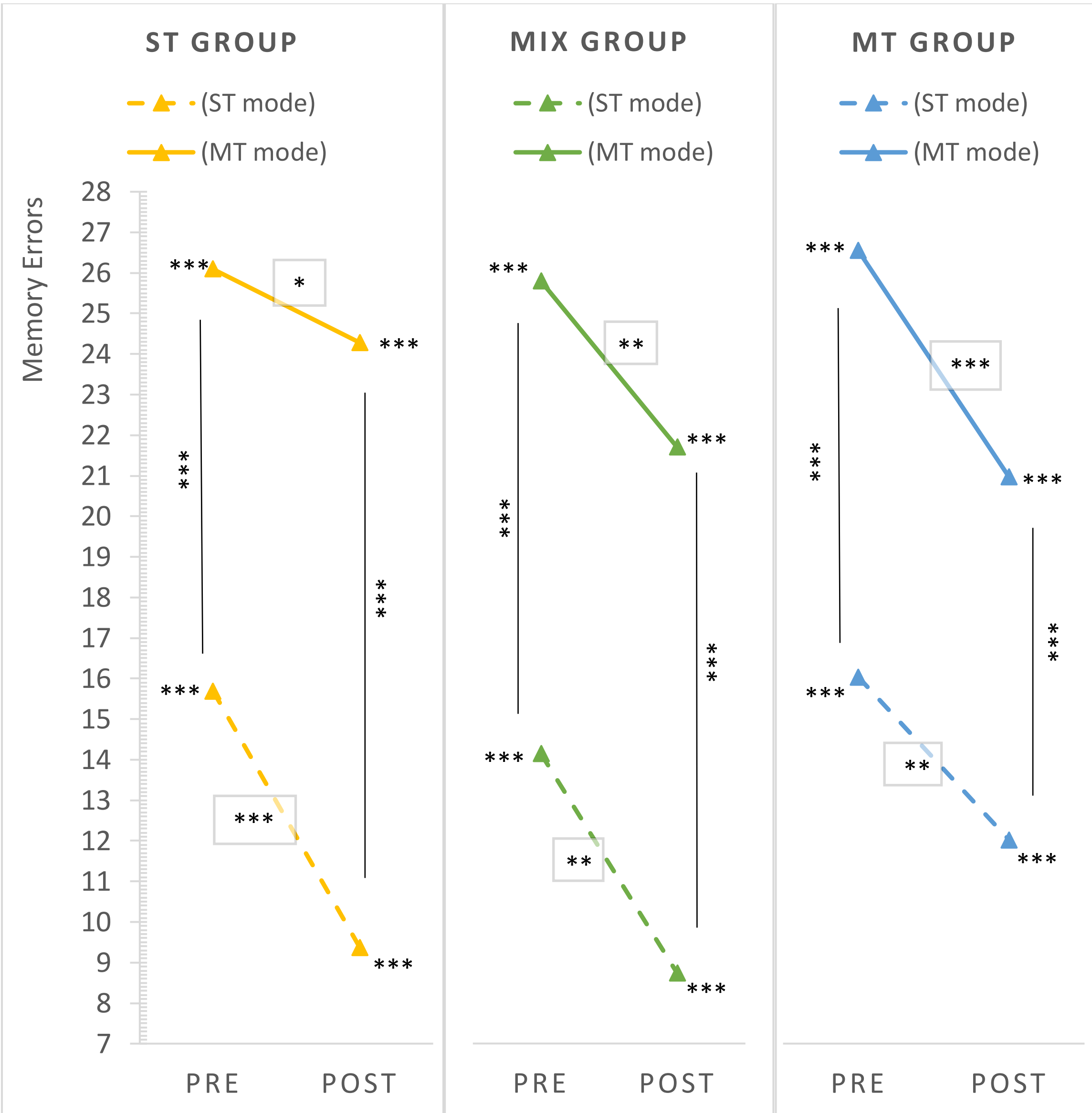
Table 4.17

Memory error raw scores. Higher scores reflect worse performance.

Session		ST GROUP		MIX GROUP		MT GROUP	
		ST mode	**MT mode**	**ST mode**	**MT mode**	**ST mode**	**MT mode**
PRE	**M**	15.69	26.1	14.22	26.0	16.0	26.5
	SD	3.83	1.78	5.46	1.13	4.10	1.62
POST	**M**	9.38	24.28	8.75	21.86	12.0	20.91
	SD	6.08	2.35	4.69	5.02	5.74	3.56

Figure 4.11

Memory error raw scores. The asterisks (<0.5; **<0.01; ***<0.001) on the lines demonstrate the statistically significant difference between ST and MT modes at pre- and post-sessions, respectively, whereas the asterisk symbols in the box on the line show the significant difference of the raw scores between the pre- and post-sessions for ST mode and MT mode, respectively.*



To test for differences in the memory raw scores, first I calculated a 2 x 2 x 3 mixed ANOVA (Table 4.18) with the within-subject factors Time (Pre, Post) and Mode (ST, MT), and the between-subject factor Group (ST, Mix, MT). Averaged across groups and modes, performance was significantly better at post-session as compared to pre-session (main effect of time, $F(1, 45)=121.12$, $p<.001$, $\eta^2=.720$). The effect of training modes (ST and MT) averaged across the groups was significant (ME of mode, $F(1, 45)=454.04$, $p<.001$, $\eta^2=.906$). The effect of the groups was not significant (ME of group, $F(2, 45)=0.762$, $p=.473$, $\eta^2=.033$).

Table 4.18

Memory error raw scores. Between subjects and within subject ANOVA.

N	48	16	16	16
	All Groups	**ST Group**	**Mix Group**	**MT Group**
		Main Effects		
Time (Pre, Post)	F(1, 45)=121.12, **p<.001**, η²=.720	F(1, 15)=31.20, **p<.001**, η²=.675	F(1, 15)=40.97, **p<.001**, η²=.732	F(1, 15)=46.60, **p<.001**, η²=.756
Mode (ST, MT)	F(1, 45)=454.04, **p<.001**, η²=.906	F(1, 15)=128.63, **p<.001**, η²=.896	F(1, 15)=264.62, **p<.001**, η²=.946	F(1, 15)=159.81, **p<.001**, η²=.914
Group (ST, Mix, MT)	F(2, 45)=0.762, p=.473, η²=.033			
		Interactions		
Time * Mode	F(1, 45)=2.41, p=.128, η²=.051	F(1, 15)=7.88, **p=.013**, η²=.344	F(1, 15)=0.52, p=.481, η²=.034	F(1, 15)=1.54, **p=.234**, η²=.093
Time *Group	F(2, 45)=0.33, p=.718, η²=.015			
Mode *Group	F(2, 45)=3.41, **p=.042**, η²=.132			
Time * Mode * Group	F(2, 45)=3.62, **p=.035**, η²=.139			

Whereas the 2-way interactions of time*mode ($F(1, 45)=2.41$, $p=.128$, $\eta^2=.051$), time*group ($F(2, 45)=0.33$, $p=.718$, $\eta^2=.015$) were not significant, the interaction of mode*group ($F(2, 45)=3.41$, $p=.042$, $\eta^2=.132$) showed significance, while the 3-way interaction time*mode*group also showed significance ($F(2, 45)=3.62$, $p=.035$, $\eta^2=.139$). To further investigate the significant 3-way interaction time*mode*group, I analysed the results of three training groups one by one.

<u>*MT Group*</u>

Before the training took place, in the pre-session (Fig 4.17), the MT group produced a significant number of memory errors in MT mode (M=26.5 memory errors, one-sample t-test vs 0, $t(15)=65.46$, $p<.001$) and in ST mode (M=16.0 memory errors, one-sample t-test vs 0, $t(15)=15.60$, $p<.001$). This suggests that the MT group showed significant MT costs of on average 10.5 memory errors (one-sample t-test, $t(15)=12.34$, $p<.001$) (see Tab 4.19).

Table 4.19

Memory error raw scores. T-tests within the training groups.

Comparison	ST Group	Mix Group	MT Group
ST Mode (Pre) vs MT Mode (Pre)	t(15)=13.12, **p<.001**, d=3.481	t(15)=9.36, **p<.001**, d= 2.986	t(15)=12.34, **p<.001**, d=3.357
ST Mode (Post) vs MT Mode (Post)	t(15)=8.40, **p<.001**, d=3.237	t(15)=11.45, **p<.001**, d= 2.701	t(15)=7.97, **p<.001**, d=1.864
ST Mode (Pre) vs ST Mode (Post)	t(15)=4.59, **p<.001**, d=1.243	t(15)=4.11, **p=.001**, d=1.074	t(15)=3.68, **p=.002**, d=.802
MT Mode (Pre) vs MT Mode (Post)	t(15)=2.69, **p=.017**, d=.871	t(15)=3.97, **p=.001**, d=1.134	t(15)=7.21, **p<.001**, d=2.010

After training in the MT regime, in the post-session, the MT group produced a significant number of memory errors in MT mode (M=20.91, one-sample t-test vs 0, t(15)=23.46, p<.001) and in ST mode (M=12.0, one-sample t-test vs 0, t(15)=8.36, p<.001). This shows that the training in the MT regime resulted in MT costs of on average 8.91 memory errors (one-sample t-test vs 0, t(15)=7.97, p<.001) (see Tab 4.20).

Table 4.20

Memory Costs, SPSS One-sample t-tests within the groups

Memory Costs	ST Group	Mix Group	MT Group
Pre-session	t(15)=13.12, p<.001, d=3.279	t(15)=9.36, p<.001, d=2.339	t(15)=12.34, p<.001, d=3.085
Post-session	t(15)=8.40, p<.001, d=2.101	t(15)=11.45, p<.001, d=2.863	t(15)=7.97, p<.001, d=1.993

Notably, the reduction in memory errors was more pronounced in the MT mode (from 26.5 at pre- to 20.91 at post-session, a reduction by 5.59 points on average, t(15)=7.21, p<.001, paired-sample t-test pre vs post) as compared to the ST mode (from 16.0 at pre to 12.0 at post-session, a reduction by 4.0 points, t(15)=3.68, p=.002, paired-sample t-test pre vs post). This resulted in a non-significant interaction between Time and Mode (F(1, 15)=1.54, p=.234, η^2=.093, interaction in a 2 x 2 ANOVA with Time and Mode; ME time F(1, 15)=46.60, p<.001, η^2=.756; ME mode F(1, 15)=159.81, p<.001, η^2=.914). Consequently, the MT costs were numerically higher at pre-session (M=10.41) than at post-session (M=8.91), resulting in a MT learning effect of on average 1.5 MT costs, which did not reach significance (paired two-sample t-test of costs pre vs post t(15)=1.24, p=.234). Although the learning effect in MT group did not reach significance, this shows that in 7 sessions numerically participants still improved their overall performance and still learned how to multitask.

Mix Group

Before the training took place, in the pre-session (Fig 4.11), the Mix group produced a significant number of memory errors in MT mode (M=26.0 memory errors, t(15)=92.41, $p<.001$, one-sample t-test vs 0) as well as in ST mode (M=14.22 memory errors, t(15)=10.41, $p<.001$, one-sample t-test vs 0). This suggests that in the pre-session, the Mix group showed significant MT costs of on average 11.78 memory errors (one-sample t-test, t(15)=9.36, $p<.001$) (Tab 4.19).

After training in the Mix regime, in the post-session, the Mix group produced a significant number of memory errors in MT mode (M=21.86, t(15)=17.44, $p<.001$, one-sample t-test vs 0) and a significant number of memory errors in ST mode (M=8.75, t(15)=7.46, $p< .001$, one-sample t-test vs 0). This shows that in the post-session, the Mix group produced significant MT costs of on average 13.11 memory errors (one-sample t-test, t(15)=2.74, p=.015) (see Tab 4.20).

Notably, the reduction in memory errors was more pronounced in the ST mode (from 14.22 at pre to 8.75 at post-session, a reduction by 5.47 points, t(15)=4.11, p=.001, paired-sample t-test pre vs post) as compared to the MT mode (from 26.0 at pre- to 21.87 at post-session, a reduction by 4.13 points on average, t(15)=3.97, p=.001, paired-sample t-test pre vs post). Consequently, the Mix group showed a non-significant interaction between Time and Mode ($F(1, 15)=0.52$, p=.481, $\eta^2=.034$, interaction in a 2 x 2 ANOVA with Time and Mode; ME time $F(1, 15)=40.97$, $p<.001$, $\eta^2=.732$, ME mode $F(1, 15)=264.62$, $p<.001$, $\eta^2=.946$). As a result, the MT costs were lower at pre-session (M=11.78) than at post-session (M=14.41). This shows that the training in the Mix regime resulted in improved performance in ST and MT modes, there was no MT costs reduction from pre- to post-session, i.e., there was no multitasking-specific learning.

ST group

Before the training took place, in the pre-session, the ST group produced more memory errors in MT mode (M=26.1 memory errors, one-sample t-test vs 0, t(15)=58.59, $p<.001$) as compared to ST mode (M=15.69, t(15)=16.37, $p<.001$, one-sample t-test vs 0), suggesting that the ST group produced significant MT costs of an average 10.41 memory mistakes (t(15)=13.12, $p<.001$, one-sample t-test vs 0) (see Tab 4.19).

After training in the ST regime, in the post-session the ST group produced a significant number of memory errors in the MT mode (M=24.28, one-sample t-test vs 0, t(15)=41.42, $p<.001$) and in ST mode (M=9.38, one-sample t-test vs 0, t(15)=6.17, $p<.001$), suggesting that at post-session, the ST group produced significant MT costs of an average 14.9 memory errors (t(15)=8.40 $p<.001$, one-sample t-test vs 0).

Noteworthily, the reduction in memory mistakes was more pronounced in the ST mode (from 15.69 at pre to 9.38 at post-session, a reduction by 6.31 memory mistakes, t(15)=4.59, $p<.001$, paired-sample t-test pre vs post) as compared to the MT mode (from 26.1 at pre- to 21.87 at post-session, a reduction by 4.13 on average, t(15)=2.69, p=.017, paired-sample t-test pre vs post). Therefore, it appears that the ST group improved less in MT mode and did not learn how to multitask in comparison to the MT group.

Furthermore, the ST group illustrated a significant interaction between Time and Mode ($F(1, 15)=7.88$, p=.013, $\eta^2=.344$, interaction in a 2 x 2 ANOVA with Time and Mode; ME time $F(1, 15)=31.20$, $p<.001$, $\eta^2=.675$, ME mode $F(1, 15)=128.63$, $p<.001$, $\eta^2=.896$). However, the MT costs were higher at post-session (M=14.9) than at pre-session (M=10.41), and did not result in a significant MT learning effect (in fact, deteriorated by on average 4.49 memory errors points (t(15)=2.81, p=.013). This shows that although the ST group improved memory task performance both in ST and MT modes, they did not improve as much in MT mode as they did in ST mode. This learning (gained in ST practice) did not fully transfer to MT mode. One may argue that if one gets better at a task, then this improvement should also show when the task is done as a component task during multitasking. In response-time research this is usually found. In other words, one would expect the performance in the MT to improve by the same amount as in the ST, but never less. However, for this task, this assumption may not hold; see below for further discussion.

Comparison of Learning Effects in MT costs across groups

The central question of this study is to assess whether the three different groups showed differences in multitasking learning. For this, I calculated, separate for each group, the *learning effect*, which is the MT costs in the pre-session minus the MT costs in the post-session. Therefore, larger learning effects reflect a stronger reduction in MT costs from the pre- to the post-session, i.e., more MT learning (Table 4.21, Figure 4.12).

Table 4.21

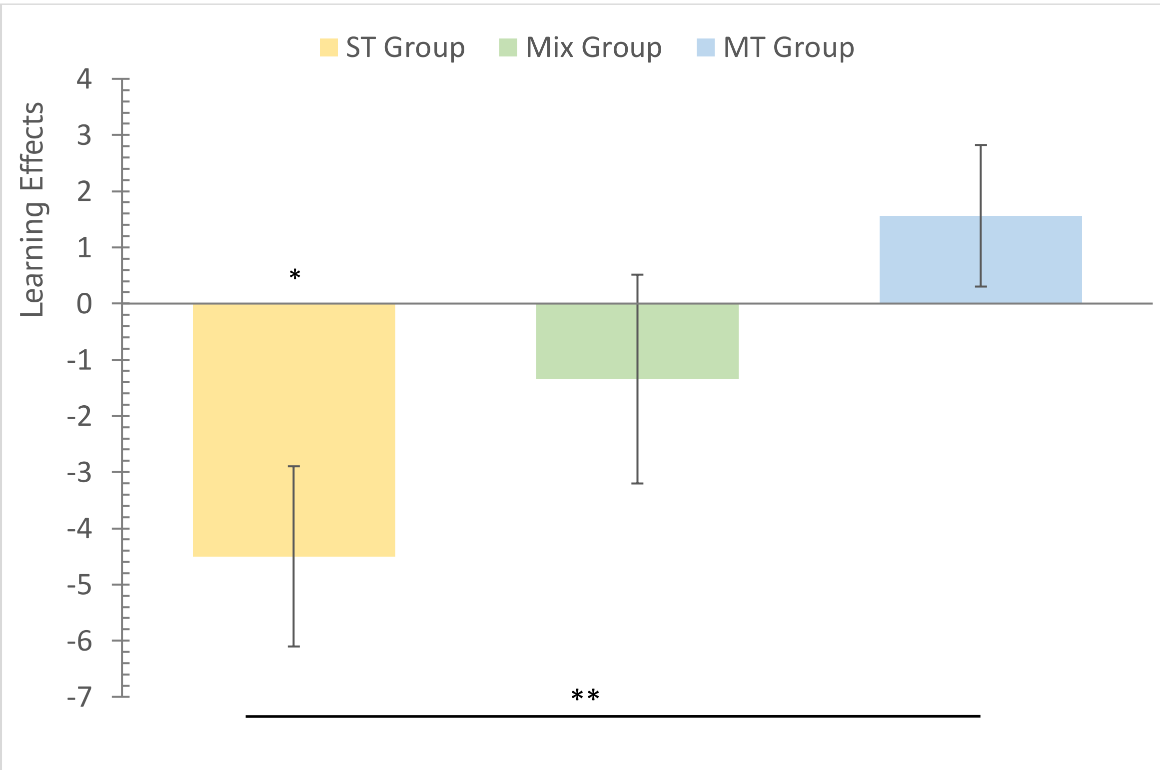
Learning effect in MT Costs, calculated as pre- minus post-session memory task values.

	ST GROUP	MIX GROUP	MT GROUP
N	16	16	16
M	-4.50	-1.34	1.56
SD	6.41	7.43	5.04

Descriptive results showed the learning effect were observed only in the MT group (M=1.56). The Mix group showed a slight deterioration (M=-1.34) and ST showed largest deterioration (M=-4.50) in comparison to the MT and Mix groups. This deterioration was caused by the costs difference in pre and post sessions, mostly because, while both groups showed improvements in both modes, the improvements in MT mode were smaller than in ST mode, resulting in no learning of MT in memory task after training for 7 sessions in ST and Mix regimes.

Figure 4.12

The learning effect in Memory MT Costs for ST, Mix and MT groups. The asterisk symbols (*<0.5; **<0.01) at the top of the bar chart shows the learning effect, i.e., significant difference of the MT costs between the pre-test and post-test. The asterisk symbols on the bottom lines represent the statistically significant differences between the groups, e.g., ST group vs Mix group.



To test whether the size of the learning effects differ between groups, a one-way ANOVA with the factor group (ST, Mix, MT) was calculated, which was significant ($F(2, 45)=3.62$, $p=.035$, $\eta^2= .701$). To understand which groups differed from each other, three two-sample t-tests were calculated. These tests showed that the learning effect in the MT group ($M=1.56$) was significantly higher than in the ST group ($M=-4.5$; $t(30)=3.44$, $p=.002$, $d=.193$), but not significantly higher than in the Mix group ($M=-1.34$; $t(30)=1.31$, $p=.200$, $d=.063$). Finally, the learning effect in the Mix group was not significantly higher than in the ST group ($t(30)=1.29$, $p=.208$, $d=.065$).

Overall, the largest reduction of MT costs from pre- to post-session (i.e., MT learning), occurred after learning in the MT training regime. The fact that Mix and ST groups improved largely in the ST mode and only slightly improved in the MT mode resulted in no significant learning effect after the training. Although there is no significant difference in ST and Mix learning effects, numerically the Mix regime still stands in between the learning effects of the ST and MT regimes. Therefore, overall, this pattern of findings is still in line with the other DVs and as expected.

4.4 Discussion

This laboratory-based study examined learning in three different regimes (ST, Mix and MT) to determine which regime resulted in the best multitasking learning. The results indicated that the MT regime showed the highest MT learning effect as compared to the Mix and ST regimes. The ST regime showed the lowest MT learning effect, and the Mix regime was numerically in between the MT and ST regimes.

(It is important to note that there is only limited room for discussion of the current study in the context of past studies, because, as stated in the introduction, so little work has been done in the area of learning complex real-life MT activities. However, so far as they are relevant and shed light of the fundamental hypothesis of the current study, past studies will be discussed with these considerations always in mind.)

In this study, the four tasks were a combination of a continuous sensorimotor task (Driving Task), a visual Monitoring Task, WM task (Memory game with identical pairs) and a mental arithmetic Math Task (which also has a WM element to it). In the next sections, I will first discuss each task separately and then in combination.

Driving Task

The Driving Task involved a relatively complex and demanding performance in a driving simulation setup, which can be considered as MT performance on its own, because it was fairly closely mimicking real-life driving with other cars and pedestrians randomly crossing the road. Participants were asked to follow navigation instructions and to avoid getting any penalties (e.g., exceeding speed limit, running past a red traffic light). Therefore, just like in real-life driving, the environment was unpredictable, and participants had to quickly react to constantly changing situations. Thus, even after the training participants in all three groups still showed a statistically significant number of raw penalties in ST and MT modes.

The overall trend of learning in the Driving Task showed that, while the learning effects in the Driving Task in all three groups were not statistically significant compared to zero, the MT group obtained statistically significantly larger learning effects compared to the ST group. And the learning effects of the Mix group were also statistically significantly larger compared to the ST group. The learning effects in the ST group were negative, because the ST group showed slightly more MT costs in the driving task in the post-session as compared to the pre-session. The learning effects obtained by the Mix group were numerically in between the MT and ST groups, while there was no significant difference between the MT and Mix groups.

Additionally, there was an unexpected finding showing that the ST group had relatively low MT costs at the pre-session in the Driving Task. As described in the Results section, I suggest that this unexpected finding was caused by a combination of two factors. First, the ST group had numerically slightly more penalties during the ST mode as compared to the Mix and MT groups. And second, the ST group had markedly (not significantly) less penalties during the MT mode compared to the Mix and MT groups. This resulted in the ST group producing an average of only 0.41 penalties (MT costs) at the pre-session (which was not statistically significant), whereas the Mix group (5.47 penalties) and MT group (9.19 penalties) produced significant MT Costs in penalties (see Results section, Driving Task). Although the raw penalty scores differed between the ST and other groups numerically, these differences were not statistically significant. Since it is not clear where this difference in the performance levels at the pre-test originated, it could be related to a random variation in sampling. A potential explanation might be that the ST group (for unknown reasons) prioritised the Driving Task over the Math Task, since the ST group showed numerically (but not statistically significant) higher MT costs in the Math Task, compared to the other groups.

The cognitive demands of the Driving Task in ST mode are comparable to the combined continuous and sensorimotor tasks in other MT studies. In detail, the Driving Task on its own in the current study required WM resources (e.g., keeping up with navigation instructions, different speed limits and different road signs) and motor responses (e.g., continuous visual tracking and steering). The Driving Task was even more demanding in the MT mode with even greater cognitive load on the WM with the Memory Task, Math Task and Monitoring Task (Broadbent et al., 2023). Therefore, in line with Broadbent et al.'s findings, in the MT condition the cognitive demands (including WM and attentional demands) were higher than in the ST condition.

The closest MT study which is somewhat similar to this driving simulator task in the MT mode is the video race game study conducted by Anguera et al. (2013). In this study, the first task consisted of tracking a car on a simulated road with left/right turns as well as downhill/uphill movements, while the second task was a detection task (go/no-go task) with green and red signs representing a traffic light. They found that after training for twelve sessions, participants improved their multitasking performance and exhibited improvements in cognitive control abilities, such as sustained attention and working memory. They highlighted the important role of managing interference during training MT abilities; as noted earlier the reduction of such interference improves MT performance. They also reported that only the MT group showed reduction of MT costs compared to the ST group, while both groups demonstrated similar improvements in component tasks. This evidence shows that for the MT group the learning took place specifically in MT learning, not only in improved component task performance. Additionally, Anguera et. al. excluded the possibility of a speed accuracy trade-off explaining their data, because the MT costs were also diminished after the training. These findings showed that MT learning resulted in resolving conflicting goals and interfering processes by improving participants' abilities to resolve conflicting tasks. It is noteworthy that the obtained skills in Anguera's MT group remained stable for six months, as verified when participants were invited for follow-up testing with no booster sessions during that period.

Anguera's study sought to assess the effect of age differences in MT learning. Therefore, the methodology and results of Anguera's study and the current study are not fully comparable. However, in line with Anguera's results, the MT group obtained the larger learning effect compared to ST group. The similarities in findings regarding the reduction of MT costs after the training are interesting, and in line with the hypothesis of the current study, but do not imply that both studies are covering exactly the same ground. Additionally, Anguera et al. emphasised the importance of targeted MT training approaches to specifically focus on task coordination and interference training. I would propose that the current study, meanwhile, has made the first steps towards examining these MT training approaches.

Math Task

In the Math Task, participants were asked to answer to a continuous recording of simple math equations (summing and subtracting, such as 5-4) and remember the previous answer, when the new equation occurs (such as +5). Participants had to keep in mind what was the previous number (e.g., 5-4=1) to add or subtract the next number (e.g., 1+5=6). Mental arithmetic (such as calculating 1+6) is generally assumed to rely on WM, and therefore on WM capacity (Zhang et al., 2023). When the Math Task was performed on its own it was relatively easy and in the ST mode at the pre-session participants made relatively few raw math errors, which did not differ significantly between the groups. After the training, all three groups made virtually no mistakes in the ST mode.

This task brought a considerable mental demand when it was performed in an MT mode in combination with the other 3 tasks, requiring divided attention or rapid switching, as well as WM. The overall pattern of learning in Math Task was similar in all three groups, showing a reduction of MT costs from pre- to post-session. As described above in the Driving Task, the learning effect in the Math Task obtained by the MT group was significantly larger than the learning effects obtained by the ST and Mix groups. The ST group obtained the smallest learning effect in the Math Task; however, not significantly different from the Mix group.

Additionally, the results of the current study showed that the learning effect was higher in MT compared to the ST and Mix groups: once more indicating that MT training enables an adaptation to the cognitive demands of MT activities. Moreover, the results showed that learning strategies adopted during MT training demonstrated the most effective learning of MT activities among the three groups.

The Math Task can be compared to one of the two WM tasks in the study conducted by Oberauer & Kliegl (2004). In their study, after the training, participants virtually abolished the MT costs, basically performing two WM tasks in parallel. The combination of Memory and Math task constituted a WM span task comparable to those studied in Oberauer & Kliegl (2004). Since the MT costs were still high after training in MT regime in the Memory task in comparison to the Math task, could this mean that learning is slower with difficult tasks and more sessions are needed? It is worth bearing in mind that, while Oberauer's study had 24 sessions with two WM tasks, the present study had 7 sessions with 4 different complex tasks.

Therefore, it would be interesting to examine how much trainees can reduce the MT costs with more practice.

Regardless of the duration of WM training of dual-task activities, some literature suggests that WM capacity can be improved through training (Lawlor-Savage & Goghari, 2016; Morrison & Chein, 2011; Sprenger et al., 2013; von Bastian & Eschen, 2016). In this case, Morrison & Chein (2011) suggested different ways to achieve cognitive enhancement, such as training attention (Yang et al., 2019), processing speed (Dux et al., 2009), and dual-task performance (Bherer et al., 2005). Furthermore, the results from the present study indicate that the learning in the Math task in MT mode was related to the WM, because initially three different types of errors were collated as one Math Task error measure (see Methods Math Task). The greatest contribution of the learning effect (above 81%) was observed specifically in memory errors (when participants did not remember the previous number), which is in line with findings that WM capacity can be improved by training.

Therefore, since the arithmetic part of the task was relatively simple and participants in the MT group mostly obtained learning effects related to WM, it may be that during MT training the learning process is related specifically to WM capacity aspects of MT performance. It is important to point out the difference between the ST and MT performance of the Math Task, because the key errors (forgetting the last result) were observed in MT mode, when there were concurrent other processing demands (the other tasks) during the intervals between numbers. Thus, it potentially shows the demands of MT on WM, or the limits of WM capacity preventing performance of all tasks at the same time. In ST mode, this type of errors would not be related to WM, but to STM (Short-Term Memory), because there would not be concurrent task interference and participants would only remember the number and recall it every 5-15 seconds. This once more shows the importance of MT training, because the same mechanisms are not involved in ST training.

Monitoring Task

The visual monitoring task involved two screens with randomly changing colours on PowerPoint slides (red, blue, yellow, and green) with different place names such as "King's Lane". Participants were asked to read out loud the locations only on the slides with a red background. One of the screens was placed behind and participants had to actively remember to turn around and check that screen, because it was out of view when sitting normally on the chair. This was the easiest task among the four tasks in this study when performed in the ST mode. It was so simple that participants reached ceiling performance straight away and therefore showed no learning effect in the ST mode. However, in MT mode this task introduced additional demands, because monitoring involved a shift of attention and participants had to remember to check the screens regularly (see Methods, every 24 seconds in MT mode).

The overall learning pattern in the Monitoring Task was in line with all three previous tasks. The MT group showed a significantly larger learning effect compared to the ST group, whereas the Mix group was numerically (although not significantly) standing between the learning effects of ST and MT groups.

It is worth mentioning that some unexpected results did occur during the experiment. At the pre-session, a small difference in raw errors appeared between the groups; specifically, the MT group (M=1.41) initially made significantly more errors than the ST (M=0.50) group in MT mode. Since each group had 16 participants randomly assigned, this difference was unexpected, and most likely originated from a random variation. Since performance in Monitoring Task in ST mode was virtually perfect, no learning could take place. Thus, while the calculations of MT costs included ST mode performance (MT mode values minus ST mode values), the learning effects were mostly determined by the MT mode raw data.

As already briefly mentioned above, the MT group had considerably higher error rates at pre-session in MT mode. This implies that the MT group had more potential to learn, i.e., there is more potential for a difference between pre- and post-sessions and, thus, a larger learning effect. It is worth noting that all three groups in MT mode at the post-session produced error rates still significantly higher in MT mode than in ST mode. This implies that there could be further scope for learning; in theory the error rates in MT mode could have been potentially brought down to the level of ST mode performance.

The Monitoring Task required cognitive processes involving monitoring components of executive function, which is considered as a crucial part of daily tasks, such as driving. This monitoring executive function is the ability to observe, update and keep track of information, as well as recognising when the next action or a switch is required when presented with two or more tasks (Miyake & Friedman, 2012; Shallice et al., 2009). In the example of driving, this would mean systematically checking all the mirrors and monitoring the unpredictable surrounding environment while driving. Previous studies highlighted the important role of monitoring in driving and its relation to preventing car accidents (Bachar et al., 2018; Duchek et al., 1998).

The main idea of this study was to mimic the real-life complex MT environment, and at times some tasks among the four were presented in parallel, whereas at other times participants had a chance to switch from one task to another. This would imply that the concurrent demands on central processes such as response selection were shifting from one to up to four tasks at a time. It is plausible that learning MT in the sense of coordinating processes at these stages happens in the general cognitive control which mediates monitoring, working memory and reasoning processes.

Memory Task

The Memory Task involved 28 pairs of identical cards on a tablet screen mounted on the left-side of the table beside a driving simulator. The participants had to remember the image of the card as well as its location on the screen (among 56 cards with identical backsides). This task brought additional challenges, because the cards were relatively small, and a different set of card images was used in each 6-min trial. Some sets had very similar images, which made it even harder to find the identical pair.

This task can be considered as very STM (Short-Term Memory) demanding in ST mode, since the cards were turning back and showing only one pair at a time. Participants had to keep in mind several locations of flipped unmatched cards so when by chance they flipped another familiar card, they would remember the location of its pair. This task becomes truly WM demanding in MT mode when other tasks interfere and new information must be stored and analysed, because participants have to keep the memory content in their mind while doing other cognitive processing.

The pattern of learning effects in the Memory Task was similar to the pattern in the Driving Task. The MT group obtained significantly larger learning effects than the ST group, whereas the learning effects obtained by the Mix group were numerically in between the ST and MT groups. This might indicate that the MT group improved their task processing and task coordination skills more, as well as adopting more efficient cognitive processing strategies than the Mix and ST groups. It should be noted that while the ST and Mix groups had more time to train this task as a single task, even after the training all groups showed relatively high raw error scores, even in the ST group. The ST group had 34% errors v 31% in the Mix group, and 42% in the MT group (‘errors’ refer to pairs not found - see Methods/Results for details). This illustrates that the Memory Task was very challenging and required full resources of attention and WM.

Furthermore, the results can be interpreted in line with previous findings which suggest that WM capacity is a predictor of MT ability (Colom et al., 2010; Szameitat, 2022). These reinforce the proposition argued by Constantinidis & Klingberg (2016) that training in MT regime might have a stronger effect than training in ST regime on WM capacity, which in turn improves the speed and accuracy of the executive functions (e.g., directing attention, decision making, maintaining task goals), resulting in better MT performance. The findings from the current study are consistent with this conclusion.

In a wider sense, the Memory Task in MT mode can be loosely compared to the complex WM span tasks described in a study conducted by Oberauer & Kliegl (2004), where participants performed a spatial memory task with arrows, which could point in one of eight possible directions, combined with a numerical task with high- and low-pitched tones. In the numerical task, participants were asked to add 2 to the current value when the high-pitched tone was presented, and subtract 1 from the current value when the low-pitched tone was presented. They found that the MT group significantly reduced MT Costs (in RTs and errors) after the training (24 session duration). The reaction time latencies of operations in MT mode were similar to reaction time latencies in ST mode, virtually removing the MT costs, with participants learning how to perform these two tasks in parallel. Oberauer & Kliegl concluded that since participants learned the “perfect timesharing” of the combination of the 2 updating tasks and showed a significant reduction of MT costs in both tasks, therefore such reduction of MT costs was a result of MT training, not just a result of automatization of individual operations (Oberauer & Kliegl, 2004). Additionally, the results of the second experiment with the same tasks but an altered number of blocks revealed that even with a smaller number of training sessions (12), the MT group was very close to perfect results with no errors and 100ms RT costs, although not all of the participants in the MT group reached the criteria for perfect time sharing. However, in comparison to the MT group, the ST group still showed significant MT costs after the training (Oberauer & Kliegl, 2004).

These findings are in accord with the results of the present study, since in all of the above, the MT group showed higher learning effect than the other two groups. Additionally, there were some unexpected results, showing that the ST group did not exhibit the expected improvements in learning effects in the Memory Task in ST mode, which should have appeared if they obtained faster task processing to MT condition. If the transfer of learning from ST to MT had taken place, one would expect at least as much learning in MT mode as in ST mode. One possible explanation is that there was a partial speed/accuracy trade-off for the ST group, because they were put in a demanding MT situation where they could not apply the same learned strategies as the MT and the Mix groups. However, the present study did not measure the reaction times to compare these findings, and the learning effects were based only on the error rates.

Furthermore, in the MT group the reduction of raw errors in the Memory Task was statistically significantly more pronounced in MT mode than in ST mode, whereas in the ST and Mix groups, the reduction of errors was more statistically significant in the ST mode. A potential explanation could be that in ST mode, participants would be able to devote more mental effort to finding good strategies to perform the task (e.g., thinking about flipping cards in certain patterns which might help them remember where items were). Since the MT group did not have the ST mode in their training, it is plausible that the MT group never had a chance to fully focus on how to improve performance in that task, such as developing effective strategies. The ST and Mix groups, however, did have the ST mode embedded in their training, which might be a potential explanation as to why they showed better ST learning.

Curiously, it might be expected that this learning in ST would fully transfer to the MT mode, but that was not the case. One explanation could be that these new strategies developed during ST mode training to perform the Memory Task better might be cognitively demanding (e.g., memorising patterns, flipping cards according to an exact scheme, etc). If they were cognitively demanding, participants might not be able to apply them during MT mode performance. They might have to revert to less demanding strategies to be able to perform all four tasks during MT mode, which might potentially explain why the learning did not fully transfer from ST mode to MT mode.

Additionally, several non-learning MT studies investigated the role of WM capacity in MT behaviour in the contexts of executive functions (Constantinidis & Klingberg, 2016; Covre et al., 2019; Himi et al., 2019). Miyake et al. (2000) described a model of three main executive functions involving shifting, updating and inhibition. In this model, shifting is related to Monsell's (2003) model of task-switching. This model might explain the executive functions learned during the MT training in this study; the shifting involves disengaging with the "irrelevant tasks" (for a brief period), for example Math Task and Monitoring Task, and actively engaging with the Memory Task as the "relevant task" (Miyake et al., 2000). At the same time, updating requires encoding the new information for relevance (in this case the images and locations of the flipped cards in Memory Task). In this instance, updating would also involve revising the current information held in WM (for example, a place name on the screen in the Monitoring Task).

Overall MT performance

As discussed above, the overall trajectory of MT learning was similar across all four tasks. As predicted, the training resulted in MT cost reduction, where the MT group showed the highest learning effects compared to the ST and Mix groups. The fact that the learning effects in the Mix group were in between the learning effects of the ST and MT groups supports the proposition that the Mix group had more opportunities to adopt MT strategies than the ST group and less opportunities than the MT group, as expected. Overall, this evidence clearly supports the proposition that the learning strategies adopted by the MT group after training in the MT regime were superior to the learning strategies adopted by the Mix and ST groups.

Previous research on MT learning was mostly based on dual-task designs (Kobiela et al., 2018; Liepelt et al., 2011; Strobach et al., 2012), while the current study was based on four tasks. Additionally, while most dual-task studies commonly employed relatively simple tasks, the tasks in the current study were deliberately made more challenging to create a complex MT situation reflecting real-life MT demands. The findings produced strong evidence that the DTPA phenomenon also applies to complex, real-life, demanding MT activities, where the learning in MT regimes enabled development of task coordinating skills in comparison to learning in ST regimes (Strobach, 2020). This is the first time that the role of the DTPA phenomenon in complex MT tasks was demonstrated experimentally.

Furthermore, the DTPA phenomenon is applicable to both MT and Mix groups in this study, because both groups had MT training, with the difference that the MT group had 100% MT training, and the Mix group had 50% MT training and 50% ST training. As far as I am aware, this is the first MT training study to differentiate a pure MT regime from a Mix training regime. In previous research, the MT regimes were mostly described as a hybrid of ST and MT modes. While the MT group showed significantly higher learning effects in all four tasks in comparison to the ST group, in comparison to the Mix group the learning effect in the MT group was significantly higher only in the Math Task. However, the learning effect in the Mix group was significant only in the Math Task, while in all other tasks the learning effects in pure MT were always numerically higher than in the Mix regimes. This strongly implies that the DTPA phenomenon is in fact applicable to mixed training regimes as well as MT regimes. Again, as far as I am aware, the current study is the first to demonstrate the evidence to support this conclusion. Additionally, since the Mix group learning effects fell in between the learning effects of ST and MT groups in all four tasks, this suggests that more MT training results in a better overall MT learning effect, as expected.

Conceivably, similar mechanisms proposed in allocation and scheduling theories, such as switching between the central response stage and developing task coordination strategies, may also be involved in four-task situations (Karbach & Strobach, 2022). Learning in MT regimes enables participants to develop strategies allowing faster task response execution by scheduling conflicting cognitive processes. Therefore, during MT training, participants develop skills which allow effective coordination of tasks and a reduction of the number of errors. According to Strobach's conclusions (Strobach, 2020), the specific mechanisms in these allocation and scheduling theories are not generalised across all tasks with completely different cognitive demands and modalities. There is a need for further investigation to explain the acquired task coordination skills in a more specific way (e.g., updating the stimuli from different modalities in WM). This can open an opportunity for further studies to determine specific mechanisms involved in processing complex MT activities with multiple modalities (e.g., including reaction times into analysis of complex four (and more) task MT activities, and determining how processing stages switch and coordinate concurrent tasks). Multiple researchers suggested the lack of unified theoretical foundations which would describe the exact cognitive mechanisms and the specific processes associated with executive functions during MT and MT learning (Ducrocq et al., 2016; Karbach & Strobach, 2022; Strobach, 2020).

Regardless of the theoretical basis for learning these mechanisms, it is evident that in the context of applied research, complex MT activities can be trained, and there is a possibility that a longer training may result in complete removal of MT costs. This might require ranking different tasks by their cognitive demands to investigate the specific mechanisms and processes involved in learning MT activities. This could shed some light on what MT strategies are most effective to overcome MT costs (for example in RTs and errors) by adapting training according to difficulty levels, duration, and strategic objectives (e.g., speed of responses vs accuracy).

Further research could also provide beneficial knowledge to organisations which require MT skills in employees (Bechmann & Lomborg, 2013; Chérif et al., 2018; Ferris & Sarter, 2011; Mark et al., 2005). In particular, informing instructors on how to specifically highlight the strategies in performing tasks in MT mode, as well as explaining to the trainees a specific order of tasks in complex MT activities, could yield better results. As an instance, in the Memory Task with 56 individual cards it was more beneficial to flip cards one by one in a row or a column instead of randomly picking different cards to turn, making it easier to memorise locations and order of the images on the cards. Although the current study did not investigate the effectiveness of instructions, it is plausible that these suggestions could potentially improve the training routines by enabling the instructors to organise the MT aspects of the training in a more specified and productive way, as well as making the overall training more effective.

In conclusion, the evidence suggests that the pure MT training regime resulted in the highest learning effect as compared to ST and Mix training regimes. These findings are aligned with the DTPA phenomenon review (Strobach, 2020), showing that there is a strong possibility that the DTPA phenomenon is transferable to very complex applied MT activities.

5 General Discussion

This thesis aimed to examine how people learn complex multitasking activities in applied contexts, as well as to investigate MT learning approaches and general opinions regarding learning MT activities in daily life. An additional aim was to examine the role of choice in training regimes. For this purpose, I conducted three studies which will be discussed below in relation to previous research.

The first study was an online Survey with questions related to past MT learning experiences, preferences between ST, MT or Mix learning regimes, and the influence of the general propensity to engage in multitasking. The survey was exploratory in nature, because there was no previous research investigating how people learn MT activities in everyday life; therefore, there is little room for a discussion of past existing research studies. To the best of my knowledge, this is the first study to investigate previous experiences and attitudes towards learning MT activities. The key finding is that the Mix regime is the most widely used and preferred learning regime for everyday tasks (mostly learning to drive a car); whereas in fact the pure MT regime exhibited the best learning performance in both studies with complex MT activities. These findings are in agreement with results of MT studies which showed that Mix regimes were leading to better MT learning than the ST regimes (Cassavaugh & Kramer, 2014; Levy et al., 2006; Levy & Pashler, 2008). Previous MT studies with relatively simple tasks produced results highlighting that Mix (mostly called DT or hybrid) regimes are more efficient regimes to learn MT than ST, the so-called DTPA (Strobach, 2020). In these studies, the pure MT regimes were not investigated in comparison to Mix and ST regimes. In addition, a personal preference for pure MT learning regimes correlated positively with polychronicity, i.e., the propensity to engage in MT.

In addition, these findings revealed that people have a variety of learning approaches and opinions, with some participants preferring MT, and others ST or Mix (at least partially) for similar activities. Therefore, it might be beneficial to give people a choice of training, so that they can pick what they prefer or need. In this way someone who needs more ST training may obtain the same MT learning effect as compared to someone who did only MT training. To test this hypothesis, I designed an online PRP experiment (study 2) which allowed participants to choose what training modes they wished to train in.

The second study, an online computerised MT learning study, investigated the MT learning effect for 90 participants assigned to the Choice and the Fixed groups. For the Fixed group, the training regime was set at 100% MT training, while the Choice group was given a choice of training mode (ST, MT or Mix) for each set of two blocks (out of 20 blocks per session). The Choice group chose an average of 59% MT blocks during the training phase of the study. In this study there were two complex demanding tasks, the Auditory Tone and the Visual Number tasks, and participants were asked to perform them either separately in ST mode or at the same time in MT mode, and the auditory task was always the first task. To the best of my knowledge, most of the previous research on MT used relatively simplistic tasks which might not really represent the demands and complexity of everyday tasks. Therefore, in this study, the tasks were designed to be excessively demanding. Each of the two tasks involved four stimuli mapped to each hand and were very difficult to perform. In the MT condition, the MT blocks consisted of both auditory and visual tasks.

The results showed that both the Fixed and the Choice groups obtained significant MT learning effects[1] which did not differ between the two groups. The positive correlation between the MT learning effect and the percentage of MT training in the Choice group can be considered as a direct demonstration of the DTPA phenomenon (Strobach, 2020), i.e., more MT training was associated with more MT learning. However, the interesting outcome of this research is precisely in the unexpected findings. Given that the Choice group had an average of 59% MT training as compared to the Fixed group with 100% MT training, why was the learning effect in the Fixed group only marginally and not significantly higher than in the Choice group? A potential interpretation may be that certain individual differences in MT abilities and learning processes of participants in both groups affected the results. Since this is an explorative applied study, it holds risks of getting additional noise in the data from the unknown factors. These factors may involve previous MT learning experiences which contributed to the faster MT learning in this study (Karbach & Strobach, 2022; Strobach, 2020). Therefore, another potential interpretation of these results is that some participants were more inclined to train in ST to minimise the errors because they had already acquired some MT skills beforehand and learned the MT in this study faster. These results indicated that at least some participants may have had good awareness of their skill levels and were able to adjust their training to maximise the MT learning, even if this involved ST training as well.

This finding is intriguing because the correlation analysis (Figure 5) illustrated that, in the range of participants who only completed less than 40% of MT training, there was not a

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[1] The learning effects were calculated by subtracting the MT costs at the post-session from the MT costs at the pre-session.

single participant with learning effects above 600ms. Meanwhile, a few participants with MT training less than 20% obtained notable RT2 learning effects in comparison to the Fixed group with 100% MT training. This is interesting because it indicates that, besides the sheer number of trials or training hours in pure MT mode, there is a probability of additional factors which influence the MT learning process. For example, the tasks in ST were so challenging that participants with poorer MT abilities might have chosen to improve performances of the tasks separately, and then select a more challenging MT mode.

It is evident that MT training results in learning MT skills, but the question remains whether this is the most effective approach to learning complex MT activities. Additionally, to the best of my knowledge, the majority of MT training studies compared pure ST regimes mostly to mix regimes with both ST and MT modes and referred to them as MT training regimes. This means that there are virtually no studies which have specifically investigated the results of training in pure ST, MT and mixed modes of training. For this purpose, I conducted a lab-based MT training study to compare the three learning regimes using a driving simulator. This complex MT training study involved four tasks: the driving task, monitoring task, math task and the memory task. The driving task included listening to navigation instructions and producing as few penalties as possible. The monitoring task involved two screens and participants were asked to monitor both screens and report the streets only on the red background. The math task included a pre-recorded audio with simple math equations (only summing up and subtractions with numbers below 10). Lastly, the memory task involved a tablet which displayed a “find a pair” game with 28 pairs in total to find. Participants were asked to perform these tasks in both ST and MT modes at the pre-session and were randomly divided in three equal groups (N=16, MT group, ST group and the Mix group).

The results showed that after training in pure MT learning regime, participants achieved significantly higher learning effects than with the pure ST regime. The learning effects in all four tasks after training in the Mix regime numerically fell between the ST and MT regimes. While the learning effects were significant in some tasks and not significant in others, the overall pattern always remained the same, i.e., the MT group showed higher learning effects than the ST group, and again the Mix group was numerically in between the ST and MT groups. These results showed that the DTPA phenomenon is applicable for learning applied demanding MT activities, and indeed overall the MT group showed higher learning effects than the ST and Mix groups (Strobach, 2020). Additionally, to the best of my knowledge, these findings investigated for the first time the difference in results after training in pure MT and Mix modes.

Combining the results of the online MT training study (Study 2) and the simulator study (Study 3) it clearly emphasises that MT training is the most effective approach to learning applied complex MT activities. Similarly, in both studies the groups with the most MT training showed the highest MT learning effects. Rather than the supposition that ST practice might be helpful, the combined results of the two studies indicate that in very complex, complicated, everyday tasks, directing people into pure MT training is the most effective strategy for learning MT activities. Additional areas for future research could determine whether directing people into training in stressful and demanding MT regimes may not be recommended for those with any mental issues, as well as analysing the benefits for building resilience.

Limitations

These experimental studies had several limitations. For one thing, the participants in Study 3 (laboratory study) were all students, and hence not a representative sample of the general population, at least in terms of age. It should be noted, however, that while previous research has shown that older participants learned somewhat more slowly, there is evidence that MT training was beneficial for both young and older participants (Bier et al., 2014; Lussier et al., 2012). The relative absence of applied research in learning MT meant that there were few precedents for designing experiments to capture precisely the required data. As a result, I had to pilot several versions of the experiments devised from previous studies focusing on somewhat different objectives, and multiple pilot sessions were performed to finalise the designs.

Surveys in general face challenges and criticism as methodology because of their subjective nature. One of the limitations of the survey study, which was discussed in Chapter 2, is the fact that there was no specific numeric identification of what proportions of ST and MT modes contributed to the Mix regimes. However, the survey results were compared against the actual experimental results in the online MT training study, and the findings show that while people generally choose and prefer Mix regimes, the MT regimes are the most efficient.

Future Research

One of the areas for future research would be to devise applied experiments with complex MT tasks that would also capture reaction times. In the lab-based simulator study, such RT data could show whether the RTs mirror the error rate results, which could enable exclusion of a speed accuracy trade-off. Further research could expand on the current study by investigating whether the obtained skills would last for the extended follow-up testing and whether differing ages affect the longevity of the obtained skills. Follow-up testing could analyse whether the acquired skills deteriorate at the same rate after training in different learning regimes. Such deep investigation of the learning effects and how they can be retained could also shed some light on potential disciplines to retain the acquired skills.

Another area is to create experiments which focus on clearer identification of the proportions of ST and MT modes in the mixed regimes. It is plausible that different MT activities would require different proportions of ST and MT modes to maximize the learning outcomes. In this instance, it would be logical to assume that, while police pursuit training can be performed at high risk levels on a simulator, the physical training may need additional ST mode training before training in highly risky MT situations. Similarly, other emergency services such as ambulance drivers and the fire services may benefit from studies which would determine the optimal training regimes for their particular specialty.

In addition, MT training could also be beneficial for athletes and people participating in team sports (e.g., football, basketball). In these instances, trainees are expected to perform different cognitive (analysing where teammates are, strategizing to make a pass, etc.) and motor processes (running, kicking or throwing the ball, etc.), which have to be performed at the same time (Karbach & Strobach, 2022). Karbach & Strobach (2022) suggested that further research could help develop training strategies targeting specifically MT aspects of the activities, as well as efficiently implementing them.

One other potentially valuable area of future research would be experiments conducted in partnership with the organisations that actually have a high demand for MT skills, such as emergency services, airlines, etc. These experiments would help to assess real-world performance of MT skills in stressful conditions and devise regimes to assist these applications, not only for the emergency services but more broadly.

Outlook/ Future directions

This study has already demonstrated that there is a gap in the research and literature examining learning complex MT activities, as well as the underlying cognitive mechanisms. It appears there is also a gap in real-world training and improvement of learning complex MT activities. There is potential for both fields to support each other, yielding valuable real-world outcomes as well as deeper understanding.

6 References

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7 Appendix

This appendix consists of the different documents used for the three experiments in this study. Study 1 Survey and study 2 Online MT training were conducted online; therefore, all the forms were presented in digital versions. In the Survey study 1 and the online MT training study 2 the instructions were embedded in the experiment as participants progressed. This meant that the payment would be automatically sent to the participants by the Testable Minds platform.

Study 3 was the simulator lab-study and includes an ethics confirmation letter (Appendix 3A), a participant information sheet (Appendix 3B), a consent form (Appendix 3C), a questionnaire form (Appendix 3D), an instruction paper (Appendix 3E), a debrief form (Appendix 3F), and receipts (Appendix 3G). Appendix 3 represents the forms for experiments 3, Appendix1 and 2 proceed consecutively.

7.1 Appendix 1 A

College of Health, Medicine and Life Sciences Research Ethics Committee (DLS)
Brunel University London
Kingston Lane
Uxbridge
UB8 3PH
United Kingdom

www.brunel.ac.uk

2 November 2021

LETTER OF APPROVAL

APPROVAL HAS BEEN GRANTED FOR THIS STUDY TO BE CARRIED OUT BETWEEN 08/11/2021 AND 30/09/2023

Applicant (s): Miss Aina Digaeva

Project Title: Learning multitasking in applied contexts

Reference: 30807-LR-Nov/2021- 34726-2

Dear Miss Aina Digaeva

The Research Ethics Committee has considered the above application recently submitted by you.

The Chair, acting under delegated authority has agreed that there is no objection on ethical grounds to the proposed study. Approval is given on the understanding that the conditions of approval set out below are followed:

- **Approval is given for remote (online/telephone) research activity only. Face-to-face activity and/or travel will require approval by way of an amendment.**
- **The agreed protocol must be followed. Any changes to the protocol will require prior approval from the Committee by way of an application for an amendment.**
- In addition to the above, please ensure that you monitor and adhere to all up-to-date local and national Government health advice for the duration of your project.

Please note that:

- Research Participant Information Sheets and (where relevant) flyers, posters, and consent forms should include a clear statement that research ethics approval has been obtained from the relevant Research Ethics Committee.
- The Research Participant Information Sheets should include a clear statement that queries should be directed, in the first instance, to the Supervisor (where relevant), or the researcher. Complaints, on the other hand, should be directed, in the first instance, to the Chair of the relevant Research Ethics Committee.
- Approval to proceed with the study is granted subject to receipt by the Committee of satisfactory responses to any conditions that may appear above, in addition to any subsequent changes to the protocol.
- The Research Ethics Committee reserves the right to sample and review documentation, including raw data, relevant to the study.
- You may not undertake any research activity if you are not a registered student of Brunel University or if you cease to become registered, including abeyance or temporary withdrawal. As a deregistered student you would not be insured to undertake research activity. Research activity includes the recruitment of participants, undertaking consent procedures and collection of data. Breach of this requirement constitutes research misconduct and is a disciplinary offence.

Professor Louise Mansfield

Chair of the College of Health, Medicine and Life Sciences Research Ethics Committee (DLS)

Brunel University London

7.2 Appendix 1 B

College of Health, Medicine and Life Sciences
Department of Life Sciences

PARTICIPANT INFORMATION SHEET

Study title Learning multitasking in applied contexts

Invitation Paragraph

You are being invited to participate in a research study to be conducted at Brunel University. Before you make your decision to take part, it is important for you to understand why the research is being done and what it will involve. Please take time to read the following information carefully and take time to decide whether you wish to take part. Please let us know if there is anything that is unclear or if you would like more information. Thank you for reading this.

What is the purpose of the study?

The aim of this study is to investigate people's views and experiences of how to best learn multitasking abilities.

Why have I been invited to participate?

You have been invited to take part because you meet the study inclusion criteria, being 18 years or older. We plan to test approximately 50-75 participants. We will offer £3 for completing and submitting your answers.

Do I have to take part?

No, study participation is completely voluntarily. It is up to you to decide whether to take part. If you do decide to take part, then you will be asked to agree to the consent form but are still free to withdraw without having to give a reason until your answers have been submitted.

What will happen to me if I take part?

You will be asked to fill out an online survey about your experiences and views on multitasking, lasting approximately 15-25 minutes. You will also be asked to fill out a consent form.

Are there any lifestyle restrictions?

There are no lifestyle restrictions relevant to this study.

What are the possible disadvantages and risks of taking part?

There are no anticipated risks or disadvantages in completing any of the tasks and questionnaire in the study.

What are possible benefits of taking a part?

There are no benefits of taking a part.

What if something goes wrong?

In the unfortunate event of something going wrong, you can withdraw from the study at any time and/or seek advice from Dr Andre Szameitat, Reader in Psychology, andre.szameitat@brunel.ac.uk or submit a complaint to Professor Louise Mansfield, Chair College of Health, Medicine and Life Sciences Research Ethics Committee ***louise.mansfield@brunel.ac.uk***

Will my taking part in this study be kept confidential?

All information which is collected about you during the research will be kept strictly confidential. With your permission, anonymised data will be stored and may be used in future research, and you can indicate whether you give permission for this by way of the consent form.

Will I be recorded, and how will the recording be used?

No recording will be made as part of this study.

What will happen to the results of the research study?

The research data will be analysed by the researcher before being reported. The results will be disseminated, for instance at public talks, conferences, in scientific journals, and/or social media. The data will be used for my PhD dissertation project. The anonymised research data may be analysed and reported for purposes not related to this study. The anonymised research data may also be shared with other researchers, and/or made available as "open data". This means the data will be publicly available and may be used for purposes not related to this study. However, it will not be possible to identify you from these data, which means that at no point will any uniquely identifiable data be shared. The data will be stored by the lead researcher for a period of at least ten years from completion of the project (subject to any legal, ethical, or other requirements). If you take part in this research, you can obtain a copy of the publication by contacting the researcher. You may withdraw your data, without giving a reason, until the point at which you have submitted your answers.

Who is organising and funding the research?

The research is organised by Aina Digaeva (***2048253@brunel.ac.uk***) PhD student at Brunel University London, in conjunction with Brunel University London. This research does not receive any external funding.

What are the indemnity arrangements?

Brunel University London provides appropriate insurance cover for research which has received ethical approval.

Who has reviewed the study?

This study has been reviewed by the College of Health, Medicine and Life Sciences Research Ethics Committee. Chair – Professor Louise Mansfield (***louise.mansfield@brunel.ac.uk***)

Research Integrity

Brunel University London is committed to compliance with the Universities UK ***Research Integrity Concordat****. You are entitled to expect the highest level of integrity from the researchers during the course of this research*

Contact for general information

Researcher name: Aina Digaeva (***2048253@brunel.ac.uk***)

Supervisor name: Dr Andre Szameitat, Reader in Psychology, ***andre.szameitat@brunel.ac.uk***, 01895 267387

For complaints and questions about the conduct of the Research

Professor Louise Mansfield, Chair College of Health, Medicine and Life Sciences Research Ethics Committee ***louise.mansfield@brunel.ac.uk***

Thank you very much for your participation!

7.3 Appendix 1 C

College of Health, Medicine and Life Sciences
Department of Life Sciences

LEARNING MULTITASKING IN APPLIED CONTEXTS

AINA DIGAEVA

APPROVAL HAS BEEN GRANTED FOR THIS STUDY TO BE CARRIED OUT BETWEEN

08/11/2021 AND 30/09/2023

Please confirm the following:

	Yes	**No**
• I have read the Participant Information Sheet included with this questionnaire;		
• I am over the age of 18;		
• I understand that no personal identifying data is collected in this study, therefore I know that once I have submitted my answers I am unable to withdraw my data from the study;		
• I agree that my data can be anonymised, stored and used in future research in line with Brunel University's data retention policies;		
• I agree to take part in this study		

7.4 Appendix 1 D

Learning Multitasking in applied contexts

Survey Flow

Block: Consent (1 Question)
Standard: Personal Details (5 Questions)
Standard: Learning MT Experience (8 Questions)
Standard: MPI (15 Questions)
Standard: Learning MT Opinion (8 Questions)

End of Block: Consent

Start of Block: Personal Details

PD.1 Please select your age band

- 18-24 (2)
- 25-34 (3)
- 35-44 (4)
- 45-54 (5)
- 55-64 (6)
- above 65 (7)

PD.2 What is your gender?

- Male (1)
- Female (2)
- Non-binary / third gender (3)

PD.3 What is your current occupation?

____

PD.4 Do you hold a driving license?

○ No (1)

○ Yes (2)

Skip To: End of Block If PD.4 = No

Display This Question:

If PD.4 = Yes

PD.5 For how many years have you held your license?

____

End of Block: Personal Details

Start of Block: Learning MT Experience

Intro In this study, we are interested in your experiences of learning complex activities. Such activities require the performance of more than one task at once, so-called ‘multitasking’. For example, driving a car is often considered an activity requiring multitasking (steering the car, monitoring road and hazards, listening to the SatNav, reacting to traffic lights). Some computer games can also require multitasking (press buttons with both hands, monitor multiple events on the screen, make decisions). Further examples could be playing certain instruments or performing certain sport activities.

Broadly speaking, there are different approaches to learn multitasking activities:
1) One first learns all individual activities on their own until one masters them well, and only then trains them together (for example, first learn to operate clutch, stick and gas pedal in synchrony on a parking lot for one or more sessions before driving on the road in normal traffic)
2) One learns all activities at the same time (for example, drive on the road in normal traffic straight away)

3) A mixture of both: Learning the individual activities a little bit, but quickly doing them all together (for example, training clutch, stick, and gas pedal for a couple of minutes only and then driving on the road in normal traffic)

And there may be many more ways how to learn multitasking activities, and we are curious to learn about them. So please fill in the text boxes whenever asked.

Q1 How good do you think you are at multitasking?

- ○ Excellent (11)
- ○ Good (12)
- ○ Fair/Average (13)
- ○ Poor (14)
- ○ Very Poor (15)

Q2 Please briefly describe/characterise the multitasking activity for which you would like to share your experiences (for example, “learning to drive a car”)

____

Q3 During your training, did you first learn the different elements of the activity separately on their own, or did you practice them all together right away, or a mixture of this?

○ First, I thoroughly learned each activity separately until I was very good/confident at them (1)

○ I learned all activities at the same time right from the start (2)

○ A mixture: First I learned each activity separately a little bit, but then quickly started learning it all at the same time (3)

Q4 If you had an instructor/trainer, did they help you in managing explicitly the 'multitasking' aspect of the activity? For example, they may have pointed out how two elements of the task can be done in parallel easier.

○ Yes (1)

○ No (2)

○ I did not have a trainer/instructor (3)

Skip To: Q5 If Q4 = I did not have a trainer/instructor

Skip To: Q5 If Q4 = No

Q5 When your instructor/trainer taught you the multitasking aspect explicitly, how did they do it? (In addition, what do you think was useful or was not useful?)

____

Q5 Would you have preferred to learn the activity in a different way? Please briefly explain why.

○ Yes, (1) ____

○ No, (2) ____ Q6 During your training, how did you like it the way trainer/instructor did it (for example, showed how to operate the clutch whilst steering the car and changing the gear)? Would you have preferred a different approach (if so, briefly describe)?

- ○ I prefer how my instructor taught me multitasking aspect of the activity. (1)
- ○ I would prefer a different approach to my instructor's way, such as (2) ____

End of Block: Learning MT Experience

Start of Block: MPI

Intro In this section you will be asked to indicate how much you agree or disagree with series of statements.

MPI.1 I prefer to work on several projects in a day, rather than completing one project and then switching to another.

- ○ Strongly agree (12)
- ○ Somewhat agree (13)
- ○ Neither agree nor disagree (14)
- ○ Somewhat disagree (15)
- ○ Strongly disagree (16)

MPI.2 I would like to work in a job where I was constantly shifting from one task to another, like a receptionist or an air traffic controller.

- Strongly agree (7)
- Somewhat agree (8)
- Neither agree nor disagree (9)
- Somewhat disagree (10)
- Strongly disagree (11)

MPI.3 I lose interest in what I am doing if I have to focus on the same task for long periods of time, without thinking about or doing something else.

- Strongly agree (6)
- Somewhat agree (7)
- Neither agree nor disagree (8)
- Somewhat disagree (9)
- Strongly disagree (10)

MPI.4 When doing a number of assignments, I like to switch back and forth between them rather than do one at a time.

- Strongly agree (7)
- Somewhat agree (8)
- Neither agree nor disagree (9)
- Somewhat disagree (10)
- Strongly disagree (11)

MPI.5 I like to finish one task completely before focusing on anything else.

- Strongly agree (6)
- Somewhat agree (7)
- Neither agree nor disagree (8)
- Somewhat disagree (9)
- Strongly disagree (10)

MPI.6 It makes me uncomfortable when I am not able to finish one task completely before focusing on another task.

- Strongly agree (6)
- Somewhat agree (7)
- Neither agree nor disagree (8)
- Somewhat disagree (9)
- Strongly disagree (10)

MPI.7 I am much more engaged in what I am doing if I am able to switch between several different tasks.

- Strongly agree (6)
- Somewhat agree (7)
- Neither agree nor disagree (8)
- Somewhat disagree (9)
- Strongly disagree (10)

MPI.8 I do not like having to shift my attention between multiple tasks.

- Strongly agree (7)
- Somewhat agree (8)
- Neither agree nor disagree (9)
- Somewhat disagree (10)
- Strongly disagree (11)

MPI.9 I would rather switch back and forth between several projects than concentrate my efforts on just one.

- Strongly agree (6)
- Somewhat agree (7)
- Neither agree nor disagree (8)
- Somewhat disagree (9)
- Strongly disagree (10)

MPI.10 I would prefer to work in an environment where I can finish one task before starting the next.

- Strongly agree (7)
- Somewhat agree (8)
- Neither agree nor disagree (9)
- Somewhat disagree (10)
- Strongly disagree (11)

MPI.11 I do not like when I have to stop in the middle of a task to work on something else.

- Strongly agree (6)
- Somewhat agree (7)
- Neither agree nor disagree (8)
- Somewhat disagree (9)
- Strongly disagree (10)

MPI.12 When I have a task to complete, I like to break it up by switching to other tasks intermittently.

- Strongly agree (2)
- Somewhat agree (3)
- Neither agree nor disagree (4)
- Somewhat disagree (5)
- Strongly disagree (6)

MPI.13 I have a “one-track” mind.

- Strongly agree (2)
- Somewhat agree (3)
- Neither agree nor disagree (4)
- Somewhat disagree (5)
- Strongly disagree (6)

MPI.14 I prefer not to be interrupted when working on a task.

- Strongly agree (2)
- Somewhat agree (3)
- Neither agree nor disagree (4)
- Somewhat disagree (5)
- Strongly disagree (6)

End of Block: MPI

Start of Block: Learning MT Opinion

LMT.1 In your opinion, what would be the best approach to learn multitasking activities? Please shortly describe, why?

- I prefer to first learn each task on its own until I master them all, and only then train them together (1) ____
- I prefer to start right away learning all tasks together (2) ____
- I think the best strategy depends on the nature of the task (3) ____
- It is useful if instructors/teachers explicitly teach how to integrate the task (in other words, they teach how to multitask) (4) ____
- Any other comments on “How to best learn multitasking activities" (5) ____

LMT.2 What do you think might have a positive effect on learning how to multitask?

____

____

LMT.3 What do you think might have a negative effect on learning how to multitask?

____

____

LMT.4 Do you think that you might benefit from receiving a generic training (such as an online course) on how to learn multitasking activities in general? In other words, a course which would teach a strategy of how to best learn multitasking activities. Please elaborate why?

- Yes, (1) ____

- No, (2) ____ LMT.5 Learning a multitasking activity differs from learning a single-task activity

- Strongly disagree (6)
- Somewhat disagree (7)
- Neither agree nor disagree (8)
- Somewhat agree (9)
- Strongly agree (10)

LMT.6 Learning a multitasking activity would benefit from a learning strategy which takes the multitasking aspects explicitly into account

- Strongly disagree (7)
- Somewhat disagree (8)
- Neither agree nor disagree (9)
- Somewhat agree (10)
- Strongly agree (11)

LMT.7 Current practices of learning multitasking activities (training, instructions) are well suited to learn multitasking activities

- ◯ Strongly agree (2)
- ◯ Somewhat agree (3)
- ◯ Neither agree nor disagree (4)
- ◯ Somewhat disagree (5)
- ◯ Strongly disagree (6)

LMT.8
Current practices of learning multitasking activities could be improved

- ◯ Strongly agree (2)
- ◯ Somewhat agree (3)
- ◯ Neither agree nor disagree (4)
- ◯ Somewhat disagree (5)
- ◯ Strongly disagree (6)

End of Block: Learning MT Opinion

7.5 Appendix 1 F

College of Health, Medicine and Life Sciences
Department of Life Sciences

LEARNING MULTITASKING IN APPLIED CONTEXTS

AINA DIGAEVA

APPROVAL HAS BEEN GRANTED FOR THIS STUDY TO BE CARRIED OUT BETWEEN

21/11/2021 AND 30/09/2023

Debrief form

We would like to take this opportunity to say **Thank You** for taking the time to take part in our experiment.

Please be assured, all data collected will be treated in the strictest confidence. You are free to withdraw your data without giving a reason, until the point at which your data is anonymised, the results of the study are published in any form, and/or until the point at which your data is made publicly available in an anonymised form. If you would like to withdraw your data, please contact Aina Digaeva ***2048253@brunel.ac.uk*** or Dr Andre Szameitat ***andre.szameitat@brunel.ac.uk***.

The completed research will help to gain an understanding of general attitude towards learning how to multitask and the most efficient way to multitasking. This can be beneficial for a range of occupations and impact multitasking performance, specifically, how people can learn multitasking in applied contexts such as driving/cycling. You were chosen to take part in the study because you are aged 18 years or older.

If you were unduly or unexpectedly affected by taking part in the study, please feel free to feed it back to the researcher. If you feel unable for whatever reason what-so-ever to talk with the researcher then please either contact their supervisor (***andre.szameitat@brunel.ac.uk***) or one of the Division of Psychology Research ethics coordinators led by ***Justin.OBrien@brunel.ac.uk***.

7.6 Appendix 2 A

College of Health, Medicine and Life Sciences Research Ethics Committee (DLS)
Brunel University London
Kingston Lane
Uxbridge
UB8 3PH
United Kingdom

www.brunel.ac.uk

17 March 2023

LETTER OF APPROVAL

APPROVAL HAS BEEN GRANTED FOR THIS STUDY TO BE CARRIED OUT BETWEEN 22/03/2023 AND 30/09/2023

Applicant (s): Miss Aina Digaeva

Project Title: Online Multitasking Training

Reference: 42231-LR-Mar/2023- 44329-2

Dear Miss Aina Digaeva

The Research Ethics Committee has considered the above application recently submitted by you.

The Chair, acting under delegated authority has agreed that there is no objection on ethical grounds to the proposed study. Approval is given on the understanding that the conditions of approval set out below are followed:

- - PIS/Consent form/debrief form - You say 'You may withdraw your data, without giving a reason, until the point at which your data is anonymised, the results of the study are published in any form, and/or until 25 May 2023 the point at which your data is made publicly available in an anonymised form.' This is not sufficiently clear to participants. Please either give a date before which data can be withdrawn or let participants know that they cannot withdraw after the 5th session (this is when you tell them that you will delete their email addresses). Please ensure that you are consistent throughout your study documents.

- Debrief - Please correct the spelling of Justin O'Brien's email address.

- **The agreed protocol must be followed. Any changes to the protocol will require prior approval from the Committee by way of an application for an amendment.**
- **Please ensure that you monitor and adhere to all up-to-date local and national Government health advice for the duration of your project.**

Please note that:

- Research Participant Information Sheets and (where relevant) flyers, posters, and consent forms should include a clear statement that research ethics approval has been obtained from the relevant Research Ethics Committee.
- The Research Participant Information Sheets should include a clear statement that queries should be directed, in the first instance, to the Supervisor (where relevant), or the researcher. Complaints, on the other hand, should be directed, in the first instance, to the Chair of the relevant Research Ethics Committee.
- Approval to proceed with the study is granted subject to any conditions that may appear above.
- The Research Ethics Committee reserves the right to sample and review documentation, including raw data, relevant to the study.
- If your project has been approved to run for a duration longer than 12 months, you will be required to submit an annual progress report to the Research Ethics Committee. You will be contacted about submission of this report before it becomes due.
- You may not undertake any research activity if you are not a registered student of Brunel University or if you cease to become registered, including abeyance or temporary withdrawal. As a deregistered student you would not be insured to undertake research activity. Research activity includes the recruitment of participants, undertaking consent procedures and collection of data. Breach of this requirement constitutes research misconduct and is a disciplinary offence.

Professor Louise Mansfield

Chair of the College of Health, Medicine and Life Sciences Research Ethics Committee (DLS)

Brunel University London

7.7 Appendix 2 B

College of Health, Medicine and Life Sciences

Department of Life Sciences

PARTICIPANT INFORMATION SHEET

Study title Online Multitasking Training

Invitation Paragraph

You are being invited to participate in a research study to be conducted by Brunel University London. Before you make your decision to take part, it is important for you to understand why the research is being done and what it will involve.

Please take time to read the following information carefully and discuss it with your relatives and/or friends if you wish.

Please let us know if there is anything that is unclear or if you would like more information. Thank you for reading this.

What is the purpose of the study?

The aim of my PhD research is to investigate how people learn multitasking. This study will consist of five sessions on separate days. Each session will last approximately 30-35 minutes. The entire study will take 5-14 days.

Why have I been invited to participate?

You have been invited to take part because you meet the study inclusion criteria of being 18 years or older. We plan to test approximately 50 participants.

Do I have to take part?

As participation is entirely voluntary, it is up to you to decide whether to take part. If you do decide to take part, you will be provided with this information and you will be asked to give consent. If you decide to take part you are still free to withdraw your data, without giving a reason, until the point at which your data is anonymised, the results of the study are published in any form, until 25 May 2023, and/or the point at which your data is made publicly available in an anonymised form. If you decide to not take part or to withdraw your data, this will in no way adversely affect you.

What will happen to me if I take part?

You will be asked to attend an online study and will be given different tasks to practice individually and at the same time (multitasking). For example, you will be instructed to press buttons on your keyboard in response to numbers presented on the screen and beeps presented via speakers/headphones. You will be introduced to all tasks and have an opportunity to practice them first. In addition, you will be asked to fill out a questionnaire, for example about your demographics, and how demanding you found the tasks. The study consists of five sessions, each lasting for 30-35 minutes. You will be asked to attend all five sessions within a period of 2 weeks, and you can do only one session per day. At the end of the 5th session, a debrief form will be presented to you. You will be paid a total of £21 via Testable Minds at the end of the last session (equivalent to £8.40/hour). If you decide to withdraw earlier, you will be paid pro-rata for the sessions you attended. To organise the testing of the five sessions, we will need an email address from you.

Are there any lifestyle restrictions?

There are no lifestyle restrictions relevant to this study.

What are the possible disadvantages and risks of taking part?

Regarding the tasks and questionnaires, you will be asked to do in this study, there are no anticipated risks or disadvantages.

What are the possible benefits of taking part?

This study has no individual benefits for participants. However, this study helps our understanding of how people learn multitasking activities.

What if something goes wrong?

In the unfortunate event of something going wrong, you can withdraw from the study at any time and/or seek advice from Dr Andre Szameitat, Reader in Psychology, andre.szameitat@brunel.ac.uk or submit a complaint to Professor Louise Mansfield, Chair College of Health, Medicine and Life Sciences Research Ethics Committee ***louise.mansfield@brunel.ac.uk***

Will my taking part in this study be kept confidential?

All information which is collected about you during the course of the research will be kept strictly confidential. With your permission, the anonymised research data may be analysed and reported for purposes not related to this study. The anonymised research data may also be shared with other researchers, and/or made available as "open data". This means the data will be publicly available and may be used for purposes not related to this study. However, it will not be possible to identify you from this data, which means that at no point will any uniquely identifiable data be shared. The data will be stored by the lead researcher for a period of at least ten years from completion of the project on secure Brunel network servers.

Will I be recorded, and how will the recording be used?

You will not be recorded in this study.

What will happen to the results of the research study?

The only personal information collected will be email addresses which will be deleted at the end of 5th session when participants receive the payment. The research data will be coded and analysed by the researchers before being reported. The results will be disseminated, for instance at public talks, conferences, in scientific journals, and/or social media. The data will be used for my PhD dissertation project. If you take part in this research, you can obtain a copy of the publication by contacting the researcher.

Who is organising and funding the research?

The research is organised by Aina Digaeva (2048253@brunel.ac.uk) PhD student in conjunction with Brunel University London. This research does not receive any external funding.

What are the indemnity arrangements?

Brunel University London provides appropriate insurance cover for research which has received ethical approval.

Who has reviewed the study?

This study has been reviewed by the College of Health, Medicine and Life Sciences Research Ethics Committee.

Research Integrity

Brunel University is committed to compliance with the Universities UK Research Integrity Concordat. You are entitled to expect the highest level of integrity from our researchers during the course of their research.

Contact for general information

Researcher name: Aina Digaeva (2048253@brunel.ac.uk)

Supervisor name: Dr Andre Szameitat, Reader in Psychology, (***andre.szameitat@brunel.ac.uk***)

For complaints and questions about the conduct of the Research

Professor Louise Mansfield, Chair College of Health, Medicine and Life Sciences Research Ethics Committee ***louise.mansfield@brunel.ac.uk***

7.8 Appendix 2 C

College of Health, Medicine and Life Sciences
Department of Life Sciences

ONLINE MULTITASKING TRAINING

AINA DIGAEVA

APPROVAL HAS BEEN GRANTED FOR THIS STUDY TO BE CARRIED OUT BETWEEN

22/03/2023 AND 30/09/2023

Please confirm the following:

	Yes	**No**
• I have read the Participant Information Sheet included with this questionnaire.		
• I am over the age of 18.		
• If I decide to take part I am free to withdraw my data, without giving a reason, until the point at which my data is anonymised, the results of the study are published in any form, until 25 May 2023, and/or the point at which my data is made publicly available in an anonymized form.		
• I agree that my data can be anonymised, stored, and used in future research in line with Brunel University's data retention policies.		
• I agree to take part in this study.		

7.9 Appendix 2 D

Personal Details

a) What is email address? (Open box)
b) What is your age? (Open box)
c) What is your gender? 1- male; 2- female; 3- other

Feedback questions after each block:

a) How much do you think you improved at the task(s) you have just practiced? (Scale)
b) How much do you think the practice you just did improved your abilities to do the tasks as multitasking? (Scale)
c) How difficult did you find the task(s) you just did? (Scale)
d) How hurried or rushed was the pace of the task? (Scale)
e) How discouraged and/or struggling were you while completing the task? (Scale)

Feedback at the end of session 5: Learning MT Experience

a) How good do you think you are at MT? (Scale: Poor-Excellent)
b) Do you generally prefer learning Multitasking:
  1- First, I thoroughly learn each activity separately until I was very good/confident at them (ST regime);
  2- I learn all activities at the same time right from the start (MT regime);
  3- A mixture: First I learn each activity separately a little bit, but then quickly started learning it all at the same time.

c) How would you describe your training experience, please choose the main reasons why you switched from ST to MT regime and vice versa? (Multiple choice)

I) From ST regime to MT regime: (Multiple answers possible)
  1) I prefer training each task separately
  2) MT regime was too difficult/challenging
  3) MT regime was too fast
  4) MT regime was frustrating/annoying
  5) Other: (optional open box)

II) From ST regime to MT regime: (Multiple choice)
  1) I prefer training all tasks together
  2) ST regime was too simple/boring
  3) ST regime was too slow
  4) ST regime was frustrating/annoying
  5) Other: (optional open box)

7.10 Appendix 2 F

College of Health, Medicine and Life Sciences
Department of Life Sciences

ONLINE MULTITASKING TRAINING

AINA DIGAEVA

APPROVAL HAS BEEN GRANTED FOR THIS STUDY TO BE CARRIED OUT BETWEEN

22/03/2023 AND 30/09/2023

Debrief form

We would like to take this opportunity to say **Thank You** for taking a part in this experiment.

Please be assured, all data collected will be treated in the strictest confidence. You may withdraw your data, without giving a reason, until the point at which your data is anonymised, the results of the study are published in any form, and/or until 25 May 2023 the point at which your data is made publicly available in an anonymised form. If you would like to withdraw your data, please contact Aina Digaeva (2048253@brunel.ac.uk), or Dr Andre Szameitat, Andre.Szameitat@brunel.ac.uk

The completed research will help to gain an understanding of learning how to multitask and the most efficient way to train multitasking in everyday life. This can be beneficial for a range of occupations and impact multitasking performance, specifically, how people can learn multitasking in applied context.

If you were unduly or unexpectedly affected by taking part in the study, please feel free to feed it back to the researcher. If you for any reason feel unable to talk with the researcher, then please either contact their supervisor (Andre.Szameitat@brunel.ac.uk) or one of the Division of Psychology Research ethics coordinators led by Justin.O’Brian@brunel.ac.uk.

7.11 Appendix 3 A

College of Health, Medicine and Life Sciences Research Ethics Committee (DLS)
Brunel University London
Kingston Lane
Uxbridge
UB8 3PH
United Kingdom

www.brunel.ac.uk

3 February 2022

LETTER OF APPROVAL

APPROVAL HAS BEEN GRANTED FOR THIS STUDY TO BE CARRIED OUT BETWEEN 21/11/2021 AND 30/09/2024

Applicant (s): Miss Aina Digaeva

Project Title: Learning multitasking in applied contexts

Reference: 32240-A-Jan/2022- 37383-1

Dear Miss Aina Digaeva

The Research Ethics Committee has considered the above application recently submitted by you.

The Chair, acting under delegated authority has agreed that there is no objection on ethical grounds to the proposed study. Approval is given on the understanding that the conditions of approval set out below are followed:

- B3 - PIS - What is the purpose of the study? - Please amend the number of sessions here. (It still says eleven).
- B3 - Typo in PIS "Do I have to take part?" says "intill" instead of "until". Please amend.
- B3 - Your end dates vary by document, be consistent and use your approved dates (above).
- **The agreed protocol must be followed. Any changes to the protocol will require prior approval from the Committee by way of an application for an amendment.**
- **Please ensure that you monitor and adhere to all up-to-date local and national Government health advice for the duration of your project.**

Please note that:

- Research Participant Information Sheets and (where relevant) flyers, posters, and consent forms should include a clear statement that research ethics approval has been obtained from the relevant Research Ethics Committee.
- The Research Participant Information Sheets should include a clear statement that queries should be directed, in the first instance, to the Supervisor (where relevant), or the researcher. Complaints, on the other hand, should be directed, in the first instance, to the Chair of the relevant Research Ethics Committee.
- The Research Ethics Committee reserves the right to sample and review documentation, including raw data, relevant to the study.
- If your project has been approved to run for a duration longer than 12 months, you will be required to submit an annual progress report to the Research Ethics Committee. You will be contacted about submission of this report before it becomes due.
- You may not undertake any research activity if you are not a registered student of Brunel University or if you cease to become registered, including abeyance or temporary withdrawal. As a deregistered student you would not be insured to undertake research activity. Research activity includes the recruitment of participants, undertaking consent procedures and collection of data. Breach of this requirement constitutes research misconduct and is a disciplinary offence.

Professor Louise Mansfield

Chair of the College of Health, Medicine and Life Sciences Research Ethics Committee (DLS)

Brunel University London

7.12 Appendix 3 B

College of Health, Medicine and Life Sciences

Department of Life Sciences

PARTICIPANT INFORMATION SHEET

Study title

Learning multitasking in applied contexts.

Invitation Paragraph

You are being invited to participate in a research study to be conducted at Brunel University. Before you make your decision to take part, it is important for you to understand why the research is being done and what it will involve.

Please take time to read the following information carefully and discuss it with your relatives and/or friends if you wish.

Please let us know if there is anything that is unclear or if you would like more information. Thank you for reading this.

What is the purpose of the study?

The aim of this study is to investigate how people learn multitasking. The study will last approximately 30-45 minutes for eleven sessions.

Why have I been invited to participate?

You have been invited to take part because you meet the study inclusion criteria, such as being over 18 years old with driving training or experience (driving license and learner permit (UK or non-UK equivalent) are acceptable). You will not be the only participant and we plan to test approximately 50 participants.

Do I have to take part?

As participation is entirely voluntary, it is up to you to decide whether to take part. If you do decide to take part, you will be given this information sheet to keep and you will be asked to sign a consent form. If you decide to take part you are still free to withdraw your data, without giving a reason, intill 25 May 2023. You may withdraw your data, without giving a reason, until the point at which your data is anonymised, the results of the study are published in any form, and/or until the point at which your data is made publicly available in an anonymised. If you decide to not take part or to withdraw your data, this will in no way adversely affect you.

What will happen to me if I take part?

You will be asked to attend a study in the SIM Laboratory (room 225, HNZW), and will be given different tasks to practice individually and at the same time (multitasking). For example, you will be asked to drive in a driving simulator (similar to a computer game), solve puzzles on a tablet, and solve simple math operations. You will be introduced to all tasks and have an opportunity to practice them first. In addition, you will be asked to fill out a questionnaire, for example about your driving experience, your attitudes towards multitasking, and how you liked the tasks.

The study consists of eleven sessions, each lasting for 30-45 minutes. You will be asked to attend all eleven sessions in a period of 4 weeks. At the end of the study, you will be given a debrief form. You will be paid a total of £100 in cash at the end of the last session (equivalent to £9/hour). If you decide to withdraw earlier, you will be paid pro-rata for the sessions you attended.

Are there any lifestyle restrictions?

There are no lifestyle restrictions relevant to this study.

What are the possible disadvantages and risks of taking part?

Regarding the tasks and questionnaires, you will be asked to do in this study, there are no anticipated risks or disadvantages.

However, please note that this study involves face-to-face testing, so there are potential risks related to COVID-19. The following measures are taken to reduce the risks of Covid-19:

- Participants are advised to undertake Covid-19 tests on the day they are due to take part. The researcher will undertake Covid-19 tests at least twice a week.
- Please be aware that while every effort is made to ensure your safety, vaccination is proven to decrease the risk of transmission of Covid-19 and to reduce the likelihood of severe illness.
- Researchers and participants should wash or sanitise their hands regularly.
- All equipment will be sanitised between participants. The room will be well ventilated between participants and (weather permitting) throughout the sessions.
- The experimenter will wear a face mask throughout the sessions and will maintain social distancing as much as possible.
- We will ask you to wear a face mask for the whole duration of the experiment.

What are the possible benefits of taking part?

This study has no individual benefits for participants. However, this study helps our understanding of how people learn multitasking activities.

What if something goes wrong?

In the unfortunate event of something going wrong, you can withdraw from the study at any time and/or seek advice from Dr Andre Szameitat, Reader in Psychology, andre.szameitat@brunel.ac.uk or submit a complaint to Professor Louise Mansfield, Chair College of Health, Medicine and Life Sciences Research Ethics Committee ***louise.mansfield@brunel.ac.uk***

Will my taking part in this study be kept confidential?

All information which is collected about you during the course of the research will be kept strictly confidential. Any information about you which leaves the University will be anonymised, which means it will have personal information such as your name removed so that you cannot be identified from it.

Will I be recorded, and how will the recording be used?

Every session is video-recorded using a web-cam. The recordings are used for offline data analysis. For example, you will be asked to say out loud the answers to easy math questions, and the correctness of those answers may be checked after the study. Recordings of you will not be shared or made public in any form.

What will happen to the results of the research study?

The research data will be coded (for anonymity) and analysed by the researchers before being reported. The results will be disseminated, for instance at public talks, conferences, in scientific journals, and/or social media. The data will be used for my PhD dissertation project. The anonymised research data may be analysed and reported for purposes not related to this study. The anonymised research data may also be shared with other researchers, and/or made available as "open data". This means the data will be publicly available and may be used for purposes not related to this study. However, it will not be possible to identify you from these data, which means that at no point will any uniquely identifiable data be shared. The data will be stored by the lead researcher for a period of at least ten years from completion of the project. If you take part in this research, you can obtain a copy of the publication by contacting the researcher. You may withdraw your data, without giving a reason, until the point at which your data is anonymised, the results of the study are published in any form, and/or until the point at which your data is made publicly available in an anonymised form.

Who is organising and funding the research?

The research is organised by Aina Digaeva (2048253@brunel.ac.uk) PhD student at Brunel University London. This research does not receive any external funding.

What are the indemnity arrangements?

Brunel University London provides appropriate insurance cover for research which has received ethical approval.

Who has reviewed the study?

This study has been reviewed by the College of Health, Medicine and Life Sciences Research Ethics Committee.

Research Integrity

Brunel University is committed to compliance with the Universities UK Research Integrity Concordat. You are entitled to expect the highest level of integrity from our researchers during the course of their research.

Contact for further information and complaints

For general information

Researcher names: Aina Digaeva (2048253@brunel.ac.uk)

Supervisor name: Dr Andre Szameitat, Reader in Psychology, andre.szameitat@brunel.ac.uk, 01895 267387

For complaints and questions about the conduct of the Research

Professor Louise Mansfield, Chair College of Health, Medicine and Life Sciences Research Ethics Committee ***louise.mansfield@brunel.ac.uk***

Thank you very much for your participation!

7.13 Appendix 3 C

College of Health, Medicine and Life Sciences

Department of Life Sciences

LEARNING MULTITASKING IN APPLIED CONTEXTS

AINA DIGAEVA

APPROVAL HAS BEEN GRANTED FOR THIS STUDY TO BE CARRIED OUT BETWEEN

21/11/2021 AND 30/09/2023

The participant (or their legal representative) should complete the whole of this sheet.		
	YES	NO
Have you read the Participant Information Sheet?	☐	☐
Have you had an opportunity to ask questions and discuss this study? (via email/phone for electronic surveys)	☐	☐
Have you received satisfactory answers to all your questions? (via email/phone for electronic surveys)	☐	☐
Do you understand that you will not be referred to by name in any report concerning this study?	☐	☐
Do you understand that:		
• You are free to withdraw from this study at any time	☐	☐
• You don't have to give any reason for withdrawing	☐	☐
• You can withdraw your data any time until the point at which your data is anonymised, the results of the study are published in any form, and/or until the point at which your data is made publicly available in an anonymised form (until 25 May 2023)	☐	☐
I agree to my training sessions being video-recorded	☐	☐
The procedures regarding confidentiality have been explained to me	☐	☐
I agree that my anonymised data can be stored and shared with other researchers for use in future projects.	☐	☐
I agree to take part in this study.	☐	☐

7.14 Appendix 3 D

Participant№…………………Date……………………Time……………………

1) Do you have a driving license? (Including Learner Permit)
   a) Yes
   b) No

2) If yes, for how many years?_______

3) Did you drive right hand car, like in UK or on the left side?
   a) Right hand car
   b) Left hand car
   c) both

4) Did you drive automated or manual car?
   a) automated
   b) manual
   c) both

5) How experienced in driving do you consider yourself?
   a) No experience at all
   b) Somewhat experienced
   c) Experienced
   d) Very experienced

6) Do or did you play videogames of the type driving simulation and/or racing?
   a) Yes
   b) No

7) If yes, please name the main games you were playing?__________

8) On which platforms did you play? (Multiple answers possible)
   a) Smartphone
   b) Game Console (e.g., Xbox, PlayStation), please specify:
   c) Computer

9) Did you use gaming steering wheel?
   a) Yes
   b) No

10) Did you use gaming pedals (for brake/gas)?
    a) Yes
    b) No

11) How experienced would you consider yourself (in playing driving simulation / car racing games)?
   a) Novice/played rarely
   b) Somewhat experienced
   c) Confident gamer
   d) Very experienced gamer

Please indicate your preferences in the use of hands in the following activities or objects

Item	Always left	Usually left	Both equally	Usually right	Always right
Writing					
Throwing					
Toothbrush					
Spoon					

Feedback Sheet

Participant №:________ Training Session №:____________ Date:______________

Dear Participant, thank you for taking a part in this research. Please answer the following questions because your feedback will provide valuable insights to improve our study.

1.

On a scale, where 0 - very poor and 10 – excellent, how good do you think you performed today overall?										
0	1	2	3	4	5	6	7	8	9	10

2.

On a scale, where 0 - very poor and 10 – excellent, how good do you think you performed the following tasks?											
Tasks	0	1	2	3	4	5	6	7	8	9	10
Driving Tasks											
Screens Reading											
Math Tasks											
Tablet											
Multitasking											

3. During your learning experience today, what went very well (and/or what did you like)?

____

4. During your learning experience today, what didn't go so well today (and/or what would you change)?

____

Figure 8.6

NASA Task Load Index

Hart and Staveland's NASA Task Load Index (TLX) method assesses work load on five 7-point scales. Increments of high, medium and low estimates for each point result in 21 gradations on the scales.

P [redacted] S [redacted] D [redacted]

	Task	Date

Mental Demand — How mentally demanding was the task?

Very Low — Very High

Physical Demand — How physically demanding was the task?

Very Low — Very High

Temporal Demand — How hurried or rushed was the pace of the task?

Very Low — Very High

Performance — How successful were you in accomplishing what you were asked to do?

Perfect — Failure

Effort — How hard did you have to work to accomplish your level of performance?

Very Low — Very High

Frustration — How insecure, discouraged, irritated, stressed, and annoyed wereyou?

Very Low — Very High

7.15 Appendix 3 E

College of Health, Medicine and Life Sciences

Department of Life Sciences

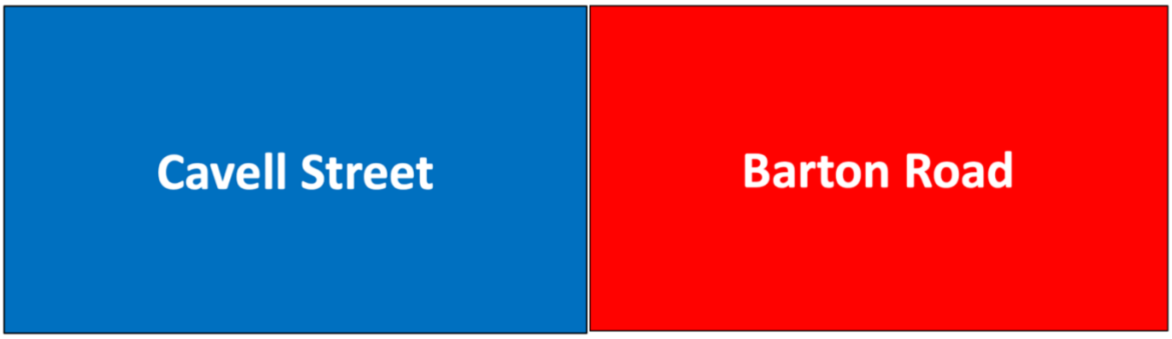
LEARNING MULTITASKING IN APPLIED CONTEXTS

PRACTICE INSTRUCTIONS

Monitoring Task

There are two screens showing changing PowerPoint slideshows; one is in front of you and one is behind. Your task is to monitor the slides frequently and to read aloud the text (usually street names) only on the slides with a **red** background. You can ignore the slides if their background is not red. The slides change every 24 seconds, so you are advised to check regularly for red slides.

<u>What we are measuring:</u> We are recording the number of correctly read-out red slides as well as errors; for example, if you missed a red slide or if you read the text on a non-red slide.



Maths Task

In this task you will hear simple maths problems (for example, “5 plus 4”) every 15 seconds. You should state aloud the equation AND the answer (for example, “5 plus 4 equals 9”). You should also memorise the answer (in this example, 9) for the next equation; for example, the next instruction might be “minus 1”, in which case you should say out loud “9 minus 1 equals 8”.

Please note: You **must** say the entire mathematical operation as your answer, such as “three plus two equals five”, and not only the result (e.g., “five”), because we can then adjust our scoring for subsequent problems accordingly. In other words, if you get one equation wrong, this will not affect your performance on the following equations.

- So, if you forget the previous result, please do not stop the task, but instead continue with your best guess.
- If you miss an equation, then please ignore that equation and continue with the next equation (using the last number you remember).

What we are measuring: We will measure how many maths problems you answered correctly.

Memory Matching Task (tablet device)

In this task you are required to find pairs of identical images in an array of ‘cards’ on the tablet screen; you have unlimited attempts to do so. At each attempt, you will flip over two cards by touching them, to show the images on their undersides. If you find an identical pair, then they will be removed from the game (success!); if not, they will automatically face down again. Each card initially depicts a question mark on its back, which disappears once it has been flipped over once. A good strategy is to start in one corner and then work your way systematically through the array of cards, instead of tapping randomly.

What we are measuring: We are measuring your performance according to (a) the number of times you flip over cards and (b) the number of pairs you find. While finding pairs is a priority, please remember that continuing to flip over cards (even if you don’t manage to find pairs) indicates your engagement with the task.

Driving Simulator Task

Please adjust the chair so that you can comfortably reach the steering wheel and pedals. Please note that the simulator will operate in 'automatic' mode, so you only need to use the middle pedal (the brake pedal) and the right pedal (the gas/accelerator pedal).

Like in real life, before you can start driving you have to perform several tasks:

- Press the "seatbelt" button on the steering wheel to fasten your seatbelt
- Press the "key" button to start the car
- Press the "lights" button twice to switch on the vehicle lights
- Change gear to Drive (D) or Reverse (R) by pressing the brake pedal and pressing the up and down arrows on the steering wheel. You can see the gear changes in a graphic on the right-hand screen
    - *Please note: you must depress the brake pedal to change gear*
    - *You only require two gear settings: "D" for Drive and "R" for Reverse. "N" stands for Neutral (car is not moving) and "P" for Parking*
- To activate the direction indicators, pull the metal bars either side of the steering wheel: the left one for a left turn, and the right one for a right turn
- The red button is a horn, which you can use if there is a vehicle blocking your way.

Driving Practice

Once you have prepared the vehicle, you can start driving by pressing the gas pedal. During the practice, please familiarise yourself with the vehicle controls and steering. It is a good idea to try out the following things as many times as you like, until you feel comfortable:

1. Depress the gas and brake pedals frequently and note the effects on the screen.
2. Like in real-life, do not drive faster than the speed limit, but also not much slower (traffic permitting).
3. Practice the steering, by making turns, changing lanes and swerving slightly. You should use the indicator to change lanes or make a turn.
4. Try crashing into a vehicle or an obstacle! To get out of an accident, you usually must reverse.

After you have practised, you will drive for a 6-minute period. During this period, the researcher will give you navigation instructions (e.g., "Please turn left at the next junction")

<u>What we are measuring:</u> You will receive penalties if you violate normal driving rules and laws. The penalties have different severities, for example driving 5 miles per hour (mph) over the speed limit has a lower penalty than driving 10 mph over the limit. We are measuring the number and severity of such penalties.

Penalties include:

9. Driving through a red traffic light
10. Driving in the wrong lane (i.e., toward oncoming traffic)
11. Driving over the speed limit
12. Having an accident
13. Not using indicators to make turns
14. Being a hindrance to other vehicles
15. Driving off the road
16. Not following the researcher's direction instructions

Multitasking Practice

This experiment involves performing all four tasks at the same time: driving while monitoring the screens to the front and rear of you, providing answers to the maths problems, and finding identical pairs on the tablet device.

Please note that you <u>must only do the tablet task while the car is moving</u>. You are not allowed to work on the tablet task if the car is standing still, for example when waiting at a traffic light or zebra crossing, or when in a traffic jam.

This is a very demanding task. You will make a lot of errors, and the task may seem overwhelming. However, please keep in mind that this is a complex training study and we do not expect you to perform perfectly, so please don't feel discouraged. Your performance will improve over the course of the study, and we are interested in such performance changes.

We will assess your performance at the beginning, in the middle, and at the end of your training. This allows us to examine how fast people learn this challenging task and how they develop strategies to multitask more effectively.

We hope you enjoy the challenge!

7.16 Appendix 3 F

College of Health, Medicine and Life Sciences
Department of Life Sciences

LEARNING MULTITASKING IN APPLIED CONTEXTS

AINA DIGAEVA

APPROVAL HAS BEEN GRANTED FOR THIS STUDY TO BE CARRIED OUT BETWEEN

21/11/21 AND 30/09/2023

Debrief form

We would like to take this opportunity to say **Thank You** for taking a part in this experiment.

Please be assured, all data collected will be treated in the strictest confidence. You may withdraw your data, without giving a reason, until the point at which your data is anonymised, the results of the study are published in any form, and/or until the point at which your data is made publicly available in an anonymised form. If you would like to withdraw your data, please contact Aina Digaeva (2048253@brunel.ac.uk), or Dr Andre Szameitat, Andre.Szameitat@brunel.ac.uk

The completed research will help to gain an understanding of general attitude towards learning how to multitask and the most efficient way to train multitasking. This can be beneficial for a range of occupations and impact multitasking performance, specifically, how people can learn multitasking in applied context.

If you were unduly or unexpectedly affected by taking part in the study, please feel free to feed it back to the researcher. If you for any reason feel unable to talk with the researcher, then please either contact their supervisor (Andre.Szameitat@brunel.ac.uk) or one of the Division of Psychology Research ethics coordinators led by Justin.O’Brian@brunel.ac.uk.

7.17 Appendix 3 G

Receipt

Study: ***"Learning Multitasking in applied contexts"*** *Researcher: Aina Digaeva*

I, ________________________________

(please print full name)

living at ____

(please provide full address)

confirm that I have received payment of £63 for my participation in the above study.

Signed ____________________ Date _________________