Limitations in dual-task performance

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Chapter 6

Discussion and Conclusion

Dual-task experiments to investigate working memory and attention

In this thesis, the effect of information-processing overload on working-memory (WM) dependent information processing was examined using dual-task paradigms. Dual-task limitations represent the inability to execute two tasks concurrently: The reaction time (RT) for both tasks is longer and accuracy is lower than when the two tasks would be presented and processed separately (e.g., Bertelson, 1967; Gottsdanker, Broadbent, & Van Sant, 1963). The origin of this delay, and the circumstances that elicit it, still remain unclear. What ís known is that these limitations are largely — if not entirely — determined by attention and WM.

Attention is a multifaceted concept that refers to the way in which limited resources are put to work to process a subset of the available information for the task at hand, be it through spreading the resources (divided and sustained attention), recruiting extra resources (effort, arousal, or alertness), or through investing them selectively for a specific purpose (selective attention). Attention does not only reflect the way processing limitations are handled: controlling attention itself is also a limited-capacity process. It is in the latter sense that the relation between attention and dual-task performance was investigated.

Although several WM models have been proposed, with considerable differences among them (e.g. Baddeley, 2000; Cowan, 1988), they all rely on three main functions: memory storage, cognitive operations on the content of memory, and control (see e.g., Baddeley, 1986; Baddeley & Hitch, 1974; Baddeley & Logie, 1999; Logie, 1995; D'Esposito, 2007; Oberauer, Demmrich, Mayr, & Kliegl, 2001 for these distinctions). Each of these functions could be responsible for processing limitations. The first function, storage, holds relevant information in WM entering from the outside world or from long-term memory. The second function, operations, processes the information that is stored in memory. The third function controls the operations that occur, for example by biasing one operation over the other so as to select one operation to be performed first. Together, these three functions form an active system in which information is processed.

An example of a WM model was proposed by Baddeley and Hitch (1974; Baddeley, 1986) and was extended by Baddeley in 2000. The model contains the three functions of storage, operations and control and shows three systems that allow for storage and processing of information within a particular domain: the phonological loop, the visual-spatial sketchpad and the episodic buffer. The phonological loop deals with auditory information and is composed of a passive phonological store and an active rehearsal process (Baddeley & Logie, 1999). The visual-spatial sketchpad deals with visual-spatial information and is composed of a storage part called the visual cache, and an active processing system called the inner scribe (Logie, 1995). The episodic buffer (Baddeley, 2000) provides WM with a short-term storage and processing module for information that allows for functions that do not fit the other systems, such as cross-modal integration. The episodic buffer also holds information that is bound with temporal codes in an episodic representation and is subsequently temporarily stored. These subsystems are controlled by the so-called central executive or control system that, for example, manages goal maintenance and updating, and that can focus and switch attention. The differentiation into three parts is theoretically interesting, but not all models accommodate this differentiation to explain WM; instead, some are limited to two of the three components.

Structural and functional processing limitations

The limitations that are present during dual-task processing can be structural or functional in nature, and they each relate in a different way to the three WM functions – storage, operations and control. Structural processing limitations occur when the processing hardware is overloaded by the load of the presented tasks. First, *storage* can be subject to capacity limitations (Kahneman, 1973; Norman & Bobrow, 1975; Navon & Gopher, 1979; Tombu & Jolicœur, 2003). However, which structural underpinnings cause this limited capacity remains unclear. This storage limitation is evident, for example, from the inability to memorize more than a certain number of random words without forgetting some of them. This suggests that information can be processed concurrently until the available WM capacity is exhausted. When more capacity is needed than is available, the encoding of information is either delayed, leading to a later arrival of the information in memory, or the surplus of information is forgotten, leading to a drop in performance.

Second, WM *operations* can be subject to structural processing limitations when relevant information is translated into adequate actions. For example, Pashler (1994) suggested that only one stimulus-response translation process can be performed at a time, analogous to a road lane that passes not more than one car at a time.

Third, structural limitations to executive *control* could lie, for example, in the restriction that in a transition from one task to another it is necessary to reconfigure the task set. Reconfiguring the task set (cf. tracks) causes switch costs which takes up time (Allport, Styles, & Hsieh, 1994), while in a task repetition there is no need for task-set reconfiguration and therefore not for executive control, and hence no extra time costs are incurred (Monsell, Yeung, & Azuma, 2000; Rogers & Monsell, 1995). By analogy, a railroad switch can be set to pass traffic in one direction, and after a switch to pass traffic in another direction, but never more than one direction at a time (Rogers & Monsell, 1995).

Functional-limitation models, on the other hand, attribute the dual-task delay to conflict between simultaneously active task features or processes (Hommel, 1998), to the level of necessary control demands (Luria & Meiran, 2005) or to the strategic settings during a task (Meyer & Kieras, 1997a, 1997b). First, the information that can be *stored* in WM depends on the combination of tasks. For example, storing information of two tasks with completely overlapping responses or features is easier to accomplish than storing information of two tasks with partially overlapping responses or features, arguably because in the latter case the binding of a stimulus feature to an event is preceded by the unbinding of that same stimulus feature from a previous event (Müsseler & Hommel, 1997; Stoet & Hommel, 1999). The Stroop task is a distinct example of how the feature "word-meaning" interferes with the feature "colour-naming" in case the features don't represent the same colour.

Second, *control* processes can also be subject to impairment because of interference created by incompatible additional control processes. For example, Mayr and Keele (2000) systematically investigated the control process of backward inhibition, when in order to activate a new task set, the previous task set needs to be suppressed. They used an odd-item out task, in which participants had to indicate the deviant stimulus out of four stimuli, depending on dimension. The relevant dimension – color, orientation or movement – was indicated by a verbal cue at the start of each trial. Backward inhibition was measured by presenting the trials in sequences of three: the control condition had a CBA sequence of dimensions, and the inhibition condition had a ĀBA sequence of dimensions. Responses for the third trial (A) in the sequence were slower for the ĀBA trial than the CBA trial. Mayr and Keele argued that this delay was established when activation of the new task set in the B-trial instigated suppression of the task set used in the previous trial. In ĀBA compared to CBA sequences, reactivation of task A in the third task is more difficult in the face of residual suppression of task A. Another example of control processes presents itself when people switch from their first, native language to a second language, this is easier than when they switch from a second language to their first language (Costa & Santesteban, 2004; Meuter & Allport, 1999). A greater suppression of the first language is necessary when the second language is used, while less suppression is necessary for the second language when the first language is required. A switch from second language to first language would take longer because retrieval of the native language takes longer (because it was suppressed more strongly).

Last, limitations also exist for *operations*, in which certain aspects of processing unrelated to load — the so-called content — can influence the dual-task delay. What role these processes play in dual-task slowing, however, has not been investigated before, and can help us understand the underlying mechanisms that cause this delay. One of the aims of this thesis was to clarify exactly this type of dual-task limitations. The hypothesis tested in this thesis was that in a dual task, compatibility between processes of two tasks would decrease dual-task costs, while incompatibility between processes of two tasks would incur an increase in dual-task costs, similar to the way feature processing works.

In sum, structural models on the one hand focus on a set capacity within which restrictions are caused by exceeding this capacity. Functional models on the other hand are more flexible in the sense that it is not only capacity itself, but also how it is used – e.g., the strategy or combination of tasks – that determines its limitations.

Summary of the results

In this thesis the functional role of WM in dual-task processing was investigated, to extend our knowledge on dual-task limitations and why they occur. Dual tasks overload WM and are therefore suited to investigate the origins of capacity limitations. Regarding dual-task limitations, previous research has focused on the structural impairment of dual-task processing, such as a restriction to the number of items stored in WM (e.g., Tombu & Jolicœur, 2003). In the experiments presented in this thesis we aimed to clarify to what extent functional processing limitations affect dual-task processing. More specifically, the aim was to investigate whether process compatibility could facilitate the response to the first of two stimuli in a dual task. This compatibility was varied independent of response category to separate any effect of a category match from the effect of a process compatibility (Chapter 2). Additionally, it was investigated to what extent dual-task limitations observed in different paradigms could be attributed to similar mechanisms. In order to study this, individual WM operation span and IQ were measured and correlated with individual dual-task performance (Chapter 3). Next, the role of attention in dual-task processing was investigated and whether capacity-limited processes and attention might share capacity-limited resources. In order to do so, event-related potentials (ERPs) were used to measure deployment of visual-spatial attention and encoding into visual short-term memory (Chapter 4). The last aim was to investigate whether the effect of response facilitation in case of compatible processes in a dual task was affected by an additional WM load and to determine more specifically the location of dual-task delay (Chapter 5). A summary of the results and their implications is presented below.

Operation compatibility and dual-task costs

The aim in chapter 2 was to examine whether the ability to perform two stimuli concurrently was dependent on task difficulty only – as suggested in structural limitation models (e.g., Pashler, 1994; Tombu & Jolicœur, 2002; 2003) –, or that other factors like compatibility between tasks would also play a role – as suggested in functional limitation models (e.g., Hommel, 1998; Logan & Gordon, 2001; Meyer & Kieras, 1997a; 1997b). We investigated the influence of process compatibility on response speed by presenting two stimuli quasi-simultaneously in a dual task. For both stimuli, a rotated character was presented that required mirror / normal discrimination in a classic mental rotation task (Shepard & Metzler, 1971). Previous research (Corballis, 1986) showed that a stimulus is rotated to upright position before a mirror / normal distinction can be made. Consequently, a stimulus presented in a greater angle from upright will show a slower response (Corballis, 1986; Cooper, 1976). When both tasks required a mirror response or when both tasks required a normal response this was called a category response match. Similarly, rotations were considered compatible when both stimuli needed a clockwise rotation to upright position or both stimuli required a counter-clockwise rotation to upright. We measured the effect of stimulus 2 (S2) processes on reaction time for stimulus 1 (S1), because this shows any facilitation due to simultaneous activation of mental rotation for the two stimuli, whereas an effect of S1 processes on the reaction time to S2 also reflects repetition.

The main result showed a facilitation of the response to S1 when the category responses matched but only when rotations were compatible. This outcome suggests that how fast a task can be processed is not only dependent on the difficulty of the task, but also on the combination of processes. Rotating a stimulus e.g., 60º clockwise or 60º counter-clockwise taxes WM exactly the same; the difference lies in the combination of tasks. This result is an argument against structural models in which dual-task delays are explained in WM-load differences only. The result supports functional processing limitation models in which combination of operations or features, or a strategy are an essential element in explaining dual-task processing.

The second experiment built on the first, and saw S2 moving in a circular path around S1. While S1 was still presented at a particular angle, S2 was presented in upright position. Rotation compatibility was defined as the compatibility between the angle to upright for S1 and the direction of the circular movement for S2.

The main result showed that even though S2 movement was not taxing WM - since not necessary for response - a compatibility between rotations still facilitated the response to S1 in case of a category match. This suggests functional limitations induced by conflict at the level of representing task properties between the direction of mental rotation (Task 1) and the direction of the physical rotation (Task 2).

Similarities between refractory period and attentional blink

The aim in chapter 3 was to investigate whether the delays found in different dual tasks would share a common functional basis (Jolicœur, 1999; Jolicœur &

Dell'Acqua, 1999) or whether their basis would be different (Arnell, Helion, Hurdelbrink, & Pasieka, 2004; Duncan & Arnell, 2002; Wong, 2002). This would ultimately lead to a better understanding of the underlying mechanisms involved in dual-task processing. Thereto, we compared the measures of delay in the attentional blink (AB; Raymond, Shapiro, & Arnell, 1992) and the psychological refractory period (PRP; Telford, 1931; Welford, 1952) and investigated whether they share limitations with respect to a similar mechanism and similar constructs. In the AB, two targets are presented in a string of distractors and require an unspeeded response at the end of the trial. Performance of target 1 and 2 is generally quite high, except for target 2 with intermediate time intervals (100-500 ms post target 1) which shows a marked drop in target-2 performance. This is called the blink (Raymond et al., 1992) and it is the measure of dual-task delay we used for the AB. In the PRP, two targets are presented shortly after each other that need immediate, speeded response. Reaction time for S1 is generally independent of the time interval between S1 and S2 onset. For S2, however, there is an increase in reaction time to S2 as a function of decreasing interval duration between the S1 and S2. This is called the PRP effect (Pashler, 1994; Welford, 1952) and it is the measure of dual-task delay we used for the PRP.

Additionally, we conducted two tasks to measure the constructs underlying WM operation span - which represents mainly the executive control component of WM (Arnell, Stokes, MacClean, & Gicante, in press) - and fluid intelligence (IQ). WM operation span was measured by the OSPAN task (Colzato, Spapé, Pannebakker, & Hommel, 2007; Engle, Kane, Tuholski, 1999; Turner & Engle, 1989) and IQ was measured by the Raven's Standard Progressive Matrices test (Raven, Court, & Raven, 1988). Since WM and IQ are highly correlated but not identical (Conway, Kane, & Engle, 2003; Süβ, Oberauer, Wittmann, Wilhelm, & Schulze, 2002), it is important to control for IQ when a WM construct is correlated with another component. All the components were entered into correlation analysis to investigate the size of the correlation as an indicator of the communality between the two dual tasks.

Results showed that a high blink in the AB correlated with a large PRP effect: people who performed well on the AB also showed proficient performance on the PRP. Additionally, the effects of both paradigms correlated with OSPAN. These two findings both point to a functional relation between AB and PRP. When these correlations between AB magnitude - OSPAN and PRP effect - OSPAN were controlled for IQ, the results showed a small reduction in the respective correlations. The former correlation was still significant; the latter correlation however, was reduced to non-significance, because its initial correlation was somewhat weaker. This suggests that in the AB, WM operation span is more engaged than in the PRP. This could be due to the higher number of stimuli in the AB and the need for participants to filter the targets from distractors. In sum, on the one hand there is evidence for a common functional basis for the dual-task delay in AB and PRP. On the other hand, results showed that OSPAN correlates differently with PRP than with AB and there is still an amount of unexplained variance.

The effect of mental rotation on deployment of visual-spatial attention

In chapter 4, we further investigated dual-task processing and its limitations, this time with the use of electrophysiological measurements. While previous research established response selection as the main culprit for dual-task delay (e.g., Pashler, 1994), we examined whether two processes other than response selection would delay each other. In order to do so, we presented a mental rotation task and a visual-spatial attention task in a PRP set-up to investigate whether shifting visual-spatial attentional processes and subsequent storage of stimuli into visual short-term memory is possible during mental rotation, or whether this is delayed. Earlier studies established mental rotation as capacity limited and preceding response selection (Band & Miller, 1997; Ruthruff, Lachman & Miller, 1995; Van Selst & Jolicœur, 1994). Whether visual-spatial attention causes capacity limitations is less clear, with some evidence showing no limitation (Johnston, McCann, & Remington, 1995; Pashler, 1991) and other evidence showing the opposite: Brisson & Jolicœur (2007a; 2007b) showed that response selection postpones attentional processes of a second task.

Results in our current experiment showed that mental-rotation caused a delay for visual-spatial attention in the second task. The deployment of attention and the arrival of information into visual short-term memory were measured with two components of the ERP. First, the N2pc was used as a measure of deployment of attention. Second, the sustained posterior contralateral negativity (SPCN) was used as a measure of encoding information into visual short-term memory. These results suggest that processes preceding response selection (i.e. mental-rotation and visual-spatial attention) could not be processed concurrently and response selection is not necessary for the dual-task delay to occur. Furthermore, the results indicated that response selection, mental rotation and visual-spatial attention are likely to share a common resource like executive control.

Cognitive operations and working memory

The aim in chapter 5 was twofold. First, we wanted to further explore the contribution of functional processing limitations to general dual-task limitations. Second, we wanted to make a further specification as to exactly which processes are capacity limited. Thereto, we conducted two experiments that were both a continuation of chapter 2. The same dual task as in experiment 1 of chapter 2 was presented with a mental rotation for both tasks. Again, we measured rotation compatibility and category response match. This time, we added an extra WM task aimed to take up considerable WM space during the course of the trial. We were interested to see the effect of this on compatibility independent of category response match.

Results showed that even though a considerable part of WM was taken up by this background WM task, there was still a facilitation of the response to S1 when the category responses matched but only when rotations were compatible. While WM was significantly taxed, still one process could activate two stimuli and open the way for category match to facilitate the response. Specifically, this result suggests that crosstalk is not dependent on WM storage. Instead, it is probably the outcome of the processes that are stored in WM to avoid decay. In general, these results stress the necessity to incorporate a component that explains functional-processing limitations in any model that is used to describe dual-task limitations.

In the second experiment, we focused on the finding that category match facilitates the response to S1, but only in case of a rotation compatibility. Which process constitutes the main limitation of this operation of mental rotation? Is it the implementation of the rotation, or the execution of the rotation? In order to investigate this we separated the onset of these two processes. We presented a cue at the start of each trial that validly predicted the stimulus angle in task 2 75% of the time. This cue gave participants the opportunity to implement the rotation before each trial, while S2 presentation triggered the execution of the mental rotation.

Results showed that implementing different parameters of the same operation is possible, but the execution of the operation is serial. This outcome suggests that implementation is not capacity limited, and does not take up WM space. The capacity limitation could be caused by the active use of WM space by execution processes.

The current results fitted in relevant dual-task models

The results (specifically Chapters 2 and 5) show that, in order to accommodate crucial aspects of the findings summarized in the preceding section, any model of dual-task limitations, especially WM models, should include an explanation for functional processing limitations. Dual-task limitations that are caused by the way processes are combined cannot be explained sufficiently by structural-limitation models. Three models provide or imply a functional explanation of processing limitations: 1) the Executive-Process/Interactive Control model (EPIC; Meyer & Keiras, 1997a, 1997b), 2) the Executive Control Theory of Visual Attention (ECTVA; Logan & Gordon, 2001) and 3) the Theory of Event Coding (TEC; Hommel, Müsseler, Aschersleben, & Prinz, 2001).

First, the EPIC model describes dual-task limitations as strategic, and suggests that under optimal circumstances, dual-task limitations will be decreased to none (Schumacher et al., 2001). A delay occurs when the strategy of the participants results in a more serial processing mode.

Second, the ECTVA model (Logan & Gordon, 2001) is a hierarchical model in which the executive control coordinates which parameters are manipulated at any one time. It uses an extension of the parameters put forward in the Theory of Visual Attention (TVA; Bundesen, 1990). The TVA is run twice; once for each of the two tasks in a dual task. Set-switching costs, concurrence costs and crosstalk all affect the dual-task delay. Set-switching costs depend on how many parameters need adjusting and how much adjusting they need. Costs involved in keeping two tasks active are called concurrence costs. However, there is always one task that is prioritized, and only when the set of one task can be applied to the stimulus from another task (i.e., when the stimulus or response sets of the two tasks overlap), crosstalk occurs.

Third, the TEC is aimed to provide a functional framework for perception and action that stores them together in one module called the unified coding medium (Hommel et al., 2001). It includes relevant and irrelevant features of stimuli, operations and responses (actions). In the unified encoding medium different feature codes are bound together into an event file. For example, the feature codes ‘edible’, ‘red’, ‘grows-on-trees’ and ‘round’ can be combined into an event file named ‘apple’. Because the TEC uses one module for stimulus features and response features, it allows for relevant and irrelevant features to be activated within the same medium which can cause interaction. This interaction can take place between stimulus features, response features, or between stimulus- and response features. This line of reasoning can explain the results in experiment 2 of chapter 2 of this thesis, in which a nondemanding, irrelevant movement of the S2 in a circular path around S1 facilitated the response to S1 when this movement was compatible with the rotation direction of S1. While this outcome was in line with the predictions of the TEC, the EPIC or ECTVA would only predict an effect when task load (or WM load) was manipulated. Additionally, the TEC differs from multi-modular models like the multi-component WM model by Baddeley and Hitch (1974; Baddeley, 2000). In their model, visual-spatial information, auditory information and episodic information is stored in separate modules that are controlled by a higher order central executive. Multi-component models cannot explain the cross-over effects of different elements in different event files because the information is not stored together, and action processes are not taken into consideration.

Attention and capacity-limitations

Brisson and Jolicœur (2007a; 2007b) showed that visual-spatial attention is delayed by response selection. Additionally, with the results presented in chapter 4 we showed that visual-spatial attention is delayed by mental rotation — a bottleneck process preceding response selection. Thus, response selection is not the only process responsible for the dual-task delay in the PRP paradigm and, moreover, is not necessary for the PRP effect to occur. During mental rotation visual-spatial attention is put (partly) on hold, either because visual-spatial attention in itself is capacity limited (like mental rotation), or because visual-spatial attention is regulated by a top-down process.

We showed that when processes like mental rotation are active, visual-spatial attentional selection processes are postponed. This suggests that when WM is activated by mental rotation, visual-spatial attention cannot be active concurrently. This in turn suggests that instead of a unitary process, attention is a set of related but separate selection processes in which visual-spatial attention competes with mental rotation to be selected by central attention that prioritizes the different processes. A model that has incorporated attention in its WM framework is the embedded-process model of WM proposed by Cowan (1988; 1995). The model consists of a three-layered core, containing a long-term memory store, a short-term activated memory store and a focus of attention. Long-term memory has the least restricted capacity and the focus of attention has the most restricted capacity. The limited short-term activated memory store is part of the larger long-term memory store. Within the short-term activated memory store, the focus of attention selects one item at a time, just like a real spotlight singles out items in the dark (see also Oberauer, 2002). The focus of attention is directed top-down by a central executive on the one hand, and bottom-up by stimuli that are new or relevant on the other hand. Consequently, visual-spatial attention is considered a process that regulates the focus of attention bottom-up (by stimulus presentation), and then takes up the limited capacity available and in that way interferes with mental rotation and response selection. Alternatively, visual-spatial attention is regulated by a limited-capacity top-down process which in turn also causes interference.

Future research

The general aim of this thesis was to investigate the functional limitations of dual-task processing, to obtain a better understanding of the reason why they occur and to what extent they are limited, of the relation between different dual tasks, of the attentional processes involved during dual-task processing, and of WM in general.

Although this thesis has done exactly that, this doesn't mean that there are no remaining questions or for that matter new questions to be answered.

Questions that still require an answer are mostly concerned with the circumstances in which dual-task delay occurs. In what way can the organisation of information influence the amount of information that can be stored or processed, and what are the core parameters that underlie or limit these processes? Is there a delaying effect of organization of demanding tasks, related to the exertion of executive control? In what way does the combination of e.g., task sets, stimuli, processes and responses influence the delay in the organization of executive control, without influencing the overall available capacity itself?

The use of tools like EEG (electro-encephalogram), fMRI (functional magetic resonance imaging) or MEG (magneto-encephalogram) opens up an interesting approach, because it allows us to measure differences that cannot be distinguished behaviourally. For example, the ERP component N2pc (e.g., Eimer, 1996; Luck & Hillyard, 1994) can be used as a measure for deployment of attention in a way behavioural measures cannot. Similarly, the P3 (e.g., Donchin, 1981; Donchin & Coles, 1988; Vogel, Luck, & Shapiro, 1998) – also an ERP component – can be used as a measure of activity associated with relevant representations in short-term memory or context updating (Donchin & Coles, 1988). More recently, Shapiro, Schmitz, Martens, Hommel, and Schnitzler (2006) used the size of the P3 as a measure of the amount of resources invested in processing a particular target.

One paradigm in which performance differs between participants and between conditions is the AB paradigm, which depends for example on the individual's WM operation span (e.g., Colzato et al., 2007; see also Chapter 3 of this thesis), or possibly on one's mental state (Olivers & Nieuwenhuis, 2005). In the latter study, half of the participants conducted an AB task, and the other half conducted the same AB task while performing a background task, e.g., responding to a yell presented in a background beat. Results showed increased target 2 performance when the background beat was present. They gave a functional interpretation to the AB results and argued that a more diffused mental state would allow better AB performance.

Shapiro et al. (2006) also investigated whether the bottleneck that causes the blink in the AB paradigm was structural or functional. They used magnetoencephalography to measure target 1 related P3 (M3) and found a correlation between target 1 peak amplitude and the size of the blink. Shapiro et al. (2006) argued that the division of capacity over two tasks in an AB paradigm can predict the performance on the two tasks. This suggests a functional division of resources and further research could be aimed at investigating how this balance of resources between the two targets can be manipulated.

By using a background beat as between-subjects variable in an AB paradigm like Olivers and Nieuwenhuis (2005) and measuring the difference in amount of resources invested in target 1, the hypothesis could be tested whether subjects overinvest resources to the target 1 at blink trials, at the expense of the available resources for target 2, and whether this overinvestment is less likely to occur in a more diffused mental state. We investigated this in a pilot study using the P3 as a measure of investment of resources in target 1 and target 2 and found no distinct results. This could be attributed to the between-subjects set-up of our study, and further research could do a lot to clarify how the division of resources operates.

In closing

To conclude, the experiments described in this thesis contribute to the vast amount of dual-task research already available, strengthening the importance of a functional explanation for dual-task limitations. First, it showed evidence for a unified coding medium (as put forward in the TEC) in which features, operations and responses are available and can influence each other. Additionally, it was shown that the response to the first of two stimuli is facilitated in case the processes are compatible (Chapter 2). Furthermore, it showed that the PRP and the AB share limitations with respect to a common resource that originates in WM operation span and that the use of individual differences can aid in examining the relation between the PRP and the AB (Chapter 3). Additionally, it showed that it is plausible that visual-spatial attention, mental rotation and response selection share limitations with respect to a common resource (Chapter 4). Finally, research in this thesis showed that processes that can facilitate a response can be simultaneously implemented but not simultaneously executed (Chapter 5). All in all, dual-task limitations can ultimately show us the boundaries of WM.

On a more general note, some advice for anyone who keeps running out of time (and who doesn’t these days): Take at heart the words spoken by Lord Chesterfield (1694-1773; published in 1774) who said: “There is time enough for everything in the course of the day, if you do but one thing at once, but there is not time enough in the year, if you will do two things at a time.” and limit yourself to doing one thing at a time!