Emotions in the Laboratory:

Task-induced Achievement Emotions and their Link with Visual Working Memory Performance

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Abstract

The ability to temporarily hold information in visual working memory (VWM) is an important cognitive function as it is not only crucial in everyday life but also in other domains, such as educational settings and academic performance (Alloway & Alloway, 2010; Conway et al., 2003; Epelboim & Suppes, 2001; Fukuda et al., 2010). Even though VWM has been shown to be a stable construct in general, it can be influenced by other factors. For instance, previous research has demonstrated that emotional states or emotional stimuli can influence VWM performance (e.g. Spachtholz et al., 2014; Xie & Zhang, 2016). However, up to date there is a striking lack of research on whether a VWM task, which is used to measure VWM, may induce emotional experiences itself, and whether they in turn affect VWM performance. Some authors have speculated that a standard VWM task arouses emotions in participants and that these task-induced emotions are related to VWM performance (Luck, 2014; Rouder et al., 2008). The aim of the present thesis was therefore to establish if and how emotions, should they occur because of the VWM task itself, are linked with individuals' VWM performance.

To meet this objective an interdisciplinary approach was taken and well-established findings from educational psychology were applied to a core cognitive research question, namely that of VWM. In a first qualitative study (N=19), by adapting a qualitative method of inquiry, the think-aloud technique (van Someren et al., 1995), results revealed that the task induced different positive and negative emotions, such as joy and anger, which varied on the inter-individual as well as on the intra-individual level. The emotional experiences seemed to be tied to the implicit achievement requirement of the VWM task (getting it right vs. wrong; Elliot et al., 2017). To investigate whether these task-induced emotions were linked to VWM performance, two quantitative studies (N = 45, and N = 41, respectively) were carried out. Here, findings revealed that VWM performance was positively linked to joy, and negatively

linked to anger, frustration and boredom on the inter-individual and intra-individual level. Notably, these emotions were also affected by an experimental manipulation of task difficulty (set size 4 vs. 8). This research is the first to demonstrate that a task designed to measure VWM in itself triggers emotions, specifically achievement emotions (e.g. Pekrun, 2006), which, in turn, are linked with VWM performance. The findings from the studies highlight the relevance of achievement emotions as potentially confounding variables for interpreting VWM scores as resulting from typical laboratory-based paradigms for measuring VWM capacity.

Given the relevance of these findings for research on VWM, cognitive research in general and other fields of research in which VWM plays a role, for example academic performance, another aim of the present thesis was to consider further factors, such as achievement goal orientation, which may affect the link between task-induced achievement emotions during a VWM task, and VWM performance. Therefore, a registered report was designed which aims to replicate and further explore the findings from Studies 1 through 3 on the one hand and on the other hand consider the role of further variables in the achievement-emotion-VWM-relationship. Specifically, it is hypothesized (1) that task-induced achievement emotions will correlate with VWM performance and that this link is (2) mediated by subjective task performance (i.e. how well or poorly participants think they are doing on the VWM task). Further, as goal orientation is thought to be strongly related to achievement emotions (Pekrun et al., 2006), it is hypothesized (3) that the emotion-performance links are moderated by performance goal orientation. Finally, it is hypothesized (4) that achievement emotions, performance goal orientation, and task difficulty interact in predicting VWM. $N = 225$ participants will be recruited to perform the continuous color-report task. Participants' achievement emotions and subjective task performance will be obtained by self-report after the VWM task. It is expected that the findings from the registered

report will further highlight the relevance of achievement emotions as a potentially confounding variable for interpreting an individual's VWM ability.

Abstract (deutsch)

Die Fähigkeit Informationen vorübergehend im visuellen Arbeitsgedächtnis (VAG) zu speichern, ist eine wichtige kognitive Funktion: zum einen ist sie im täglichen Leben essentiell, zum anderen spielt sie auch in anderen Bereichen, wie zum Beispiel bei der Erbringung schulischer Leistung, eine wichtige Rolle (Alloway & Alloway, 2010; Conway et al., 2003; Epelboim & Suppes, 2001; Fukuda et al., 2010). Obwohl das VAG allgemein als relativ stabiles Konstrukt gilt, können gewisse Faktoren dessen Leistung beeinflussen. Die bisherige Forschung hat gezeigt, dass beispielsweise vorab induzierte emotionale Zustände oder emotionale Reize einen Einfluss auf das VAG haben können (Spachtholz et al., 2014; Xie & Zhang, 2016). Bis heute herrscht jedoch ein auffallender Mangel an Studien, die sich mit der Frage beschäftigt haben, ob eine Aufgabe, die zur Messung des VAG verwendet wird, Emotionen in Versuchspersonen hervorruft und, sollte dies der Fall sein, ob diese Emotionen mit der Leistung des VAG zusammenhängen. Einige Autoren haben die Vermutung geäußert, dass gängige VAG-Aufgaben bestimmte Emotionen in Versuchspersonen hervorrufen könnten und dass diese Emotionen wiederum die VAG-Leistung beeinflussen könnten (Luck, 2014; Rouder et al., 2008).

Das Ziel der vorliegenden Dissertation war es demnach zu untersuchen, ob und wie Emotionen mit der VAG-Leistung eines Individuums zusammenhängen, wenn sie durch die VAG-Aufgabe selbst ausgelöst werden.

Um dieses Ziel zu erreichen, wurde eine interdisziplinäre Herangehensweise gewählt, in welcher etablierte Befunde aus der pädagogischen Psychologie auf eine zentrale Forschungsfrage der kognitiven Psychologie, nämlich die des VAGs, angewendet wurden.

In einer ersten qualitativen Studie (N=19) konnte mithilfe einer adaptierten qualitativen Befragungsmethode (die Methode des Lauten Denkens; van Someren et al., 1995) gezeigt werden, dass die Gedächtnisaufgabe sowohl verschiedene positive als auch negative

Emotionen, wie beispielsweise Freude und Ärger, bei den Versuchspersonen hervorrief. Diese Emotionen variierten auf der inter- sowie der intra-individuellen Ebene. Des Weiteren schienen die emotionalen Reaktionen mit den implizierten Leistungsanforderungen der Gedächtnisaufgabe verknüpft zu sein (die Aufgabe „richtig zu machen“ versus „falsch zu machen“; Elliot et al., 2017).

Um zu erforschen, ob diese von der Aufgabe selbst ausgelösten Emotionen auch mit der VAG-Leistung zusammenhingen, wurden zwei weitere quantitative Studien durchgeführt ($N = 45$ und $N = 41$). In diesen Studien konnte gezeigt werden, dass die VAG-Leistung positiv mit Freude und negativ mit Ärger, Frustration und Langeweile sowohl auf der inter- als auch auf der intra-individuellen Ebene zusammenhing. Besonders hervorzuheben ist, dass diese Emotionen auch durch die experimentelle Manipulation der Aufgabenschwierigkeit beeinflusst wurden (vier versus acht zu merkende Objekte).

Diese Forschung demonstriert erstmals, dass eine VAG-Aufgabe dezidiert Leistungsemotionen (z.B. Pekrun, 2006) in Versuchspersonen hervorruft, die wiederum mit der VAG-Leistung zusammenhängen. Die Befunde der oben genannten Studien deuten darauf hin, dass die Leistungsemotionen, die durch eine typische, laborbasierte Aufgabe zur Messung der VAG-Leistung ausgelöst werden, potenzielle Störvariablen bei der Interpretation von VAG-Werten darstellen.

In Anbetracht der Relevanz dieser Ergebnisse für die Gedächtnisforschung, der allgemeinen kognitiven Forschung sowie weiteren Forschungsgebieten, in denen das VAG eine Rolle spielt (bspw. in der pädagogischen Psychologie), war ein weiteres Ziel dieser Dissertation, mögliche andere Faktoren zu diskutieren: beispielsweise Leistungsziele, die den Zusammenhang zwischen Leistungsemotionen und der VAG-Leistung beeinflussen könnten. Folglich wird im Rahmen dieser Arbeit ein registrierter Bericht (Registered Report) vorgestellt, welcher zum Ziel hat, die Ergebnisse aus den oben genannten Studien zu

replizieren und weitere mögliche Einflussvariablen im Zusammenhang zwischen Leistungsemotionen und VAG-Leistung zu untersuchen. Insbesondere wird vermutet, dass (1) die Leistungsemotionen, die durch die VAG-Aufgabe ausgelöst werden, mit der VAG-Leistung korrelieren und (2), dass diese Korrelation durch das subjektive Leistungsgefühl (wie gut bzw. wie schlecht Versuchspersonen glauben bei der Gedächtnisaufgabe zu sein) bei der VAG-Aufgabe mediiert wird. Da Leistungsziele stark mit Leistungsemotionen zusammenhängen (R. Pekrun et al., 2006), wird des Weiteren vermutet, dass (3) der Zusammenhang zwischen den Emotionen und der VAG-Leistung durch die Leistungsziele moderiert wird. Abschließend wird vermutet, dass (4) Leistungsemotionen, Leistungsziele und die Schwierigkeit der Gedächtnisaufgabe interagieren und gemeinsam die VAG vorhersagen.

Um diese Hypothesen zu überprüfen, ist geplant $N = 225$ Versuchspersonen zu rekrutieren. Es wird vermutet, dass die Ergebnisse des Registered Reports die Relevanz von Leistungsemotionen als potenzielle Störvariablen in der VAG-Forschung weiter hervorheben werden.

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Table of Abbreviations

AGQ-R	Achievement Goal Questionnaire Revised
CDA	Contralateral Delay Activity
cf.	compare, consult
cm	Centimeter
EEG	Electroencephalogram
ERP	Event Related Potential
H	Hypothesis
ms	Milliseconds
OSF	Open Science Framework
PH	Pilot Hypothesis
Q1-8	Question(s) 1 through 8
RQ	Research Question
SPCN	Sustained Posterior Contralateral Negativity
VWM	Visual Working Memory

1. General Introduction

As educational psychologists, we are interested in understanding individual differences in cognitive abilities and what may facilitate these abilities, in order to accumulate tangible evidence with implications as to how learners can be supported in maximizing their performance. To do so, educational researchers must stray away from their own research field and consider additional factors typically explored in other fields of research, such as visual working memory (VWM).

VWM, which can be defined as "the active maintenance of visual information to serve the needs of ongoing tasks" (Luck & Vogel, 2013, p. 392), is crucial in everyday life (Alloway & Alloway, 2010; Conway et al., 2003; Fukuda et al., 2010), but also in educational settings as it has been shown to correlate with higher cognitive functions, such as problem solving and fluid intelligence (e.g. Epelboim & Suppes, 2001; Fukuda et al., 2010) - abilities that are essential for learning and successful academic performance. Therefore, VWM is an important cognitive construct to fully understand in cognitive as well as educational research.

In order to understand psychological constructs, reliable and valid measurement paradigms are needed. VWM researchers have developed different computer-based VWM measurement tasks, such as the change detection task (Luck & Vogel, 1997; Pashler, 1988) or the continuous color-report task (Wilken & Ma, 2004; Zhang & Luck, 2008a). These tasks require participants typically to recall one or more previously shown item(s) or features thereof (such as color) and by doing so have been shown to provide reliable and valid estimates of individuals' VWM capacities (Johnson et al., 2013; Kyllingsbæk & Bundesen, 2009). Specifically, researchers have demonstrated on many occasions that on average humans can retain information regarding three to four simple items in VWM (Luck & Vogel, 1997; Zhang & Luck, 2008).

Despite this finding being quite stable, there is also evidence suggesting considerable variance in participants' VWM performance, with the number of retainable visual items ranging between 1.5 and over 6 (Rouder et al., 2008; Vogel & Awh, 2008). In recent decades, researchers have turned their attention to possible factors related to these differences in VWM performance and have identified several potential reasons, such as neural activity, attention and motivation (Fougnie et al., 2016; Luck & Vogel, 2013; Vogel & Machizawa, 2004). However, researchers have not yet explored what role the VWM measurement paradigm itself may play in VWM performance.

In the present thesis, the author proposes that performing a VWM task in order to measure VWM performance may trigger emotional experiences in participants, which in turn may account for individual differences in VWM performance.

In educational settings, it often has been shown that performing tasks can trigger certain emotional experiences in individuals. Moreover, these emotions can have an effect on the performance outcome of the task. It is therefore highly likely that engaging in a VWM task will trigger emotional experiences in individuals, which in turn may affect their VWM performance.

Emotions have been shown repeatedly to be related to individual differences in VWM performance (e.g. Spachtholz et al., 2014; Xie & Zhang, 2016). However, in these studies, emotions were induced prior to the VWM task or emotionally loaded stimuli were used. To the author's knowledge, there is no research on whether the VWM task itself induces certain emotional experiences in participants, which in turn are linked to individual differences in regards to VWM performance.

Moreover, paradigms used to measure VWM are arguably situations in which participants need to demonstrate competence. Demonstrating competence implies succeeding or failing according to some standard (Elliot et al., 2017). As mentioned above, VWM

paradigms require participants to recall one or more previously shown item(s). It is an inherent characteristic of those tasks that participants can succeed or fail at them (recalling the item correctly or failing to do so), making the setting in the laboratory an achievement situation. Research on academic performance has demonstrated that achievement situations trigger different achievement emotions in students, which in turn influences how well they perform (Pekrun & Linnenbrink-Garcia, 2014). It is therefore likely that participants performing VWM tasks will experience achievement emotions induced by the task itself. However, research in educational as well as cognitive psychology has not yet specifically explored the role of achievement emotions in VWM performance.

The overarching objective of the present thesis was thus to establish if and how emotions, specifically achievement emotions, should they occur because of the VWM task itself, are linked with individuals' VWM performance. To meet this objective an interdisciplinary approach was taken and well-established findings from educational psychology, specifically achievement emotion research, were applied to a core cognitive research question, namely that of VWM. The findings from the studies presented here highlight the relevance of achievement emotions as potentially confounding variables for interpreting VWM scores as resulting from typical laboratory-based paradigms for measuring VWM capacity. Therefore, achievement emotions pose a potential threat to the validity of the VWM performance scores and future VWM research may want to consider these task-induced emotions in their study designs. Moreover, researchers from other domains who rely on laboratory-based measurement paradigms may also want to consider the effects of achievement emotions on their outcome variables.

Further, the results from this research also highlight the importance of interdisciplinary research as well as mixed-method designs and different methodological approaches, such as

between-person and within-person analyses, to further understand important psychological constructs, processes and their relationships, specifically emotional experiences and VWM.

Finally, findings from the research presented here also remind us as researchers that even in a controlled environment such as the laboratory, participants differ from each other and these individual differences need to be taken into consideration.

1.1 Overview of the Present Research

The first aim of this thesis was to establish whether emotions occur when performing a VWM task because of the VWM task itself and if so, what discrete emotions these are. So far, research has merely hinted towards the possibility of emotions occurring incidentally during VWM tasks (Rouder et al., 2008). Further, the general opinion seems to be that if any emotional state is evoked by the VWM task, it is most likely to be boredom, as VWM tasks are traditionally lengthy and monotonous. Study 1 was designed to answer the first research question of this thesis: Does performing a VWM task induce emotional experiences in participants (see Chapter 3)? Using a qualitative approach, the results of Study 1 revealed that participants indeed experienced different discrete emotions (including but not limited to boredom), which seemed to be related to their subjective feeling of how well they performed on the VWM task, and were thus considered achievement emotions.

The second aim of the present thesis was to verify hints in the literature which speculated that, if emotional experiences are induced by a VWM task, they may account for individual differences in VWM performance (Luck, 2014; Rouder et al., 2008). Based on the results from Study 1, Study 2 was designed to explore whether achievement emotions, which were triggered incidentally by the VWM task itself, were related to VWM performance on the between-person level (see Chapter 4). Further, a third study was designed (Study 3) in order to explore the emotion/performance links on the within-person level (see Chapter 5). Results

from both Study 2 and Study 3 revealed that task-induced achievement emotions were indeed related to VWM performance on the between-person as well as the within-person level. Further, findings from Study 3 suggested that variations in the difficulty of the VWM task effected how participants felt while performing the task.

The third aim of this thesis was to consider further factors, which may affect the link between task-induced achievement emotions during a VWM task, and VWM performance. Therefore, a registered report was designed, which aims to replicate and further explore the findings from Studies 1 through 3 on the one hand and on the other hand consider the role of further variables, such as achievement goals, in the achievement-emotion-VWM-relationship (see Chapter 6). In doing so, the author adopts a publication approach, which emphasizes best practice research and thus contributes to transparent and responsible conduct of research.

The research reported herein was conducted in accordance with the ethical standards expressed in the Declaration of Helsinki and has received a formal waiver of ethical approval by the ethics committee of the Department of Psychology, Ludwig-Maximilians-University Munich. Participation was voluntary and written informed consent was obtained from all participants for each study. The data files can be found on the Open Science Framework (see Chapters 3, 4, 5 and 6 for the respective OSF-Links).

1.2 Chapter Summaries

The present thesis is comprised of seven chapters. After the general introduction (Chapter 1), Chapter 2 provides an overview of the theoretical and empirical background to the overarching goals of this thesis as well as the research questions and hypotheses of the individual studies. Here, the main theoretical focus lies on achievement emotions (as these emotions were mainly identified in Study 1) and the construct of VWM. This is followed by an overview of the empirical findings regarding the effects of emotions on VWM in general

and previous research regarding the relationship of achievement emotions, achievement goals and VWM.

Chapters 3 through 5 describe the three consecutive studies mentioned above, which were carried out within the context of this thesis and yielded first evidence demonstrating the relationship between achievement emotions, which were triggered by a VWM task, and VWM performance (see above).

Chapter 6 introduces a registered report which is designed to further explore the link between incidentally induced achievement emotions and VWM performance.

Finally, Chapter 7 provides a general discussion of the research presented here. Further, limitations are discussed and implications for future research are outlined.

2. Theoretical and Empirical Background

The following chapter provides an overview of the theoretical constructs relevant for the research questions and hypotheses of the three studies presented here. Further, respective empirical findings are outlined and discussed.

2.1 Emotions

There are numerous approaches to and definition of *emotion* in the literature. For the present thesis, emotions are defined as multi-component processes, including affective, motivational, cognitive, physiological, and expressive components (Mulligan & Scherer, 2012), which are activated by appraisals of external (e.g. changes in situations) or internal (e.g. thoughts) stimuli, and are thought to last for short periods of time (Scherer, 2000). Further, emotions can be experienced as pleasant or unpleasant (i.e. *valence*) and can either lead to activation or deactivation of the individual (Scherer, 2000).

Emotions can be differentiated into *state* emotions and *trait* emotions (Cattell & Scheier, 1960; Spielberger, 2006). An emotional state can be conceptualized as an emotion occurring in the moment, which is strongly influenced by situational changes and is measured on the within-person or intra-individual level (Hertzog & Nesselroade, 1987). State emotions therefore pertain to emotional experiences and changes thereof, which occur within an individual. Trait emotions, on the other hand, are thought to be more stable over time and reflect the general tendency of individuals to experience certain emotions. They are measured on the between-person or inter-individual level, and thus reflect the different emotional experiences between individuals in the same situation (Hertzog & Nesselroade, 1987).

Setting a clear definition of emotion helps to distinguish the phenomenon from other terms or similar constructs such as *affect*, *mood* and *feelings:* In the literature, *affect* is sometimes used to refer to emotional states of high intensity and short duration. However, it is generally used as a broader term to summarize emotion and mood (Shuman & Scherer, 2014). *Mood* can be viewed as a diffuse affective state, which is low in intensity but lasts for longer periods of time and does not necessarily have a specific trigger (Scherer, 2000). Although the term *feeling* is often used synonymous to the term *emotion* in everyday language, Scherer (2000) suggests to define “the subjective experiential component of the emotional reaction as "feeling"” (p. 139).

Research has found ample evidence pertaining to the influence emotions have on individuals, including their thoughts, memories, behaviors, and performance (Beal et al., 2005). In the following, the relationship between emotions and performance is discussed in more detail. Here, the focus lies on *achievement emotions* as this sub-type of emotion has been found to be an important factor regarding performance, especially in educational settings.

2.1.1 Task-induced Emotions

As mentioned above, emotions are thought to be triggered by individual appraisals of specific objects or events (Mulligan & Scherer, 2012). Tasks and activities can also act as objects, which trigger emotional experiences. For instance, people experience joy when engaging in an activity that they appraise as pleasant, either because they receive an extrinsic reward for their engagement in the task, such as praise, or because the task itself is rewarding to the individual (Csikszentmihalyi, 2000). Specifically, task enjoyment is thought to play a major role in different concepts such as flow experience (Csikszentmihalyi, 2000), intrinsic motivation (Deci & Ryan, 1990), and achievement motivation (Dweck & Elliot, 1983; Puca & Schmalt, 1999) – concepts which are important for performance.

The role of task-induced emotions in cognitive performance is commonly studied in educational and academic settings. Here, the research focus lies mainly on *epistemic* or *achievement emotions*.

Epistemic emotions are thought to be induced by the cognitive characteristics of the task (Pekrun et al., 2017a; Pekrun & Stephens, 2012). The object focus of epistemic emotions is knowledge and knowledge generation (Brun, et al., 2008), which can trigger different discrete emotions, such as surprise, curiosity, and confusion (Vogl et al., 2019, 2020). Epistemic emotions also have been linked to cognitive performance. For instance, research has found that epistemic emotions predicted processes in self-regulated learning, which in turn predicted complex mathematical problem solving (Muis et al., 2015a) and learning outcomes on climate change (Muis et al., 2015b).

In contrast, achievement emotions are considered a sub-type of emotions occurring specifically in achievement situations, i.e. situations where, based on a person's perceived competences and standards of excellence, they can either succeed or fail in this situation (e.g. Pekrun, 2006). Depending on the object focus, achievement emotions can be differentiated

into *activity emotions* and *outcome emotions* (Pekrun, 2006). The object focus of activity emotions relates to achievement-related activities, such as studying or class participation, whereas the object focus of outcome emotions relates to achievement outcomes, such as exam results (Pekrun, et al., 2011). Further, the object focus of outcome emotions can relate to *prospective* outcomes, such as future exam results, and to *retrospective* outcomes, such as receiving feedback on a past achievement (Pekrun, 2006).

Depending on how the individual appraises the achievement situation, they will either experience positive or negative achievement emotions and thus be activated or deactivated (Pekrun, 2006; Pekrun et al., 2002). According to Pekrun's (2006) control value theory of achievement emotions, two appraisals play a major role in achievement emotions. *Control appraisals* refer to the individual's subjective feeling of control over achievement activities and their outcomes (i.e. success or failure) and determine the valence of emotions (e.g. enjoyment or pride in case of high control, anger, frustration or anxiety in case of low control). V*alue appraisals* on the other hand, refer to the value the activities and their outcomes have for the individual and boost the emotional intensity (stronger with higher value).

Achievement emotions, their antecedents and outcomes have received ample research attention in academic settings, as students are regularly faced with achievement situations. In the past, research on achievement emotions focused mainly on (test) anxiety (Pekrun et al., 2017b; Pekrun et al., 2004). However, research has since identified many discrete achievement emotions, both positively and negatively valenced, such as enjoyment, pride, shame, boredom and anger (Pekrun et al., 2002).

Further, empirical findings have shown that achievement emotions play a major role in academic performance, as students are constantly confronted with situations and tasks, where, based on their perceived competences and standards of excellence, they can either succeed or

fail (e.g. Pekrun, 2006). This can lead to pleasant or unpleasant emotional experiences for the students, which in turn can influence how well they perform (Pekrun & Linnenbrink-Garcia, 2014). Generally, negative achievement emotions have been found to correlate negatively with performance (Pekrun & Perry, 2014). In contrast, positive achievement emotions typically show positive links with performance. Pekrun et al., (2017b) found that enjoyment and pride positively predicted adolescents' academic performance (*N*= 3.425). This finding proved to be extremely robust as it was found across five annual assessment waves.

2.1.2 Achievement Emotions and Achievement Goals

An important factor to consider when exploring the relationship of achievement emotions and performance is *achievement goal orientation*. Achievement goals are thought to be antecedents of achievement emotions (Pekrun et al., 2006) and are thus defined as "cognitive representations of possible outcomes that evoke psychological processes, including achievement emotions" (Pekrun et al., 2009, p. 119). Depending on the achievement goal type, they can either strengthen positive achievement emotions or weaken negative achievement emotions, which in turn affects the performance outcome (Huang, 2011).

In the achievement motivation literature, achievement goals have been differentiated into mastery and performance goals. Individuals pursuing mastery goals focus primarily on gaining skills, whereas individuals with performance goals focus on demonstrating competence in a normative sense, that is, with respect to success or failure along a certain achievement standard (Dweck, 1986). People with strong mastery orientation have a strong sense for environmental triggers of opportunities to learn or grow. In contrast, people with a strong performance orientation have a strong sense for environmental triggers of opportunities to succeed or fail.

Achievement goal literature further distinguishes between approach versus avoidance tendencies (e.g. Elliot, 2006). Accordingly, mastery as well as performance goals can be

differentiated into approach and avoidance goals (Elliot, 1999). Mastery-approach and performance-approach goals motivate individuals to attain or increase self-based (mastery orientation) or other-based (performance orientation) success. In contrast, mastery-avoidance and performance-avoidance goals motivate individuals to avoid self or other-based failure.

There is consistent empirical evidence that approach versus avoidance goals are systematically linked with discrete achievement emotions, which in turn are linked with performance (Barron & Harackiewicz, 2003; Huang, 2011; Pekrun et al., 2009; Putwain et al., 2013; Senko et al., 2011). For instance, in terms of mastery orientation, approach goals are linked with enjoyment whereas avoidance goals are linked with hopelessness. In contrast, regarding performance orientation, approach goals are linked with pride and avoidance goals are related to anxiety.

2.1.3 Conclusion

It becomes apparent that engaging in tasks can trigger emotions in individuals. If these tasks are perceived as achievement situations, in which one can either succeed or fail, individuals will experience achievement emotions, which in turn have been shown to affect performance. Moreover, in academic settings, the achievement goals that individuals pursue have been shown to affect these emotion-performance links.

Yet to date, these processes have not been examined, nor considered, in laboratory settings designed to measure cognitive functions, such as VWM - a construct essential for higher cognitive functions and therefore cognitive performance.

Research has shown, however, that emotions can generally influence higher cognitive functions, such as memory. In research regarding long-term memory, it is well established that the emotions experienced at the time of memory formation influence how the memory is stored (e.g. LaBar & Cabeza, 2006). In addition, there is also a specific body of literature

which explored the effects of emotions on working memory, specifically VWM. However, these findings are somewhat ambiguous, as is discussed in the following chapters.

2.2 Visual Working Memory

In psychology, memory is defined as the faculty of the brain, which encodes, stores, and retrieves information (Squire, 2009). Generally, memory researchers do not view memory as a unitary faculty but rather as an entity comprised of different storage systems. Atkinson and Shiffrin (1968), for instance, proposed a multi-system model suggesting that memory is composed of three different components: the *sensory register*, by which information from the outside world enters memory via the human senses, *short-term memory* (also referred to as *working memory*[1]), which holds information for only short periods of time, and *long-term memory*, where indefinite amounts of information are stored for long periods of time.

Even though the Atkinson-Shiffrin-memory-model has since been revised, it still provides the general basis of most memory theories today, in that memory has different storage systems with different storage features. For instance, evidence suggests that working memory can be differentiated into two subsystems: one responsible for verbal and one for visual/spatial information (e.g. Baddeley, 2012; Baddeley & Hitch, 1974). In the past, research on the verbal component of working memory dominated the field. However, in recent decades research on VWM has increased immensely (Luck & Vogel, 2013). In the following, the nature of VWM and how it is studied are discussed in more detail.

2.2.1 The Nature of Visual Working Memory

VWM is thought to be a subsystem of the working memory storage system and, in contrast to visual long-term memory, creates visual representations rapidly (at rates ranging

[1] In the memory literature there is an ongoing debate regarding the definitions of and distinction between *short-term memory* and *working memory* (Cowan, 2008). In the presented thesis the term *working memory* will be used and is defined as the active maintenance of information to serve the needs of ongoing tasks (Luck & Vogel, 2013).

from 20 to 50 ms per item), maintains these representations actively by neural firing (rather than passively, hence the term *working* memory), and is highly limited in terms of storage capacity (Luck, 2008). Researchers have demonstrated on numerous occasions that on average, humans can retain information regarding three to four simple items in VWM (Luck & Vogel, 1997; Wheeler & Treisman, 2002; Zhang & Luck, 2008).

There are two main theories regarding the reason for the limitation of VWM capacity: the slot-based and the resource-based theory (Luck, 2008; Luck & Vogel, 2013). The former assumes that VWM can only store a certain amount of information. Any other information which may be present will not be remembered. For instance, if a person's storage capacity equals three slots (i.e. they can store three items in VWM) but they are shown and asked to remember five items, this person will only be able to store three of the five items. No information regarding the other two items will be retained in memory. In contrast, the resource-based theory assumes VWM is more flexible in that it can retain some information of all the items shown. However, the more items shown the less information per item can be stored in memory thus reducing the precision with which each item is stored. There is supporting empirical evidence to be found for both the slot-based and the resource-based theory, but additional research is needed to provide definite evidence for one of the two models (Luck, 2008; Luck & Vogel, 2013).

Even though there is substantial evidence that VWM capacity is a stable measure in that, on average, a person can hold three to four simple items in VWM (Vogel et al., 2001), there is considerable variance in participants' VWM performance, with the number of retainable visual items ranging between 1.5 and over 6. For example, using a sample of 170 healthy undergraduates, Vogel and Awh (2008) reported the "typical" mean of 2.88 items, yet a standard deviation of 1.04. Along the same lines, Vogel et al. (2001) emphasize that the "amount of information stored in VWM varies across participants and across trials" (p. 108).

In recent years, research has begun to explore the underlying reasons for individual and group differences in VWM performance. These reasons include neural structure (Luck & Vogel, 2013), attentional processes (Vogel et al., 2005), age (Brockmole & Logie, 2013), and (mental) illness, such as schizophrenia (Johnson et al., 2013). An additional reason for individual differences in VWM capacity seems to be the emotional state of the individual (Rouder et al., 2008; Spachtholz et al., 2014), which will be discussed in more detail in Chapter 2.3.1.

VWM is crucial in everyday life as it stores and manipulates information to "serve the needs of ongoing tasks" (Luck & Vogel, 2013), when this information is no longer present or temporarily not available due to saccadic eye movement or blinking (Schurgin, 2018). Further, VWM has been found to correlate with higher cognitive functions, such as language comprehension, problem solving, fluid intelligence and processing speed (Daneman & Merikle, 1996; Epelboim & Suppes, 2001; Fukuda et al., 2010; Johnson et al., 2013). These factors make it an important cognitive construct to fully understand, as it is relevant not only for cognitive research but also for other research fields, such as educational psychology. In order to explore VWM, reliable and valid measurement paradigms are needed, which are discussed in the following.

2.2.2 Measuring Visual Working Memory

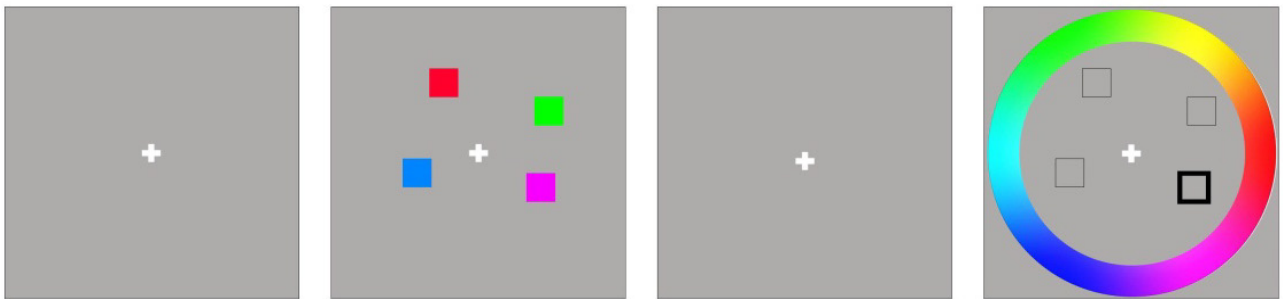
To explore VWM, many different measurement paradigms have been implemented, such as the flicker task (Rensink et al., 1997), the change detection task (e.g. Luck & Vogel, 1997), or the picture span test (Tanabe & Osaka, 2009). For the present work, the continuous color-report task as used by Zhang and Luck (2008) was chosen. This is a well-established paradigm used in VWM research and has consistently been reported as a highly reliable method for estimating individual differences in terms of quantity and quality of stored items in VWM.

The task is comprised of multiple yet similar trials and involves participants to recall a color of a probed item by clicking on a color wheel. Generally, the task is performed in the laboratory on computers, where participants are prompted to do the task in silence and, if more than one participant is performing the task at the same time, are visibly separated from one another so they can focus fully on the task.

For the studies presented here, the procedure of the continuous color-report paradigm was identical: each trial started with a fixation cross, which was briefly presented in the center of a dark grey screen for 1000 ms. Participants were then presented with the sample array which showed either five (Study 1) or four or eight (Studies 2 and 3) colored squares for 1000 ms. After a 1000 ms delay interval, participants were presented with the test array, which remained until a response was given. The test array displayed a continuous color wheel, which rotated randomly in each trial to reduce any influence of spatial memory (Zhang & Luck, 2008), and an outlined square at the location of each colored item shown in the previous sample array. One item was highlighted by thicker lines, indicating the participant to recall the color of this item by clicking on the corresponding color on the color wheel (see Figure 1).

Figure 1

Continuous Color-Report Task showing four Items



Fixation Cross (1000 ms) → Sample Array (1000 ms) → Delay Interval (1000 ms) → Test Array

According to Zhang and Luck (2008), if the participant was able to remember the probed item, the recalled color will be very close to the probed color. If this is not the case, the participant will have to guess and the response should be random.

For the studies presented here, VWM performance was operationalized by computing the absolute angular distance (in degrees) between the probed item's color (on the color wheel) and the selected color (henceforth: recall error) for each participant. When participants were able to store the probed item in VWM, the recall error was small or close to zero. In contrast, when participants had to guess, recall error was larger.

In keeping with the traditional paradigm, responses were not timed and performance feedback was not provided in any of the studies presented here. Further, trials were arranged in blocks (e.g. practice block containing 30 trials, experimental block containing 240 trials) followed by short breaks for the participants, which is also established procedure in VWM research.

There is consistent evidence that the typical paradigms used to measure VWM, including the continuous color-report task used here, produce highly reliable indicators of human's VWM capacity and are surprisingly robust against external influences (including e.g. whether or not participants are rewarded for high performance, Zhang & Luck, 2011; how many stimuli participants are required to try to memorize, Rouder et al., 2008; or whether or not they engage in another task in addition to the visual memory task; Vogel et al., 2001). However, a factor which has repeatedly been shown to potentially affect VWM performance is emotions (e.g. Spachtholz et al., 2014; Xie & Zhang, 2016). This is discussed in more detail in the following chapters.

2.3 Emotions and Visual Working Memory

2.3.1 The Effects of Emotions on Visual Working Memory

One possible way of investigating how emotions affect VWM is by confronting participants with emotional stimuli. For instance, Reinecke et al. (2006) compared the VWM performance between spider-fearful and non-fearful participants (n = 23 each). The visual material to be recalled in this experiment was images, which were either emotionally neutral or negatively valenced (spiders triggering fear). Their results demonstrated that negatively valenced stimuli enhanced VWM performance compared to neutral stimuli, and this effect was greater for participants who were spider-fearful.

Similarly, Sessa et al. (2011) demonstrated that VWM performance was increased for faces with fearful expressions compared to faces with neutral expressions. In addition to measuring VWM performance, the authors recorded electroencephalogram (EEG) activity throughout the experiment. They found that the sustained posterior contralateral negativity (SPCN) component of the event related potential (ERP), which is specifically related to the maintenance of representations in VWM, was larger for fearful faces relative to neutral faces (N = 18). Thus, the effects of performance in VWM were accompanied by corresponding electrophysiological response patterns.

Similar to the effects of fear-associated stimulus material, there is further evidence demonstrating that negatively emotional loaded stimuli in terms of anger also enhance VWM performance (Jackson et al., 2009; Jackson et al., 2014; Jackson et al., 2008). Yet, it is worth noting that negatively valenced stimuli do not always enhance VWM. For instance, Bannerman et al. (2012) asked participants to remember the specific location of emotional faces (angry versus happy versus neutral facial expressions). They found that emotional stimuli (angry faces versus happy faces) did not enhance spatial VWM relative to neutral stimuli.

When using emotionally loaded stimuli as a way to study the influence of emotions on VWM it remains open to question whether it is the emotional valence of the stimuli per se which affects VWM performance, or whether participants, while being exposed to such valenced stimulus material, are put into negative emotional states, which in turn cause effects on VWM.

One way to directly explore effects of participants' emotional states on VWM performance is to induce negative, positive and/or neutral emotions prior to the VWM task. In doing so, some researchers have found evidence that negative emotional states relate to poorer working memory performance. For instance, Figueira et al. (2017) showed that participants' contralateral delay activity (CDA) amplitudes were significantly lower in a negative emotional condition as compared to a neutral emotional condition. CDA is an electrophysiological index of VWM processing, which has been shown to correlate with the amount of information stored in working memory (Luria et al., 2016; Vogel & Machizawa, 2004). Further, on an intra-individual level, Brose et al. (2014) found that daily variations in participants' mood (measured over a 100 day period) related to working memory performance. Specifically, negative affect was negatively linked with spatial working memory performance. The authors also found that variations in positive affect were positively linked to working memory performance.

Digging deeper into the potential effects of emotional states on working memory performance, some authors proposed to explore potentially differential effects on the quality versus quantity of visual performance. For instance, Spachtholz et al. (2014) randomly assigned participants to a neutral and a negative emotional condition prior to performing the continuous color-report task. Results showed that the number of remembered items was lower in the negative affect condition but VWM performance in terms of quality (precision of color memory) increased. The authors concluded that emotional state leads to a tradeoff between

quantity and quality in terms of VWM performance, with negative emotional states favoring quality over quantity. However, those effects were not fully confirmed by Xie and Zhang (2016): manipulating emotional state on a trial by trial basis via presentation of IAPS pictures (International Affective Picture System, Lang et al., 1997), they found that negative emotion yielded higher VWM precision, but this time without any concurrent decrease in VWM capacity (see also Long et al., 2020, who found such a tradeoff). However, a large-scale attempt to replicate those findings failed to find any evidence of an enhancing effect of negative emotion on either precision or capacity with seven experiments in three different laboratories and with participants from four different countries (Souza et al., 2020).

Overall, when considering the results discussed above, it seems there is some indication for the relevance of emotional states in VWM performance. However, the results are not straightforward and attempts to replicate the findings yield even more ambiguous results. Importantly, this existing research rests on studies which used emotionally loaded stimuli or induced emotional states prior to the VWM task (either block-wise or trial-wise). Not only may such emotion induction procedures lack ecological validity, but more importantly, they are ineffective in exploring another, potentially more relevant factor: the emotions participants experience because of the VWM task itself. These may be systematically linked with performance, and may also differ across experimental conditions, thus creating an important potential confound and posing a threat to the validity of the VWM performance scores. To the author's knowledge, no study to date has explored these assumptions.

Despite the eminent lack of systematic research into potential links between incidentally induced emotions and VWM performance scores, some researchers from the VWM community hint towards the possibility that tasks designed to measure cognitive functions may induce emotions in participants, and that these emotions in turn may influence participants' performance. For instance, in his book on ERPs, Luck (2014) states the

following: “ERP experiments tend to be long and boring, with trial after trial of the same basic task. To ensure that you are collecting the highest quality data possible, it is important to keep your subjects happy and relaxed. If they are unmotivated or become bored, they may not pay close attention to their performance, weakening your effects” (p. 144). Also, the classical VWM tasks are typically lengthy, requiring participants to go through multiple-trial-blocks of either change detection or active color recall, which typically take up to 45 minutes or more to complete. To the author’s knowledge, whether or not these tasks are generally not enjoyable or evoke boredom in participants because they are long and repetitive is based purely on introspection or speculation, and has never been explored systematically.

Further, researchers in the field of VWM have conveyed their thoughts on possible task-induced emotions and how these emotions may affect participants’ performance. For instance, Rouder and colleagues (2008) found that some participants performed worse than expected on difficult as opposed to easy trials of a VWM task, and they concluded that this may have been the case because some participants were “intimidated” by the difficult trials (p. 5978). Similarly, Spachtholz et al. (2014) speculated that differences in VWM performance may “be brought about unintentionally by cues such as affective state that signal requirements of the current situation” (p. 1455). However, the presumption that such task-induced emotions may also have an effect on the obtained results has not been tested.

As stated above, the emotions induced by the VWM task, should they occur, are likely to be achievement emotions, as the VWM paradigm can be viewed as an achievement situation, in which one can either succeed or fail. As achievement goals have been shown to be linked to achievement emotions and performance in educational settings, it is also likely that they will play a role in the proposed relationship between achievement emotions and VWM performance. However, neither achievement emotions nor achievement goals have

received ample attention in VWM research. The few empirical findings regarding these constructs are discussed in the following.

2.3.2 Achievement Emotions, Achievement Goals and Visual Working Memory

Research has not yet established whether achievement emotions, which are induced by performing a VWM task, affect VWM performance. A recent study showed that negative emotions, such as shame and guilt, which can be linked to achievement situations, impaired working memory (Cesare et al., 2018). However, the authors of this study induced shame and guilt through the writing of general autobiographical past experiences, which did not specifically pertain to achievement situations or situations, in which VWM tasks were performed.

One reason why the role of task-induced achievement emotions in VWM performance has not been explored may be that the VWM task itself has not yet been recognized as a task with the potential of triggering specific emotional responses in individuals.

Research which explicitly addressed links between achievement goals and working memory is also scarce. The few studies that do exist (Crouzevialle & Butera, 2013; Avery & Smillie, 2013; Linnenbrink et al., 1999; Avery et al., 2013) used goal induction approaches. That is, they induced goals shortly before the working memory task, which always had a verbal component (figures, words etc.). Also, these studies focused on effects emerging from experimentally manipulated differences between different goal orientations (e.g. performance versus mastery, mastery-approach versus no goals). It seems that research has not yet addressed the links between individuals' trait approach or avoidance goals and VWM performance. Further, to the author's knowledge, there are no findings regarding potentially combined effects of both goal orientations and discrete achievement emotions on VWM performance.

2.3.3 Conclusion

When examining the effect of emotions on VWM, studies either use emotionally loaded stimuli or induce emotional states prior to the VWM paradigm. However, up to date there is a striking lack of research on whether a VWM task itself may induce emotional experiences. Overall, it seems highly likely that engaging in a VWM task triggers emotional experiences, specifically achievement emotions, as individuals may interpret the VWM task as an achievement situation, in which they can succeed or fail. It has been speculated that the VWM tasks may be perceived as boring or intimidating, yet they may also be experienced as challenging and engaging.

Further, research has not yet established whether such task-inherent emotions, should they occur, influence VWM performance. In other words, little is known as to the validity of typically used VWM measures – do they measure VWM capacity alone, or are the measures distorted due to the emotions participants experience during task performance?

In order to answer these questions three consecutive studies were designed and conducted, which explored whether performing a VWM task induced emotional experiences in participants and if so, whether they affected VWM performance. These studies and their rationale are outlined and discussed in the following chapters.

3. Study 1: A Qualitative Approach to the Emotional Experiences during A Visual Working Memory Task

In prior research in the field of VWM (and possibly other lab-based cognitive research fields), researchers may have viewed participants as machines who enter the laboratory and perform VWM tasks as successfully as their "hardware" (i.e. their VWM capacity) allows, while neglecting the emotional experiences the task in the laboratory setting may induce. Coming into the laboratory to get ones VWM memory ability "tested" could be quite

emotional for some participants, which in turn may affect how well they perform on the VWM task.

Research from other fields of study, such as educational psychology, have provided substantial evidence that certain characteristics of a task can lead to emotional experiences when participants engage in those tasks, which in turn affect how well they perform (see Chapter 2.1.1). Further, research on VWM has hinted towards the possibility of emotions occurring incidentally during VWM tasks as these measurement tasks tend to be lengthy and monotonous (and could therefore evoke boredom) or because some participants may be intimidated by the VWM task (see Chapter 2.3.1). However, empirical research has not yet established whether this is the case.

One could argue that if any "noise" in the data (i.e. unwanted emotional experiences during the task) occurs it is not relevant because it cannot systematically affect the results as participants are chosen randomly and any potential systematic effects therefore cancel each other out. However, many studies examining VWM in general work with extremely small sample sizes (e.g. $N = 10$ in Luck & Vogel, 1997; $N = 10$ in Vogel et al., 2001; $N = 8$ to 22 in Zhang & Luck, 2008) where it is not liable to assume that a potential influencing factor, such as task-induced emotions, is randomized and therefore controlled for.

The aim of this study was therefore to explore if participants experience emotions when engaging in a VWM task. In doing so, one goal was to discern discrete emotions that participants may experience, such as joy, pride, anger, and boredom (RQ1a). A further goal was to explore which aspects of the VWM task triggered these discrete emotions, if they occurred (RQ1b). To answer these questions, participants in this study were asked to verbalize their feelings and any related thoughts thereof while performing the continuous color-report task, a technique based on the think aloud method (van Someren et al., 1995).

3.1 Method

3.1.1 Sample and Data Availability

Participants of this study were $N = 19$ (11 female; $M_{age} = 30.21$; $SD = 8.49$) and were recruited by using convenience sampling. All participants stated not to be color-blind and to have normal or corrected-to-normal vision.

The data files can be found on the OSF database (https://osf.io/dr62j/?view_only =75252db982bb44758e12c3b287a45db0).

3.1.2 Procedure

Participants performed the VWM task alone in the laboratory at the university with only the researcher present. First, participants' demographic information as well as their consent to record and further analyze the collected data was obtained. Participants were then given the opportunity to familiarize themselves with the VWM task by reading a short introduction to the task on the computer and performing a practice block containing 20 trials. The actual VWM task consisted of two blocks, each containing 165 trials.

During the first block, participants were required to do the task in silence, as is normally the case when performing a VWM task. Before the second block, the think aloud procedure was introduced. Specifically, participants were prompted with the following instructions: "You will now complete another block of trials, just like the one you have just completed. During this next block, we ask you to please verbalize any feelings or thoughts you are experiencing during the task". If required, the researcher reminded participants to "think and feel aloud". Overall, participants took approximately between 45 and 90 minutes to complete the entire task.

3.1.3 Stimuli and Measurement

Continuous Color-Report Task Specifications. All stimuli were generated in MATLAB using the *Psychophysics Toolbox*. Stimuli were presented on 24" TFT-LCD monitors (ASUS VG248QE, 1920×1080 pixels, 60 Hz) at a viewing distance of approximately 70 cm. The to-be-remembered stimuli were five colored squares (1 x 1°) on a dark grey background (RGB: 60, 60, 60), which randomly (with a distance of at least 1.5° between each) appeared at least 2° from the white fixation cross (0.5°) within a rectangular region with a width and height of 10 × 9°, centered on the fixation cross. Colors were randomly drawn from a circle with a radius of 40 in a luminance plane of the CIE 1976 L*a*b* color space (L^* = 63, center: a^* = 9, b^* = 27, illuminant: D65, 2° standard observer).

All trials followed the same order as described in detail in Chapter 2.2.2 (see Figure 1): After the fixation cross was briefly presented for 1000 ms, the sample array appeared for 1000 ms containing five colored squares. After a 1000 ms delay interval, participants were presented with the test array, which remained until a response was given.

The Think Aloud Method and Protocol Transcription. Data was collected during the continuous color-report task by using a qualitative approach based on the think aloud method by van Someren et al. (1995). This approach is traditionally used when trying to identify and understand underlying cognitive processes in problem solving by encouraging participants to verbalize their thoughts and strategies while trying to solve a certain problem. In the current study, this approach was adopted to identify emotional experiences and related thoughts participants encountered when performing the VWM task. To this end, participants were asked to verbalize any feelings or thoughts they experienced while performing the VWM task. The resulting monologue was recorded by using the recording device on a smart phone and later transcribed verbatim (see Appendix 1 for Transcription Guidelines). During the feasibility check of the think aloud method on two participants not included in the actual data,

it became apparent that participants often verbally repeated the colors shown to them for longer periods of time. During transcription, this color-reporting was summarized by including the phrase “verbalizing colors” in the protocols.

3.1.4 Analysis Approach and Coding Reliability

Data analysis was carried out on the basis of qualitative content analysis proposed by Mayring (2014) using the open access web-application *QCAmap* (Mayring & Fenzl, 2014). As to the author’s knowledge, there are no prior findings regarding participants’ affective states when performing a VWM task in the laboratory, data regarding the research questions were analyzed using an inductive procedure (Mayring, 2014). Therefore, categories needed to be extracted from the textual material itself on the basis of a predefined selection criterion and level of abstraction.

To determine what participants feel when performing a VWM task (RQ1a), all text passages in which “participants referred to any sort of emotional states experienced during the VWM task” (selection criterion) were categorized. Here it was stressed that any references to emotional states that pertain to the think-aloud task (e.g., “It stresses me out to talk and perform the task at the same time”) should not be categorized.

In addition to such a selection criterion, the specification of a level of abstraction, on which categories are phrased, is required for the inductive procedure (Haberfellner & Fenzl, 2017). Here, categories were phrased as “specific emotional states or personal feelings, which participants referred to during the VWM task” (level of abstraction; see Table 1 for the Coding Scheme for RQ1a).

Table 1

Coding Scheme for Research Question 1a

Category Definition	Anchor Examples	Coding Guidelines
Anger	That just makes me angry.	Clear meaning component in the text; Multiple responses allowed (applies to all categories here)
Frustration	It's really frustrating	
Joy	I'm enjoying this; I was happy about that	
Boredom	It's always the same thing; It's starting to get boring	
Tension/Nervousness	It's probably because of nerves.	
Confusion	I'm a bit confused.	
Desperation	I get desperate	
Hope	I think it's better now; I hope I'll do better.	
Shame	I'm a bit ashamed.	
Disappointment	I'm disappointed when I don't know it (the correct color).	
Uncertainty	I feel uncertain and that's not pleasant.	
Anxiety	I feel afraid of not doing it right.	

To explore which aspects of the VWM task triggered these discrete emotions (RQ1b), the selection criterion was set to text passages in which "participants explicitly referred to or hinted at reasons, sources or processes related to the emotional states or feelings experienced/perceived during the VWM task". Categories were phrased as "specific reasons,

sources or processes affecting or leading to participants' emotional states and feelings experienced/perceived during the VWM task" (level of abstraction; see Table 2 for the Coding Scheme for RQ1b).

For all text analytical steps, the coding unit, which is the smallest component of the material that can be coded, was set to a clear meaning component in the text. The context unit, which serves as the background for the coding decision, was the respective think aloud protocols. By definition, the recording unit is set to all documents for inductive category formation (Mayring, 2014). According to the step-by-step models for the various techniques of qualitative content analysis, coding guidelines were revised if necessary during categorization of the textual material (Mayring, 2014).

In order to establish the degree of reliability for the category system and reproducibility of the categorizations, a subsample of six randomly chosen interviews (approx. 33% of the entire material) were coded by two independent coders. The coders reached substantial agreement for both research questions (RQ1: $K = .76$ (95% CI, .68 to .89), $p < .01$; RQ2: $K = .72$ (95% CI, .61 to .82), $p < .01$).

Table 2

Coding Scheme for Research Question 1b

Category Definition	Anchor Examples	Coding Guidelines
Self-expectations	this isn't really that difficult	Clear meaning component in the text; Multiple responses allowed (applies to all categories here)
VWM task is challenging (negative sense)	I am out of my depth	
General judgement of the VWM task	At the end of the day, it's just like a game	
Dissatisfaction with the VWM task design	it is always the same thing	
Change in motivation	it doesn't matter to me that much anymore	
Social comparison	I'm always asking myself, if I am that bad or if the others are also this bad	
Referring to missing performance feedback	It would be interesting to know your score	
Referring to missing time reference	You don't know when it'll be over	
VWM task is challenging (positive sense)	I want to continue doing this and I want to do well	
Thoughts on strategies to improve achievement	You start and build themes	

3.2 Results

Three participants did not refer to experiencing any emotions during the VWM task, thus the results for RQ1a reported here rely on the statements from the remaining 16 participants. Overall, 12 discrete emotions were identified (see Table 3). The most frequently stated emotions were anger (stated by eight participants), frustration (seven participants), joy (seven participants), and boredom (six participants). Participants varied in terms of how many different emotions they reported during the task (ranging from one to six emotions) and how often they reported experiencing them (ranging from one to nine times).

Table 3

Discrete Emotions stated by Participants during a VWM Task in order of Frequency

Discrete Emotion	Frequency by participants	Absolute Count
Anger	8 participants	24
Frustration	7 participants	20
Joy	7 participants	17
Boredom	6 participants	9
Tension/Nervousness	3 participants	3
Confusion	2 participants	2
Desperation	2 participants	5
Hope	2 participants	3
Shame	1 participant	2
Disappointment	1 participant	1
Uncertainty	1 participant	1
Anxiety	1 participant	1

These findings confirm previous speculations and provide first empirical evidence that participants experience emotions during a VWM task, which occur because of the task itself. This is in line with emotion research proposing that emotions can be triggered by (cognitive) characteristics of a task (Pekrun et al., 2017a).

In regards to RQ1b, 10 categories were identified, which involved underlying processes associated with participants' emotional experiences during the VWM task (see Table 4).

Table 4

Underlying Processes regarding Emotional Experiences in order of Frequency

Underlying Process	Frequency by participants	Absolute Count
Self-expectations	11 participants	28
VWM task is challenging (negative sense)	11 participants	23
General judgement of the VWM task	6 participants	27
Dissatisfaction with the VWM task design	6 participants	12
Change in motivation	6 participants	11
Social comparison	6 participants	10
Referring to missing performance feedback	4 participants	9
Referring to missing time reference	4 participants	7
VWM task is challenging (positive sense)	3 participants	8
Thoughts on strategies to improve achievement	3 participants	3

Participants' *self-expectations regarding the VWM task* were identified most frequently to be related to their emotional experiences (eleven participants, referred to 28 times). The majority of the coded passages in this category indicated that participants wanted and also expected to do well on the task, as it was perceived initially as a simple task. However, the

task proved to be more difficult than expected. This lead to participants experiencing negative emotions, such as anger ("You get angry when you don't know it because this isn't really that difficult, actually", Participant D).

Eleven participants perceived the *VWM task as challenging in a negative sense*. Here, participants reported the VWM task as being stressful or overwhelming for them and resulting in negative emotions for the individual, as is illustrated by the following examples:

> "I always try to remember, more or less, the general color. And when each one is different, then I am out of my depth…. That just makes me angry." (Participant C).

> "But sometimes, I don't know, sometimes the time to look at the colors is too short and then I get desperate because I try to recite the colors and to see which ones come in pairs and when there are many different colors, all of a sudden nothing works anymore." (Participant G)

Six participants referred to being *dissatisfied with the VWM task design*, such as the rotating color wheel or the number of colors to choose from, which mainly resulted in frustration: "What's also frustrating is the cross in the middle of the screen" (Participant A). One participant reported to experience boredom: "Because this is the second round, you just start noticing that it is starting to get boring, yes, because it is always the same thing" (Participant K).

Participants' *general judgement of the VWM task* (six participants) pertained to the general attitude they reported having towards the task. For instance, some participants referred to the task as being "pointless" or "silly" (Participant K), others compared the task to a game (Participant M) or an exam situation (Participant P). A *change in motivation* was also

referred to by six participants, especially towards the end of the VWM task (“For some reason I’m, I’m starting to notice that it doesn’t matter to me that much anymore, I am not clicking anywhere specific anymore” Participant S).

Pertaining to the category *social comparison*, six participants wondered how they were performing in comparison to the other participants (“I’m always asking myself, if I am that bad or if the others are also this bad.” Participant P). One participant stated to be angry for comparing their own achievement to those of others.

Four participants referred to *missing performance feedback,* which was mainly associated with interest (“It would be interesting to know your score, at the end. Maybe, I don’t know, a smiley face indicating whether you were right or wrong” Participant D).

Four participants also referred to a *missing time reference*, which seemed to be frustrating, as the following example illustrates: “You don’t know when it’ll be over. I think that’s what’s bugging me” (Participant E).

Three participants perceived the *VWM task as challenging in a positive sense*. Here, participants mainly reported that the VWM task fueled their ambition to perform well, but when they did not, they experienced negative emotions, for example:

> “I am still ambitious. It’s not as if I would stop doing this straight away. I want to continue doing this and I want to do well at this and I try every time again and again. But somehow you still are disappointed when you don’t know the answer.” (Participant D)

Finally, three participants referred to *strategies to improve their achievement* (“You start and build themes and then you wait and see, and then you try and do it well“ Participant E).

3.3 Summary and Discussion

The main goal of this study was to explore whether participants experience emotions during a VWM task, which are induced by the task itself, and which discrete emotions these are. While there have been previous speculations about (predominantly negative) emotions occurring during typical lab-based cognitive performance tasks (Luck, 2014; Rouder et al., 2008), the present research was the first to systematically explore these assumptions.

Overall, the results revealed that participants experienced various different discrete emotions, both negative and positive in valence, during a VWM task, while overall negative emotions were mentioned more frequently than positive emotions. Interestingly, these emotional experiences not only varied between individuals, in that some participants experienced more joy and others more anger, but also within them: Participants experienced a range of varying emotions, while performing this laboratory task – at some points during the experimental block, participants were activated, engaged, and enjoying it, while next they had trouble focusing, worried about their achievement, and became frustrated. Importantly, though, joy, anger and frustration clearly were the most dominant emotional experiences reported by the participants in this study. Contrary to prior speculation, boredom was mentioned less frequently than expected, suggesting that boredom is less problematic than previously assumed.

Beyond identifying which discrete emotions the participants experienced during the VWM task, qualitative content analysis was also employed to classify participants' think aloud utterances pertaining to potential reasons for their current emotional experiences. Across the various categories for triggers of emotions identified by this approach, one striking overarching theme emerged from this analysis: Participants seemed to be constantly aware that they could either succeed or fail at the VWM task (i.e. recalling the correct/exact color of the probed square versus failing to do so), and a clear majority of their thoughts centered

around corresponding achievement appraisals. This was the case even though participants were not provided with any feedback on their task achievement, so they did not know for certain how well or how poorly they were doing. However, participants seemed to have a good sense of their task achievement, as they often commented on their overall success rate and subjective success at individual trials.

This finding confirms speculations expressed earlier for example by Rouder and colleagues (2008) that some participants can be "intimidated" by the task, and Spachtholz et al. (2014) who conjectured that the VWM task can "signal requirements" which trigger emotions in the participants. Clearly, one such task requirement here is that one can fail versus succeed. As such, a key insight from this qualitative study was that this task clearly places participants into an achievement situation. That is, a situation where judgments regarding achieving or failing against some standard, be it task-based, self-based, or other based (Elliot et al., 2011) are dominant. By implication, the predominant type of emotions participants experience during the examined VWM task seem to be achievement emotions (Pekrun et al., 2017b). Only few statements pertained to epistemic emotions, such as confusion (Vogl et al., 2020).

The results confirm earlier speculations about VWM tasks inducing certain emotional experiences in participants and thus contribute new insights to the literature. Specifically, the VWM task seems to be interpreted as an achievement situation triggering achievement emotions. In other fields of study, such as educational psychology, achievement emotions have been found to affect academic performance. It is therefore likely that achievement emotions occurring during a VWM task may affect VWM performance. This was explored in two further studies, which are presented in the following chapters.

4. Study 2: Incidentally induced Achievement Emotions in the Laboratory relate to Visual Working Memory Performance on the inter-individual Level

As outlined above, in order to measure VWM, researchers have developed computer-based VWM tasks, such as the continuous color-report task (Wilken & Ma, 2004; Zhang & Luck, 2008), which have been shown to provide reliable and valid VWM estimates of individuals' VWM capacities (Johnson et al., 2013; Kyllingsbæk & Bundesen, 2009). Studies using these tasks have brought about valuable insights into the basic functioning of human visual memory (Luck & Vogel, 2013). However, this research tradition is dominated by experimental designs where (typically small) sample means are compared across experimental conditions, and any inter-individual differences are typically considered as "noise" (Kanai & Rees, 2011; Vogel & Awh, 2008). In this second study, the author suggests that participants and their complexity may have been oversimplified in such existing research paradigms. Although oversimplification is a crucial ingredient of research in general, looking into the "noise" can also be fruitful, and it can even be crucial if it proves to be confounded with experimental manipulations of interest or affects the validity of the measures. Specifically, one important human factor should be considered: the different emotions participants feel while performing experimental laboratory tasks.

Results from Study 1 showed that engaging in a VWM task induced emotional experiences in participants. These emotions were predominantly achievement emotions, as the VWM task was perceived as an achievement situation, in which one could either succeed or fail. Further, findings from Study 1 also showed that participants varied in their emotional experiences regarding the VWM task: some experienced more joy and others more anger while performing the task. The aim of this second study was therefore to explore, whether

incidentally induced achievement emotions during a VWM task are linked with participants' VWM performance on an inter-individual level (RQ 2).

Taking up the results of Study 1, the emotions joy, anger, frustration, and boredom were assessed. As joy was the only positive emotion explicitly labeled by the participants in Study 1, pride was added in this study to include a further discrete emotion also of positive valence (Pekrun, 2018; Posner et al., 2005). Pride is an important self-conscious emotion and a prototypical achievement emotion tightly linked with appraisals of task success (Lagattuta & Thompson, 2007), and given the situational salience of achievement, which was identified in Study 1, it is promising to further investigate the link between this emotion and VWM performance.

4.1 Method

4.1.1 Sample and Data Availability

Participants of this study were $N = 47$ (30 female; $M_{age} = 26.09$; $SD = 3.85$) who all stated not to be color-blind and to have normal or corrected-to-normal vision. They received either course credit or monetary compensation for their time.

Two participants were excluded from further analysis due to substantial missing data in the self-reported emotions and technical difficulties during the VWM task. Forty-five participants (30 female; $M_{age} = 26.24$; $SD = 3.86$) remained in the sample for further analysis.

The data files can be found on the OSF database (https://osf.io/dr62j/?view_only =75252db982bb44758e12c3b287a45db0).

4.1.2 Procedure

Participants familiarized themselves with the VWM task by performing a short practice block containing 30 trials, which started either with 15 trials displaying four squares followed by 15 trials displaying eight squares, or vice versa. The actual task contained 240 trials, which

were arranged in alternating blocks of 30 trials each, displaying either four- or eight-square arrays (set size; order counterbalanced). At the end of the VWM task, participants were prompted to fill in a brief paper-and-pencil questionnaire asking them to report, retrospectively, how they felt during the VWM task.

4.1.3 Stimuli and Measurements

Continuous Color-Report Task. The same VWM task as in Study 1 was employed (see also Figure 1), except that variability in the difficulty of the task was deliberately introduced by using two different sample array set sizes: four or eight colored squares. On the one hand, participants needed to be fairly comfortable with the task during certain phases of the experiment. On the other hand, they needed to be placed systematically in demanding achievement situations, as results from Study 1 indicated that emotions participants experienced during the VWM task were linked to its achievement requirements. For the easy condition a set size of four squares was chosen as it has been shown on multiple occasions that, on average, participants can hold three to four simple items in VWM. In turn, eight squares were chosen for the difficult condition, as previous study designs also displayed trials with eight squares to represent challenging arrays (e.g. Berggren et al., 2017; Rouder et al., 2008). Further, on a small scale ($N = 9$, independent from this study's sample) the difficulty of these set sizes was tested by asking participants directly whether they felt four squares were easy to remember and whether eight squares were difficult to remember. All participants confirmed this. Also, it is worth noting that it is common practice to vary array set size in VWM research.

Participation length for the 240 trials ranged between 25 and 35 minutes. VWM performance was operationalized by computing the absolute angular distance (in degrees) between the probed item's color (on the color wheel) and the selected color (henceforth: recall error) for each participant. This procedure has been used in previous studies (e.g. Blacker et

al., 2014; Ye et al., 2016) and has been recommended for studies interested in effects of independent variables on working memory performance (Ma, 2018).

Emotion Ratings via Paper-and-Pencil Questionnaire. To assess participants' emotions regarding the VWM task, participants were asked to rate five items concerning the emotions they experienced during the VWM task (*I enjoyed the task*, *I felt proud*, *I felt angry*, *I was frustrated*, *I felt bored*,) on a five-point Likert type scale ranging from *strongly disagree* to *strongly agree*. These judgments were made immediately after finishing the experiment.

4.2 Results

As expected, there were no significant effects of set size order on either recall error or self-reported emotions (all *t*s < .96, all *p*s > .34) and this group factor is therefore not considered any further. However, a paired-samples *t*-Test revealed that recall error was on average higher with set size eight, than with set size four (M_{eight} = 59.97°, *SE* =1.38; M_{four} = 34.08°, *SE* = 1.38°; *t*(44) = -21.21, *p* < .001), suggesting that participants were more comfortable with set size four than with set size eight.

To explore the link between task-induced emotions and VWM performance (recall error) on an inter-individual level (RQ2), Pearson's correlation coefficients for VWM performance and the emotions joy, pride, anger, frustration, and boredom were obtained (see Table 5). Results demonstrated that there was a significant negative association between recall error and joy (*r* = -.33, 95% BCa CI [-.594, -.041], *p* = .03), implying that the more participants enjoyed the task relative to others, the better they did on it. However, the relationship between recall error and pride was not significant (*r* = -.25, 95% BCa CI [-.535, .067], *p* = .10). Further, there were significant positive associations between recall error and anger (*r* = .31, 95% BCa CI [.025, .535], *p* = .04), frustration (*r* = .35, 95% BCa CI [.100, .554], *p* = .02), and boredom (*r* = .35, 95% BCa CI [.090, .571], *p* = .02), indicating that when

participants experienced more anger, frustration and boredom than the other participants, they performed more poorly.

To control for false discoveries, the Benjamini-Hochberg procedure was adopted, which yielded a critical *p*-value of .046 for joy, anger, frustration, and boredom. Therefore, the correlations between these emotions and VWM performance are significant at a false discovery rate of .05. Pride did not reach significance.

Table 5

Inter-Individual Correlations between Emotions and Recall Error

Achievement Emotions	*r*	95%*CI*
Joy	-.33*	-.59, -.04
Pride	-.25	-.54, .07
Anger	.31*	.03, .54
Frustration	.35*	.10, .55
Boredom	.35*	.09, .57

Note. $*p < .05$

4.3 Summary and Discussion

The goal of the present study was to establish whether achievement emotions, which are induced by a VWM task, are systematically linked with VWM performance on the inter-individual level. The findings presented here consistently implied that there are positive links between pleasant emotions and enhanced VWM performance, and negative links between unpleasant emotions and decreased VWM performance. Specifically, the more participants enjoyed the task relative to others, the better they performed on it. However, when participants experienced more anger, frustration and boredom than the other participants, they performed more poorly.

As these results are correlational and as such do not allow to draw any causal implications, it is also possible that the better participants scored, the more they reported enjoying the task, and the poorer they performed, the more they reported anger, frustration, and boredom, relative to others.

In the present research, participants were not provided with any feedback on their task achievement, so they did not know for certain how well or how poorly they were doing. However, as shown in Study 1, participants seemed to have a good sense of their task achievement, which may have affected their emotional experiences.

The findings from this study are in line with previous research demonstrating that positive emotions are associated with enhanced working memory performance (e.g. Brose et al., 2014) and negative affect with decreased performance (Figueira et al., 2017). Moreover, these findings demonstrate that achievement emotions, which occur because of a VWM itself, affect VWM performance, thus possibly biasing VWM estimates.

The results from Study 1 using a qualitative approach had suggested that not only did the participants differ from one another with respect to their task-induced emotions during the VWM task, but also, single individuals seemed to experience widely ranging levels of achievement emotions during the task. Thus, within-person variations in achievement emotions during the VWM may also be linked to VWM performance. To explore this possibility a third study was designed which is presented in the following.

5. Study 3: Incidentally induced Achievement Emotions in the Laboratory relate to Visual Working Memory Performance on the intra-individual Level

Study 2 found first empirical evidence that achievement emotions, which are induced because of a VWM task, are systematically related to VWM performance on the between-

person level. However, the results do not reveal any information regarding the relationship between achievement emotions and VWM performance on the within-person level.

Qualitative findings (Study 1) suggested that participants did not just differ from one another in regards to their achievement emotions during the VWM task. It also became evident that participating in the continuous color-report task implied going through highly intra-individually varying emotional states – at some points during the (long) experimental block, participants were activated, engaged, and enjoying it, while next they had trouble focusing, worried about their performance, and became frustrated.

Further, there is empirical evidence suggesting that within-person differences in mood relate to spatial working memory performance (Brose et al., 2014). However, research has not yet established whether achievement emotions, which are triggered by performing a VWM task, are linked quantitatively to VWM performance on the intra-individual level.

Even though Study 2 suggests a link between achievement emotions and VWM performance on an inter-individual level, these findings cannot be generalized to the intra-individual level, as they entail two different analytic approaches (e.g. Murayama et al., 2017). Further, adopting a repeated measurement approach is a particularly valid way to assess participants' emotions, as emotions are intra-psychological phenomena which occur "in the moment" (Lazarus & Lazarus, 1994). Including repeated measures of emotional experiences over the course of the experimental block also allows for modelling intra-individual variability of emotions.

Therefore, the aim of the present study was to explore whether and how task-induced emotions are linked to VWM performance on the intra-individual level (RQ3a). Additionally, as Study 1 revealed that participants experienced the VWM task as an achievement situation, a further aim was to explore whether a typical experimental manipulation (varying difficulty of the task, i.e. set size) had any systematic effect on the achievement emotions experienced

during the task (RQ3b). Thus, a further aim was to assess the intra-individual variation of emotional experiences during the continuous color-report task execution.

5.1 Method

5.1.1 Sample and Data Availability

Participants of this study were $N = 46$ (21 female; $M_{age} = 25.57$; $SD = 3.86$), who all stated not to be color-blind and to have normal or corrected-to-normal vision. Participants received either course credit or monetary compensation for their time.

One participant was excluded from further analysis due to substantial missing data in the self-reported emotions and four participants were excluded due to extremely poor performance (recall error of more than two standard deviations above the mean), indicating poor study commitment and thus low overall data quality. Forty-one participants (21 female; $M_{age} = 25.49$; $SD = 4.03$) remained in the sample for further analysis.

The data files can be found on the OSF database (https://osf.io/dr62j/?view_only =75252db982bb44758e12c3b287a45db0).

5.1.2 Procedure

The same procedure as described in Study 2 was largely adopted. The key difference was that in this study, participants were prompted to report their emotional experiences several times within the experiment (after each block of 30 trials displaying either four- or eight-square arrays), as the aim was to assess the potential intra-individual variability in emotions regarding the VWM task execution in the course of the experiment. This was realized through booklets of paper-pencil questionnaires (see Appendix 2) placed in front of the participants, which they were required to answer whenever prompted to do so on the computer screen, across the entire experimental procedure.

5.1.3 Stimuli and Measurement

Continuous Color-Report Task. The same continuous color-report task as described in Study 2 was adopted, and VWM performance in terms of recall error was operationalized accordingly. Recall error was thus obtained for each block of 30 trials.

Emotion Ratings via Paper-and-Pencil Questionnaire. To assess participants' emotions regarding the VWM task on an intra-individual level, participants were asked *How are you currently feeling?* at eight time points during the VWM task. At each time point participants were asked to rate five items concerning the emotions they experienced during the VWM task (*I am enjoying the task, I feel proud, I feel angry, I am frustrated, I feel bored*) on a five-point Likert type scale ranging from *strongly disagree* to *strongly agree*.

5.1.4 Analysis Approach

To obtain estimates of the relative proportion of variance that occurred on the inter-individual and on the intra-individual level, the intra-class correlations (ICC) for each of the measures of interest were calculated, as a preliminary analysis step. The ICC was .23 for recall error (averaged across blocks of 30 trials), indicating that 23% of the total variance of recall error was due to variability on the inter-individual level, and as much as 77% of the total variance was due to variability on the intra-individual level. The ICCs for emotions were higher: .42 for joy, .44 for pride, .59 for anger, .56 for frustration, and .44 for boredom (see Table 6).

As set size was manipulated, the ICC for each measure regarding set size was also calculated separately to see how this changed the proportion of variance that occurred within and between participants. As a result, ICC tended to increase, implying that the location of variance tended to shift from within-person variance to between-person variance and that some of the within-person variance is accounted for by an effect of task difficulty (set size).

However, considerable proportions of the variance of the variables of interest were still located at the within-person level (see Table 6) even within blocks of the same difficulty.

Table 6

Intra-Class Correlations (ICC) for Recall Error and Emotions

	ICC	ICC (set size four)	ICC (set size eight)
Recall Error	.23	.56	.55
Joy	.42	.50	.40
Pride	.44	.49	.53
Anger	.59	.60	.66
Frustration	.56	.57	.62
Boredom	.44	.46	.38

Note. Higher numbers indicate relatively stronger between-person relative to within-person variability.

The considerable proportions of variance that lay on the within-person level suggested that a two-level hierarchical analysis approach was suitable for further analysis. In those analyses, emotional experiences and recall error were considered as Level 1 variables, nested within participants (Level 2). Recall-emotion links were not expected to vary across participants, thus random intercept, fixed-slope models were calculated for each emotion/recall error combination. For this analysis, all emotion and recall error scores were transformed into *z*-scores, so that the within-person regression parameters could be interpreted as standardized correlations, to allow for comparability between the results from this study and Study 2.

5.2 Results

As in Study 2, there were no significant between-person effects of set size order on either recall error or self-reported emotions (all *t*s < 1.40, all *p*s > .17). However, within participants, set size significantly predicted recall error ($\beta = 5.97$, $p < .01$) thus easier blocks (i.e. arrays with four squares) were associated with better performance. Further, to test whether the multiple emotion ratings affected VWM performance, an independent-samples *t*-test was calculated using participants' average recall error from Study 2 and Study 3. Result yielded no significant difference between the two samples ($t(84) = -.011$, $p = .99$, $r = .0012$).

Regarding the relationship between performance and emotions (RQ3a), results showed that every discrete emotion significantly correlated with VWM performance on the intra-individual level (see Table 7). Specifically, joy and pride correlated negatively with recall error, whereas anger, frustration and boredom correlated positively with recall error.

Table 7

Intra-Individual Correlations between Emotions and Recall Error

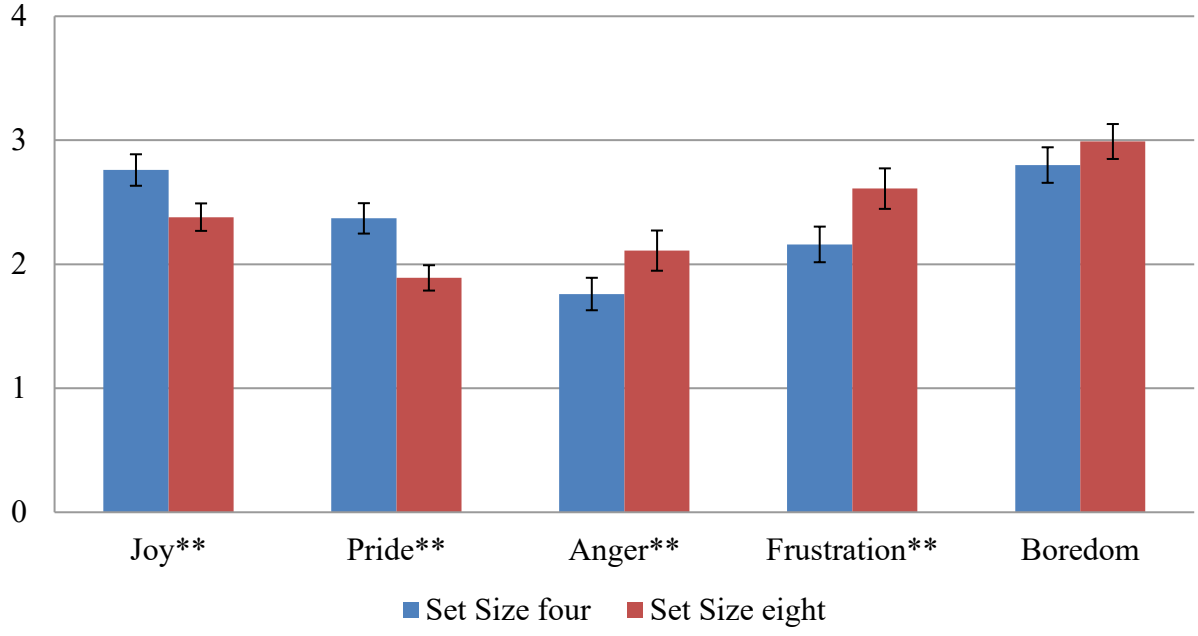
				Controlling for Set Size		
Achievement Emotions	β	SE_β	95%*CI*	β	SE_β	95%*CI*
Joy	-.29**	.06	-.41, -.18	-.10**	.04	-.18, -.03
Pride	-.42**	.06	-.53, -.31	-.15**	.04	-.23, -.07
Anger	.26**	.07	.14, .39	.07	.04	.01, .16
Frustration	.36**	.06	.24, .49	.14**	.04	.06, .23
Boredom	.22**	.06	.10, .34	.14**	.04	.06, .21

*Note. *p < .05, **p < .01; Intra-individual correlations in Study 3 were obtained by conducting two-level hierarchical models.*

In regards to RQ3b, paired-samples *t*-tests showed significant effects of set size on joy ($t(40) = 4.18$, $p < .01$, $r = .55$), pride ($t(40) = 5.75$, $p < .01$, $r = .67$), anger ($t(40) = -3.79$, $p < .01$, $r = .51$) and frustration ($t(40) = -4.65$, $p < .01$, $r = .59$), indicating that the variation in task difficulty affected how participants felt while performing the VWM task. Specifically, when confronted with set size four, participants experienced more enjoyment ($M = 2.76$, $SE = .81$) and pride ($M = 2.37$, $SE = .78$) than when confronted with set size eight (joy: $M = 2.38$, $SE = .71$; pride: $M = 1.89$, $SE = .65$). Further, participants experienced less anger ($M = 1.76$, $SE = .84$) and frustration ($M = 2.16$, $SE = .92$) when confronted with set size four than with set size eight (anger: $M = 2.11$, $SE = 1.04$; frustration: $M = 2.61$, $SE = 1.05$). The effect of set size on boredom did not reach significance ($t(40) = -2.02$, $p = .05$, $r = .30$; see Figure 2).

Figure 2

Continuous Color-Report Task: Effects of Set Size on Emotions



Note. $^{**}p < .01$*; error bars display +/- one standard error*

Finally, taking into consideration that set size had a strong effect on the emotions, in a last analysis step, set size was also considered in the analyses. This implied exploring whether, even in blocks of the same difficulty, participants' emotions varied, and whether this variation in task experiences was systematically related to performance. Intriguingly, the effects remained significant for all discrete emotions except for anger (Table 7). This implies that anger was strongly driven by task difficulty, but any other variations in task anger were unrelated to performance. However, participants' fluctuations in joy and pride across the experiment were still significantly negatively related with their error rates in the task, and their fluctuations in frustration and boredom were positively related with error rate.

5.3 Summary and Discussion

The aim of the present study was twofold. First, the relationship between participants' emotional experiences, which were triggered by engaging in a VWM task, and VWM performance was explored. In doing so, the aim was to provide insight into the intra-psychological processes, specifically achievement emotions, of participants while they performed a visual memory task.

Results showed that every discrete emotion was linked to VWM performance on the within-person level. Specifically, positive achievement emotions related positively to VWM performance, indicating that when a participant experienced more joy or pride during a block of 30 trials than on the other blocks, they performed better on the task on that particular block relative to the other blocks or vice versa: when participants performed better at a block, they enjoyed it more, and were more proud, relative to the other blocks.

In turn, anger, frustration, and boredom were negatively linked with VWM performance, implying that the more a participant experienced those negative emotions during a block, the worse they performed on that particular block, or vice versa.

Further, the results from this study add to the evidence of Study 2, that when ignored, task-induced emotions may affect the validity of the VWM task, thus distorting VWM estimates. This is an important finding for future research in VWM, and lab-based tasks in general, which will be elaborated on in Chapter 7.

The second goal of Study 3 was to explore whether variations in task difficulty (i.e. set size) had any systematic effect on the achievement emotions experienced during the task. In VWM research it is common to vary set size in measuring paradigms. Participants are therefore confronted with some sample arrays that are easier and with others that are more difficult, which may influence their appraisals of the achievement situation and in turn, their emotional experiences. The results from the present study show that task difficulty affected participants' achievement emotions. Specifically, when confronted with the easy trials (i.e. set size four), participants experienced more joy and pride, and less anger and frustration. In contrast, when confronted with difficult trials (i.e. set size eight), participants experienced less joy and pride, and more anger and frustration. Whether the trials were easy or difficult did not seem to influence participants' experience of boredom.

5.4 Overall Conclusion regarding Studies 1 through 3

The findings from Studies 1, 2 and 3 presented here showed that participants performing a VWM task in the laboratory in order to measure their VWM performance underwent different between-person as well as within-person emotional experiences, which were incidentally induced by the task itself. Specifically, the VWM task seemed to trigger achievement emotions in participants, as they attributed achievement characteristics to the VWM task. Further, these achievement emotions were linked with the difficulty of the task on the one hand and with participants' VWM performance on the other hand. The findings from Study 1 also suggested that participants sensed whether they were doing well or doing poorly

on the task (without receiving any feedback on their performance) and that this subjective feeling of performance was related to how they felt.

Overall, these findings strongly suggest that achievement emotions are potentially confounding variables for interpreting VWM scores as resulting from typical laboratory-based paradigms for measuring VWM capacity and pose a potential threat to the validity of the VWM performance scores. Therefore, further research on the role of task-induced achievement emotions in VWM performance is warranted and necessary. For this reason, the author suggests a registered report entitled "Task-induced Achievement Emotions and their Role in Visual Working Memory Performance: A Registered Report" to further investigate the relationship between task-induced achievement emotions and VWM performance. The rationale and design of this proposed study are introduced in the following chapter.

6. Task-induced Achievement Emotions and their Role in Visual Working Memory Performance: A Registered Report

In this chapter, a registered report is proposed in order to replicate previous findings found in Studies 1 through 3 and to further investigate the link between task-induced achievement emotions and VWM performance. The reasoning for choosing this publication format is outlined in Chapter 6.3.

The first aim of this registered report is to replicate findings from Study 2 and Study 3 in that achievement emotions, which are triggered by the VWM task, are linked with VWM performance on the inter-individual as well as on the intra-individual level. Besides the emotions *joy*, *pride*, *anger*, *frustration* and *boredom*, the emotion *shame* is included in the analysis. In control-value theory, shame is thought to be a retrospective outcome emotion pertaining to failure caused by the self (Pekrun, 2006) and has found to be negatively linked with performance (Pekrun et al., 2011, 2017b). Shame is often viewed as the negative

counterpart to *pride* and is therefore important to consider when exploring achievement emotions. Therefore the first hypothesis is stated as follows:

H_1: VWM performance correlates with discrete achievement emotions as experienced during a visual working memory task.

H_{1a}: VWM performance is positively linked with discrete positive achievement emotions, including enjoyment and pride: The better one does, the more joy and pride one will experience during the task, and vice versa. This holds true on the inter-individual as well as the intra-individual level.

H_{1b}: VWM performance is negatively linked with discrete negative achievement emotions, including anger, frustration, boredom and shame: The worse one does, the more anger, frustration, boredom and shame one will experience during the task, and vice versa. This holds true on the inter-individual as well as the intra-individual level.

The second aim of this proposed study is to establish the role of participants subjective feeling of doing well or doing poorly on the VWM task in the emotion-performance link. As stated above, achievement emotions occur in competence-relevant situations, where, based on a person's perceived competences and standards of excellence, they can either succeed or fail. As Study 1 demonstrated, participants viewed the VWM task as an achievement situation thus triggering achievement emotions. When they thought they were doing well, they felt good but when they thought they were doing poorly they felt bad, even though no actual feedback on their performance was provided. It is therefore possible that the subjective feeling of how one is doing on the VWM task is the underlying psychological mechanism driving the relationship between the experienced achievement emotions and VWM performance. Specifically, the following is hypothesized:

H_2: The link between VWM performance and achievement emotions is mediated by subjective task performance.

H_{2a}: The subjective feeling of 'doing well' on the VWM task mediates the link between VWM performance and positive discrete achievement emotions, such as enjoyment and pride.

H_{2b}: The subjective feeling of 'doing poorly' on the VWM task mediates the link between VWM performance and negative discrete achievement emotions, such as anger, frustration, boredom and shame.

The third aim is to investigate the role achievement goals play in the relationship between achievement emotions and VWM performance. Previous research has demonstrated that achievement goals, achievement emotions and academic performance are mutually linked. Further, research on working memory has demonstrated that achievement goals can affect memory performance. However, research has not yet established which role achievement goal orientation plays in the relationship between achievement emotions, which were induced by the VWM task, and VWM performance. The author proposes that the typical VWM laboratory tasks naturally involve performance goal triggers – the task instructions are basically about recalling correctly, which participants may succeed or fail at. However, people may well individually differ in how strongly they perceive the VWM task as an achievement task. In other words, some participants may simply not "care" as much about whether or not they succeed or fail at recalling the visual stimulus material correctly. As such, participants' performance goal orientation may have important effects on how they emotionally react to the given VWM task. As the VWM task can be interpreted as a competence-relevant situation, it is likely that participants' performance goal orientation will affect the relationship between their achievement emotion experiences and VWM performance. Therefore, the following is proposed:

H_3: The link between VWM performance and achievement emotions is moderated by performance goal orientation.

H_{3a}: Performance-approach goals moderate the link between positive discrete achievement emotions, such as enjoyment and pride, and VWM performance: The more someone endorses performance-approach goals, the stronger the joy/performance and pride/performance links will be.

H_{3b}: Performance-avoidance goals moderate the link between negative discrete achievement emotions, such as anger, frustration, boredom and shame, and VWM performance: The more someone endorses performance-avoidance goals, the stronger the anger/performance, frustration/performance, boredom/performance and shame/performance links will be.

Finally, the last aim of this registered report is to establish the role of task difficulty in the relationship between task-induced achievement emotions and VWM performance. Study 3 revealed that task difficulty played a role in the emotions participants experienced during the VWM task: easy trials (i.e. set size four) were related to experiencing more positive emotions, whereas difficult trials (i.e. set size eight) were associated with experiencing more negative emotions. Following up on these findings and on Hypotheses 1 and 3 of the present proposed study, it is hypothesized that task difficulty will interact with achievement emotions and performance goal orientation in predicting VWM performance. As described above, it has been speculated that being confronted with difficult versus easy variants of a VWM task seems to “challenge” some, yet “frustrate” or “intimidate” others (cf. Rouder et al., 2008). Then again, variations in task difficulty may simply be less relevant for others and these participants may not react so strongly emotionally, in response to differently hard tasks they have to accomplish in a laboratory experiment. It is therefore likely that it is the performance goal orientation (i.e. seeking to do well, or avoiding doing poorly in an achievement situation) which is responsible for causing both positive and negative emotions to peak as a result of (sensing to be) doing well or poorly on tasks. The proposed study is thus designed to test if

indeed participants' performance goal orientation, and their resulting emotional reactions, has effects on their task performance if they are confronted with particularly highly difficult tasks (as opposed to reasonably difficult tasks), within one single experimental setting. As such, the last hypothesis reads as follows:

H_4: Task difficulty, achievement emotions and performance goal orientation interact in predicting VWM. This three-way interaction should be qualified by the following patterns:

H_{4a}: The difference in VWM performance between easy (four items) versus difficult (eight items) trials is smaller, the more emotionally positively participants react to the task, and this effect should be particularly enhanced for participants who strongly endorse performance-approach goals ("challenge effect").

H_{4b}: The difference in VWM performance between easy (four items) versus difficult (eight items) trials is larger, the more emotionally negatively participants react to the task, and this effect should be particularly enhanced for participants who strongly endorse performance-avoidance goals ("intimidation effect").

The design and methodology proposed for this registered report is based on those of Studies 2 and 3. However, as the proposed study aims to combine inter-individual and intra-individual measurements and includes further variables, it was necessary to test the experimental procedure and design in advance. A pilot study therefore was developed on the basis of the methodology of the final registered report. The pilot study, its results and implications for the final registered report are reported in the following.

6.1 Pilot Study

One key goal of this pilot study was to establish the feasibility of the overall study procedure of the registered report. For instance, in order to preclude demand characteristics in terms of participants directly attributing the performance goal orientation scale to the VWM

task, it was deemed necessary to carry out the study in two steps at two different time points. This procedure was tested within the pilot study.

A second goal was to confirm prior to data collection for the registered report that neither the way of assessing the variables of interest, nor the study design itself would have any effects on the key outcome variables.

This chapter is structured as follows: First the study methodology, which was designed for data collection for the registered report and is generally adopted in the pilot study, is discussed. Next, on the basis of the study procedure, specific pilot hypotheses (PHs) are derived, for instance to verify the absence of systematic effects of the study design and measurements on the variables of interest. Finally, results from the pilot study are presented and their relevance for the proposed registered report is discussed.

6.1.1 Sample and Data Availability

Participants of this pilot study were $N = 89$ (55 female; $M_{age} = 25.36$; $SD = 3.21$), who were recruited during a student project at the university. Every participant of the sample stated not to be color-blind and to have normal vision or corrected-to-normal vision. Participants received either course credit or monetary compensation for their time.

After data cleaning[2], seven participants were excluded from further analysis. Eighty-two participants (49 female; $M_{age} = 25.38$; $SD = 3.27$) remained in the sample for further analysis.

The data file of the pilot study is available from the OSF database (https://osf.io/p25kf/?view_only=da941d240a3c465a8f5e444455ee5874).

[2] Criteria for excluding participants' data from the pilot study sample were substantial missing data in either the paper-pencil questionnaire or the VWM performance data (N=3 were thus excluded), and outliers in VWM performance in terms of extremely poor performance for each block of 240 trials, indicating poor study commitment and thus low overall data quality (mean plus two standard deviations; N=4 thus excluded).

6.1.2 Procedure and Study Design

Data was obtained in two separate steps. During the first part of the pilot study, participants were asked to fill in an online questionnaire via a link at least 24 hours before the laboratory experiment, in order to preclude demand characteristics. To test feasibility, a shorter version of the online questionnaire was generated in German and English, which included general and demographic information and the development of a personalized code in order to match participants' data from the online questionnaire with their data from the laboratory. Matching participants' data was not a priority in the pilot study, but this was carried out in order to test this procedure and in case participants required their data to be deleted from the pilot study at a later date.

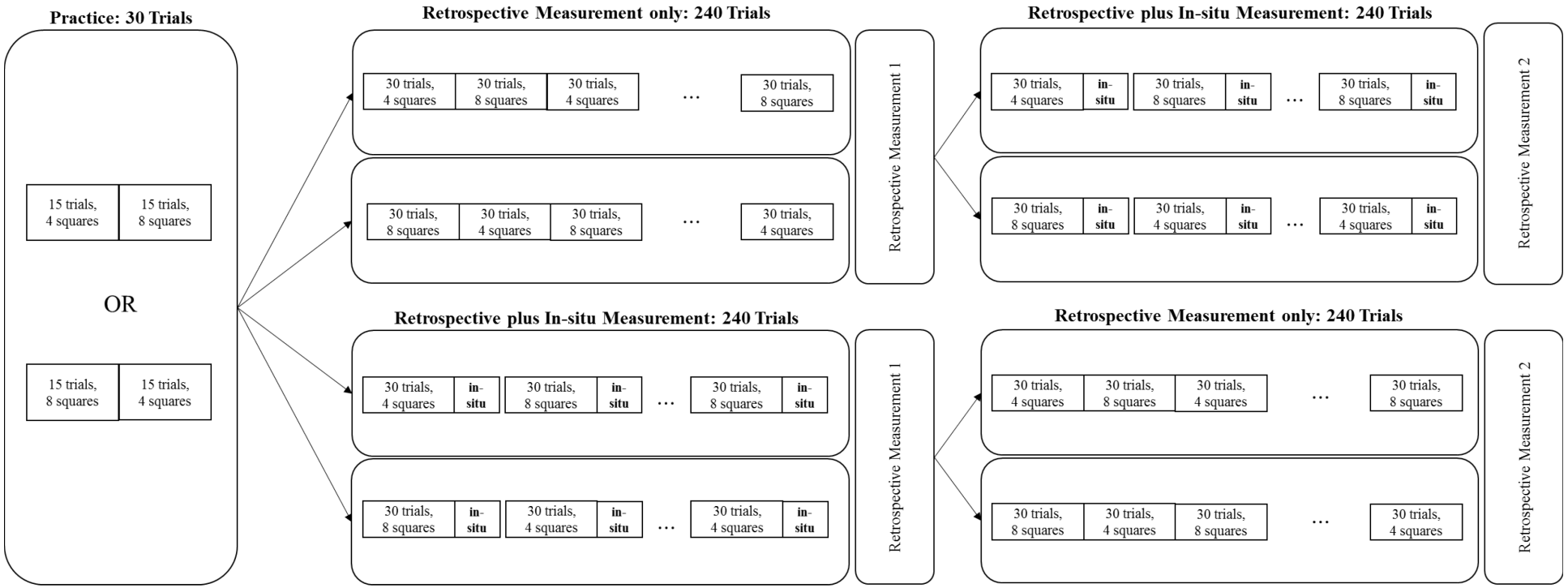
At the end of the questionnaire participants were thanked for their time and asked to contact the experimenter in order to schedule a date for the VWM task in the laboratory. To ensure participants actually completed the online questionnaire at least 24 hours beforehand, they were required to take a picture or a screenshot of the last page of the questionnaire and show it to the experimenter when they came to the laboratory.

For the second part of the pilot study, participants were asked to complete the continuous color-report task on the computers in the laboratory of the university and to fill in an accompanying paper-pencil questionnaire. At the beginning, participants were asked to repeat their personalized code generated during the first part of the study in order to match their data from the online-questionnaire to their respective data from the laboratory task. The task was performed in a quiet, windowless laboratory at the university. As each computer was visually separated from the other, up to four participants were able to take part in the task simultaneously. During the entire task, an experimenter was present in order to ensure participants followed the instructions correctly.

First participants completed a practice round, which contained 30 trials and started either with 15 trials displaying four squares followed by 15 trials displaying eight squares, or vice versa. The participants then moved on to the actual task, which consisted of two experimental blocks, each containing 240 trials. The trials within a block were arranged in alternating sets of 30, displaying either four- or eight-square arrays. Half the participants completed their first block without any breaks ("retrospective measurement only" block; similar to Study 2). At the end of this block, participants were prompted to judge how they felt during the block and how well they thought they did on this experimental block. The other participants started with the "retrospective plus in-situ measurements" block, for which they were instructed to rate the emotion and subjective task performance items after each set of 30 trials by answering the respective items in the booklets (similar to Study 3). At the end of the block, participants were prompted again to judge how they had felt during this experimental block and how well they thought they did on this block. The instructions to do so appeared on the computer screen. Both set size order (starting with four versus eight squares) and block type (retrospective only versus retrospective plus in-situ) were counter-balanced across participants. After completing both experimental blocks, participants were thanked for their time, debriefed and received either course credit or monetary compensation. For a visualization of the study design and procedure, see Figure 3.

Figure 3

Experimental Design of the Pilot Study



6.1.3 Stimuli and Measurements

Pre-Measurements via Online Questionnaire. In the pilot study, pre-measurements involved items regarding general and demographic information, such as gender, age, native language, whether participants required visual aid and whether they were color blind. Further, participants were asked to generate a personalized code involving their mothers' and fathers' names and birthdays in order to match their data from the online questionnaire with their data from the laboratory.

Continuous Color-Report Task. The same continuous color-report task as described in Study 2 and Study 3was adopted (i.e. arrays showing four or eight colored squares), and VWM performance in terms of recall error was operationalized accordingly. Recall error was thus obtained for each block of 30 trials.

Measurements via Paper-Pencil Questionnaire. Participants received booklets of paper-pencil questionnaires (see Appendix 3) in the laboratory, which they were required to answer whenever prompted to do so on the screen, across the entire experimental procedure.

An essential aspect of the pilot study was to test these two different types of self-report measurements of achievement emotions, (1) an overall retrospective measurement after a block of 240 trials and (2) an *in-situ* block measurement after every 30 trials within a 240 trials block. Even though results from Study 3 showed that multiple emotion ratings did not systematically affect VWM performance, it was open to question whether combining and counterbalancing both measurement types in one study would affect both the actual emotional experience during the experiment (hence, a problem of uncertainty relation), and also VWM performance. Therefore, a post-block retrospective approach to measuring emotions was also adopted in both blocks, assuming that participants should be able to mentally aggregate across 240 trials and provide a valid retrospective rating of their emotional experiences. Piloting both ways of measurement allowed to test the validity of the retrospective measure: the author

proposes that if the average across all in-situ ratings would correlate at least at .7 with the retrospective measure, this would provide evidence of the quality of the retrospective measure as to reliably and validly reflecting the participants' experiences during this experimental block.

For the achievement emotions, the overall retrospective measurement was realized by asking, *How were you feeling during the task?* In answering this question, participants had to rate six items (*I enjoyed the task, I felt proud, I felt angry, I was frustrated, I felt bored, I felt ashamed*) on a five-point Likert type scale ranging from *strongly disagree* to *strongly agree.* The in-situ emotion measurement was realized by asking, *How are you currently feeling?* In answering this question, participants also had to rate six items (*I am enjoying the task, I feel proud, I feel angry, I am frustrated, I feel bored, I feel ashamed*) on a five-point Likert type scale ranging from *strongly disagree* to *strongly agree*.

Overall retrospective subjective task performance was assessed by the question *When looking back across the entire last block: how well did you do at the task?* It was rated on a five-point Likert type scale (*very poorly* to *very well*). In-situ subjective task performance after every 30 trials was assessed through asking, *How well are you currently doing at this task?*, which was rated on the same five-point Likert type scale. Participants answered the self-report items in either German or English, according to their indicated preference.

Manipulation of Task Difficulty. As in Studies 2 and 3, task difficulty was manipulated by varying the number of squares shown in the trials (set size) in a within-subject design: in the *easy* condition trials displayed four colored squares, and in the *difficult* condition trials displayed eight colored squares.

6.1.4 Hypotheses – Pilot Study

The aim of this pilot study was to establish the feasibility of the overall study procedure, and confirm that neither the way of assessing participants' emotions and subjective task

performance (retrospective only vs. retrospective plus in-situ), nor block type order or array size order would have any effects on the key variables of interest, namely VWM performance and overall retrospective emotional experiences and overall retrospective subjective task performance. This pilot study therefore adopted a mixed design, with block type (retrospective only vs. retrospective plus in-situ) as the within-subject factor, and array size order and block type order as between-subject factors, to which participants were randomly assigned.

Further, the pilot study was to estimate the effect of the task difficulty manipulation within the chosen experimental design (30 trials each with array size four vs. eight), and to confirm that the repeated in-situ self-report measures, aggregated across the entire block, render basically equivalent estimates as the single, retrospective self-report measures. The following hypotheses were thus derived:

PH_1: Set size (four versus eight squares) significantly affects VWM performance: Participants' recall of the target square is more prone to error with set size eight than with set size four. (Manipulation Check)

PH_2: Assessing self-reported discrete state emotions and subjective task performance repeatedly during the experimental block (in-situ) does not systematically affect VWM performance and overall retrospective emotional experiences or overall subjective task performance (block type).

PH_3: The order in which participants start the experiment (i.e. starting with retrospective only versus retrospective plus in-situ measurements) does not systematically affect the outcome variables VWM performance, retrospective emotional experiences ratings or overall subjective task performance (block type order).

PH_4: The order of set size (starting with four versus eight squares) does not systematically affect the outcome variables VWM performance, retrospective emotional experiences ratings, or overall subjective task performance (set size order).

PH_5: The in-situ measurement approach is basically equivalent with the retrospective measurement approach: Aggregated in-situ scores and single retrospective scores for emotions and subjective task performance scores are correlated at least as high as .7.

6.1.5 Analysis Approach

All tests were analyzed using *IBM SPSS Statistics 25* for *Windows.* To test PH_1, a paired-samples *t*-test for each block (retrospective only versus retrospective plus in-situ) was conducted.

For PH_2 through PH_4, a repeated-measures analysis of variance (ANOVA) was conducted with block type (retrospective measurement only versus retrospective plus in-situ measurements) as the within-subject factor, and set size order and block type order as between-subject factors. Outcome variables for all three hypotheses were VWM performance, retrospective subjective task performance ratings and retrospective achievement emotion ratings (enjoyment, pride, anger, frustration, boredom and shame).

In order to validate the retrospective measurements of achievement emotions (PH_5), scores from the in-situ measurements were averaged for each emotion and correlated with the respective single item retrospective measurement scores by obtaining Pearson's correlation coefficient. The bootstrapping-method was used to estimate the statistical significance of the correlation.

6.1.6 Results

As expected, participants' recall error was on average higher with set size eight, than with set size four (PH_1). This was true for the block "retrospective measurement only" (M_{eight} = 60.21°, *SE* =1.21; M_{four} = 35.09°, *SE* = 1.17°; $t(81) = -27.89$, $p < .001$) as well as the block

"retrospective plus in-situ measurements" (M_{eight} = 59.37°, SE =1.23°; M_{four} = 34.03°, SE = 1.10°; $t(81) = -33.71$, $p < .001$).

Regarding PH_2, counter to expectations, the analyses revealed significant main effects of block type on two of the six outcome variables: enjoyment ($F(1,78) = 4.103$, $p = .046$) and anger ($F(1,78) = 10.251$, $p = .002$).

Regarding PH_3 and PH_4, as expected, there were no significant main effects of block type order or set size order on any of the six outcome variables of interest, confirming previous expectations that the order in which participants performed the experiment did not matter.[3]

Any two- and three-way interaction effects within the three-way mixed ANOVA analyses were also inspected. There was a significant interaction between block type and block type order regarding enjoyment ($F(1,78) = 22.168$, $p < .001$), boredom ($F(1,78) = 39.658$, $p < .001$) as well as a significant interaction between block type and set size order regarding subjective task performance ($F(1,78) = 3.969$, $p = .05$).

As shown in Table 8, all retrospective measurements correlated highly with the averaged in-situ measurements (PH_5). Those correlations were all significant, all $p < .01$. This suggested that measuring subjective task performance and achievement emotions retrospectively is a valid procedure for obtaining subjective task performance and emotional experiences during a VWM task.

[3] To substantiate this null finding additional equivalence testing was applied using the *TOST* procedure in *RStudio* for *Windows,* as described by Lakens et al. (2018). For recall error the SESOI was set to 5° (lower equivalence bound to -5°; upper equivalence bound + 5°; *alpha* = .05). For the achievement emotions and subjective task performance the SESOI was set to .7 (lower equivalence bound to -.7; upper equivalence bound to .7; *alpha* = .05). Equivalence testing showed that there was no significant difference from zero within these boundaries for any of the outcome variables, for both block type order and set size order.

Table 8

Correlations of aggregated in-situ Measurements with retrospective Measurements of Achievement Emotions and Subjective Task Performance

	Pearson Correlation	95%*CI*
Enjoyment	$r = .88$**	.815, .923
Pride	$r = .77$**	.607, .871
Anger	$r = .83$**	.768, .891
Frustration	$r = .85$**	.780, .906
Boredom	$r = .83$**	.718, .918
Shame	$r = .89$**	.806, .945
Subjective task performance	$r = .79$**	.689, .865

Note. **$p < .01$

6.1.7 Implications for the proposed Registered Report

First of all, the results from the pilot study confirmed the findings from Study 2 and 3 that the task difficulty manipulation using a set size of four versus eight is suitable to significantly affect VWM performance. Thus, it can be assumed that a set size of eight is on average more challenging for participants than a set size of four.

Regarding the overall design of the study, the results showed that the order in which the blocks are performed and the order of the set size do not affect the outcome variables. However, the results suggest that block type (retrospective measurement only versus retrospective plus in-situ measurements), affected two of the six outcome variables and interacted with the other design criteria in affecting further outcome variables. The author therefore chooses to refrain from using any in-situ measurements of subjective task performance and achievement emotions in the final registered report (see Chapter 6.2). As the results for PH_5 from the pilot study showed that the in-situ measurements correlated highly (>.7) with the retrospective measurements, subjective task performance and achievement

emotions will be measured only retrospectively (after 240 trials) for the main data collection. Therefore, the first hypothesis of the registered report will only pertain to emotion/performance links on the inter-individual level.

6.2 Registered Report

6.2.1 Sample and Exclusion Criteria

*G*Power* 3.1.9.4 was used to estimate the sample size. Aiming to be able to detect a small effect (*f* =.1; Cohen, 1988), and using the statistical test setting *ANOVA: Repeated measures, within-between interaction* (alpha = .05; power = .9; number of groups = 12; number of measurements = 2; correlation among rep measures = 0.8), *G*Power* suggests a total sample size of *N* = 204. The goal is to recruit 225 participants (approx. 10% more than estimated) in order to compensate any dropouts due to participants not finishing the study or due to data exclusion. As in the pilot study, participants will be mainly students between the ages of 18 and 35. Further criteria for exclusion from the study are color-blindness and any form of visual impairment that cannot be corrected to normal vision. Finally, participants must be able to speak German or English fluently.

Before data analysis, participants' data will be scanned for substantial missing data in either the paper-pencil questionnaire or the VWM task (e.g. due to technical difficulties, such as data not being recorded accordingly), and outliers in the VWM performance data in terms of poor performance (mean performance plus two standard deviations).

Upon acceptance, the data file of the present study will be made available on OSF.

6.2.2 Procedure and Study Design

As already successfully tested in the pilot study, data will be collected in two steps. First, participants will be asked to fill in an online questionnaire. Here, participants will generate a personalized code (for matching the data), give consent for data use, provide

general demographic information, such as gender, age and native language, as well as information on possible color-blindness or other visual impairment. Participants then move on to rate items on the adapted *Achievement Goal Questionnaire Revised* (AGQ-R; Elliot & Murayama, 2008; see below).

The second part of the study will take place in the laboratory at least 24 hours later. Here, participants will be asked to fill in an accompanying paper-pencil questionnaire while completing the continuous color-report task on the computer. Participants will perform a practice block containing 30 trials, which will start either with 15 trials displaying four squares followed by 15 trials displaying eight squares, or vice versa and then move on to perform one experimental block of 240 trials. The trials will be arranged in alternating sets of 30, displaying either four- or eight-square arrays. At the end of the block, participants will also be prompted to judge how they felt during the VWM task and how well they felt they performed.

Participants will be randomly assigned to start the task with one of the two set size order conditions by block randomization, where equal group sizes can be achieved.

6.2.3 Stimuli and Measurements

Performance Goal Orientation. To measure participants' performance approach and avoidance goal orientation, an adapted version of the corresponding subscales of the well-established AGQ-R (Elliot & Murayama, 2008) will be used. This scale was originally developed for use with university and school students and their goals regarding their academic achievement. As the present study's focus lies on achievement goals in other performance situations (i.e. the VWM task) the phrasing of the items will be changed to pertain to achievement in general. For instance, the original item reads, *My aim is to perform well relative to other students*. This item was revised and now reads, *My aim is to perform well relative to others* (see Appendix 4 for adapted items of the AGQ-R). Responses will be given

on a five-point Likert type scale, ranging from *strongly disagree* to *strongly agree*. As data will be collected from English- as well as German-speaking participants, the adapted German translation will be based on the German version of the AGQ-R as used by Pekrun et al. (2006). Answers to the three items will be averaged for each sub scale to form performance-approach and performance-avoidance indexes for each participant, as suggested by the scale's authors.

Continuous Colour-Report Paradigm. In order to measure VWM the same continuous color-report paradigm, which was used in the studies previously outlined, will be adopted. VWM performance will be operationalized accordingly. Further, to test H4, which involves task difficulty, recall errors will be calculated separately for the four versus eight set size trials (120 each). As in the previous studies, no performance feedback will be provided.

Measurements via Paper-Pencil Questionnaire. Achievement emotions will be measured retrospectively after the VWM task by asking *How were you feeling during the task?* Participants will rate six items (*I enjoyed the task, I felt proud, I felt angry, I was frustrated, I felt bored, I felt ashamed*) on a five-point Likert type scale ranging from *strongly disagree* to *strongly agree*. Further, retrospective subjective task performance will be assessed by the question *When looking back across the entire task: how well did you do at the task*? It will also be rated on a five-point Likert type scale (*very poorly* to *very well*).

Manipulation of Task Difficulty. Task difficulty will be manipulated by varying the set size shown in the trials in a within-subject design. As tested in the previous studies, there will be two conditions: (1) in the easy condition trials will display four colored squares, and (2) in the difficult condition trials will display eight colored squares.

6.2.4 Analysis Approach

Before data analysis, the data will be scanned for exclusion criteria. Further, pre-tests, such as the success of the task difficulty manipulation (four versus eight squares) and the

possible effects of counterbalanced set size order on the outcome variables will be performed. Results from the pilot study suggest, that the task difficulty manipulation will be successful. Further, it is expected that set size order will have no systematic effect on the outcome variables, as shown in the pilot study. T-tests and equivalence tests will be carried out to confirm those expectations. *IBM SPSS Statistics 25* and *RStudio* for Windows will be used for all analyses.

To test H1, stating that discrete positive achievement emotions are positively correlated with VWM performance, whereas discrete negative achievement emotions are negatively correlated with VWM performance, Pearson's correlation coefficient will be obtained.

To test whether subjective task performance mediates (H2) and whether performance goal orientation moderates (H3) the relationship between achievement emotions and VWM performance, Hayes' PROCESS macro for SPSS will be used (Hayes, 2012).

Finally, to test whether task difficulty, emotions, and performance goal orientation interact in predicting VWM performance (H4), repeated-measures analysis of variance with covariates (ANCOVA) will be executed, with array-size as the repeated-measures factor, and performance goal orientation and the discrete emotions as covariates. Specifically, two sets of three-way interactions will be tested, namely (1) between task difficulty [four versus eight], enjoyment (and pride, respectively [low, medium, high]) as well as performance approach orientation [low, medium, high], and (2) between task difficulty [four versus eight], anger (and shame, respectively [low, medium, high]), and performance avoidance orientation [low, medium, high].

In the event that one or more hypotheses cannot be verified, the respective null hypothesis/hypotheses will be investigated further by adopting equivalence testing using the TOST procedure in RStudio for Windows, as described by Lakens et al. (2018). For recall error the SESOI will be set to 5° (lower equivalence bound to -5°; upper equivalence bound +

5°; alpha = .05). For the achievement emotions, subjective task performance and achievement goal orientation the SESOI will be set to .7 (lower equivalence bound to -.7; upper equivalence bound to .7; alpha = .05) for all three variables, as the same scale was used for all three (5-point Likert type scale).

6.3 Author's Note on the proposed Registered Report

The requirements of the registered report publication process dictate that the manuscript ends at this point. It is then submitted for peer review at the respective journal, which is known as Stage 1. Upon acceptance of the Stage 1 report, the author can move on to collect and analyze data, finish the manuscript (results and discussion section) and then submit the finalized report for a second peer review process (Stage 2). When all the requirements from the reviewers are met, the manuscript is published (for an overview of the registered report process, see the Center for Open Science webpage https://www.cos.io/initiatives/registered-reports).

Registered Reports are gaining more and more acceptance in the Science Community, which is reflected by the rising number of journals offering this publishing format (Chambers, 2019). Further, a rising number of researchers are choosing to publish their research via this format, as registered reports help to reduce publication bias and also foster open science, by pre-registering manuscripts and making the data publically available (Chambers, 2019).

The registered report format for the manuscript presented in Chapter 6 was chosen for two reasons: First, as there is only little known about the link between task-induced achievement emotions and VWM, predicting their relationship, outcomes and correlates is difficult. Therefore, there is a possibility of obtaining negative results for some or even all of the hypotheses presented above. Registered reports provide the opportunity to disseminate results as they are, despite how complicated or negative they may be, which traditional

publication formats tend not to do. Put differently, the outcome of the results does not determine whether or not an article is published, thus reducing publication bias (Chambers, 2015). Further, by publishing negative findings, other researchers are prevented from engaging in redundant studies. Second, as the manuscript is submitted for review at an early stage in the research process, other researchers can contribute to improving the protocol or rationale of a proposed study, thus ensuring a sound study design and more reliable results (Chambers, 2015).

In taking this publication approach, the author hopes to ensure as well as demonstrate a clean, transparent, responsible conduct of research.

7. General Discussion

The general aim of the present thesis was threefold: First, to establish whether participants experience emotions during a VWM task, which are induced by the task itself; second, if this was the case, to explore how these incidentally induced emotions are related to VWM; and third, to consider further factors, which may affect the link between these emotions and VWM performance during a VWM task. To this end, three consecutive studies were designed and carried out, as well as a registered report proposed.

In a first qualitative study, participants emotional experiences, which were induced because of engaging in the continuous color-report task, were obtained and categorized. The results showed that participants experienced mostly achievement emotions, which varied on the between-person as well as on the within-person level. Further, in Studies 2 and 3 results showed that these task-induced achievement emotions were systematically linked with VWM performance. Specifically, positive achievement emotions, such as joy, were positively linked with VWM performance, whereas negative achievement emotions, such as anger, related negatively to VWM performance. This held true on the between-person and on the within-

person level. Based on the findings of the research presented here, a fourth prospective study in terms of a registered report was introduced.

In the following, the results of the present research are summarized and discussed in light of relevant theories. Further, limitations as well as implications and directions for future research are debated. In closing, a final conclusion regarding the present research is provided.

7.1 Visual Working Memory Tasks Induce Achievement Emotions

Previous research has hinted towards the possibility that (predominantly negative) emotions occur during lab-based cognitive performance tasks (Luck, 2014; Rouder et al., 2008). However, these assumptions have not been empirically tested so far.

Qualitative results from Study 1 demonstrated that participants indeed experienced emotions during a VWM task. However, even though negative emotions were mentioned more frequently than positive emotions, participants experienced various different discrete emotions, such as anger, frustration and joy. By comparison, boredom was reported less frequently. This is an important finding of Study 1 in and of itself: While researchers in this field seemed to have been concerned with participants' boredom, the results obtained here indicate that this seems to be less problematic than previously assumed, at least for the continuous color-report task examined here.

The findings showed further that participants' emotional experiences not only varied on the between-person level, in that some experienced more anger and others more joy, but also on the within-person level, indicating that participants experienced different emotions while performing the VWM task, for instance switching from joy, to anger, to frustration, and back to joy again during the course of one experimental block.

Results from Study 1 also indicated that the emotions experienced by participants when engaging in the continuous color-report task could be categorized predominantly as

achievement emotions (Pekrun et al., 2017b), as participants' think aloud utterances revealed that they were extremely aware of the achievement characteristics of the VWM task (i.e. recalling the correct color versus failing to do so): Even though participants were not provided with any performance feedback and thus had no way of knowing for sure if they were doing well or poorly on the VWM task, they seemed to have a good sense of their task achievement, as they often referred to their success rate.

When realizing that the continuous color-report task has such strong task-inherent achievement requirements, which triggered achievement emotions in the large majority of participants, it seems helpful to consider Pekrun's (2006) control-value theory of achievement emotions to better understand the possible underlying processes of emotion elicitation during VWM task performance. In this theory, Pekrun proposes that individuals vary in their emotional experiences depending on their appraisals concerning the achievement activity and its outcome, in terms of subjective control appraisals (which correspond with judgments of whether one can succeed at the task) and subjective value (which correspond with judgments of how important it is to succeed on the task; see Chapter 2.1.1). More specifically, Pekrun (2006, 2018) proposes that control appraisals determine the valence of emotions (e.g. enjoyment or pride in case of high control, anger, frustration or anxiety in case of low control), and value appraisals boost the emotional intensity (stronger with higher value). As such, the present findings imply that as long as participants truly commit to the task – i.e. they accept that selecting the correct color is important, and continually monitor their own performance by judging whether or not they think they got it right – both negative and positive achievement emotions are bound to occur during the task. Yet, this also implies that participants will vary in the levels of task-induced achievement emotions, depending on how much importance they attach to selecting the correct color, and how successful they sense they are at doing so.

Even though the present research yielded valuable new findings in this field, the results should be interpreted with caution due to some limitations. Findings from this study were extracted from the qualitative data by allocating participants' statements to categories which were derived by the author. Even though a systematic approach to textual analysis was chosen by using qualitative content analysis (Mayring, 2014) and the category system reached substantial intercoder agreement, textual analysis remains a subjective procedure. Future research should replicate and extend the findings from Study 1, for instance by using alternative qualitative analysis techniques.

Further, findings were obtained using the think aloud method, where participants were asked to verbalize any feelings or thoughts they had during the VWM task. Even though this procedure has been used successfully in previous research (e.g. Jaspers et al., 2004; van Gog et al., 2005; Wegner & Gold, 1995), this method relies upon participants to be able to register what they are thinking and feeling on a meta-cognitive level and to translate these complex internal processes into words for a third party to understand. Some participants seemed to struggle with this in that they did not verbalize any emotional experiences. Further, some participants found it challenging to perform the continuous color-report task and describe internal processes at the same time. Thus, these participants referred to the think aloud method as a source for certain emotional experiences. Great care was taken not to categorize emotional experiences, which were triggered by the think aloud method. However, some participants may have not been able to distinguish between emotions experienced because of the think aloud method and emotions experienced because of the VWM task. Further research using less invasive methods would be valuable to expand upon these findings. For instance, participants could be asked to report in retrospect, rather than simultaneously, their thoughts and feelings about the VWM task, or non-verbal methods such as facial expressions, or

measures of physiological arousal during task execution (e.g. galvanic skin response, heart rate) could be used to measure participants' emotional experiences.

Despite these limitations, Study 1 yielded first empirical evidence that participants experience many discrete emotions, predominantly achievement emotions, which are triggered by the VWM task itself. In doing so, this study showed that it can be fruitful to adopt alternative methodological approaches, such as a qualitative approach, in a field, which is dominated by clear quantitative, experimental approaches, in order to gain new insights into the research subject of interest.

7.2 Task Emotions and Visual Working Memory Performance are Systematically Linked

The second goal of the present research was to quantify the links between task-induced emotions and performance. The findings consistently implied that there are positive links between pleasant emotions and VWM performance, and negative links between unpleasant emotions and VWM performance. Importantly, the results demonstrate that this holds true both on the inter-individual as well as on the intra-individual level. These findings are in line with previous research demonstrating that positive emotions are associated with enhanced working memory performance (Brose et al., 2014) and negative affect with decreased performance (Figueira et al., 2017).

It is worth mentioning that pride, which was assessed deliberately despite it not being explicitly referred to by the participants during Study 1, was found to be moderately related to VWM performance on the within-person level, not, however, on the between-person level. Put differently, participants who experienced more pride did not differ from participants who experienced less pride in terms of performance on the VWM task. However, when an individual participant felt proud during the VWM task, they performed well on that particular

block compared to when they were feeling less proud (and vice versa: when a participant was doing well on a particular block, they experienced more pride in that moment). Further research is needed as to why pride seems to be relevant only on the within-person level. However, this result demonstrates the importance of adopting between-person as well as within-person analyses when investigating the role of intra-individual phenomena such as (achievement) emotions in VWM research, as results from one approach cannot simply be generalized to the other (e.g. Murayama et al., 2017). Depending on the research question of interest, this finding on the within-person level may be relevant when briefing participants in regards to the VWM task in order to reduce the effect of certain achievement emotions, such as pride, on VWM and to obtain more valid VWM estimates. Future research may want to investigate this further.

The results from Study 2 and Study 3 are correlational and as such do not allow to draw any causal implications. In line with claims and corresponding findings from field studies in applied academic contexts (e.g. Pekrun et al., 2017b), it may be assumed that emotions and performance are linked through reciprocal causation, meaning that both causal directions exist. Thus, on the one hand, doing well on the task causes participants to experience joy, but on the other hand, enjoying the task also leads to participants doing well, as it boosts their task motivation and willingness to invest effort, and focuses their attention on the task.

As in Study 1, participants in Study 2 and Study 3 were not provided with any feedback on their task achievement, so they did not know for certain how well or how poorly they were doing. However, participants seemed to have a good sense of their task achievement, as they often commented on their overall success rate and subjective success at individual trials in Study 1. Further, in Study 2, results showed the better participants scored, the more they reported enjoying the task, and the poorer they performed, the more they reported anger, frustration, and boredom. Study 3 further confirmed that those emotion/performance links

also emerged on the intra-individual level. Here, the variation in emotional experiences described above systematically aligned with variation of performance across the experimental block: the better the participants did at a certain point within the experimental block, the better they felt at this moment, while when they performed more poorly, negative emotions were aroused within them. In turn, assuming reciprocal causation, this correlative pattern also implies that the better participants felt during task execution, the higher they performed.

It is likely that such reciprocal causation between task performance and task emotions should result, in case of task success, in upward spirals, and in the case of task failure, in downward spirals. Specifically, those participants who truly have higher capacity may quickly get a subjective feeling of doing well on the task, which makes them joyous. In turn, this task enjoyment boosts their sense of challenge and opportunity to perform during the task, and as a result, they do even better at it. In contrast, those participants who have lower capacity will quickly get a subjective feeling of doing poorly on the task, which makes them angry and frustrated. This anger and frustration will undermine their task performance. At best, they will keep trying, complying with the task requirement asking them to recall the correct color. However, they may also, for the sake of emotion regulation (cf. Gross, 2002), re-appraise the situation and decide that doing well on the task is not so important for them. This then may result in decreased task commitment, which further undermines performance.

There is an important implication of these possible reciprocally spiraling emotion-performance links which seem to be initiated during classical VWM tasks, such as the continuous color-report task (or even during cognitive tasks in general), due to their strong task-inherent achievement requirement. Thus-obtained capacity scores may possibly be dually biased due to the emotional processes just described: They are positively biased, the higher the true capacity, and negatively biased, the lower the true capacity, thus resulting in an overestimation of inter-individual variability in task performance (Vogel & Awh, 2008). This

may not be the case for every participant, as individuals may vary in responding to the task-inherent achievement requirements, that is, in how much they value solving the task correctly. Future research may follow up on this notion implied by the findings presented here by systematically exploring the emotional responses of low versus high achievers in VWM and how this influences VWM performance (see also Fukuda et al., 2010; Luck & Vogel, 2013).

Further, the subjective feeling of how one is doing on the VWM seems to play a distinguished role in the relationship between participants' achievement emotions and VWM performance and also should be investigated further, as proposed in the registered report presented in Chapter 6.

In sum, the present results provide substantial evidence to confirm hints in the VWM literature about incidentally induced emotions being systematically linked with VWM performance. This may be worth considering not only in future VWM research but in lab-based cognitive research in general.

7.3 Large Array Sizes Increase Negative Task Emotions and Decrease Positive Task Emotions

A further key finding of the present research was that emotional processes involved in performing a VWM task were influenced by task difficulty. The variation of set sizes is a common practice by many researchers who use the continuous color-report task, and the findings suggest that the emotions induced by varying set sizes seem to be a confound that has not yet been sufficiently considered. Rouder et al. (2008) speculated that some participants may be intimidated by the harder trials, which in turn may harm their VWM performance. Study 3 is the first to provide evidence that participants experience more positive emotions and less negative emotions for smaller compared to larger set sizes.

Again, control-value theory (Pekrun, 2006, 2018) provides the theoretical underpinning for explaining this finding: with larger set sizes, the participants' control over succeeding at the task decreases. Given that a set size of eight clearly exceeds the VWM capacity of a large proportion of participants, their chances of remembering the correct color are low, and thus their subjective appraisals of whether they can succeed at the task are bound to be poor. As a result, negative achievement emotions emerge. In contrast, easier trials (e.g. set size four) are appraised by the participants as more controllable, resulting in more pleasant task emotions. A key implication of Study 3 is thus that the task emotions affected by set size represent an essential potential confound in any study that seeks to explore any effects of set size in the context of VWM research.

Therefore, future research should further explore the role of task difficulty in the relationship between task-induced achievement emotions and VWM performance, as proposed also in the registered report presented in Chapter 6.

7.4 Further Directions for Future Research

The present thesis generalized well established findings from the field of educational psychology (specifically achievement emotion research) to VWM research. In doing so, the research presented here generated important findings for future VWM research specifically, but also for research in other domains that for instance involve laboratory-based measurement paradigms.

An important finding obtained from the studies presented here is the relevance of task-induced achievement emotions as potentially confounding variables for interpreting VWM scores as resulting from typical laboratory-based paradigms for measuring VWM capacity. Thus, achievement emotions are likely to pose a potential threat to the validity of the VWM performance scores. If these deliberations hold true, one implication would be that new VWM

tasks would need to be developed in which the task-inherent achievement requirement is lower, therefore assessing the cognitive capacity more incidentally. This way the obtained results would not be distorted by any achievement emotions triggered by the task itself. One key characteristic of such a task would be that the participants are not even aware that they are engaged in a task which they can get right or wrong. This may be achieved by a "cover story" presented to the participants in advance, where they are distracted from the achievement characteristics of the VWM task.

Moreover, some studies have reported to "stress accuracy" before participants commenced with the VWM task (e.g. Zhang & Luck, 2008). It is likely that the achievement component of the VWM is enhanced by doing so. Based on the findings obtained in the present thesis, this is likely to trigger achievement emotions in participants and in turn affect their VWM performance. Future research may want to compare participants VWM estimates between conditions where accuracy was stressed and where accuracy was not stressed in order to establish how this "intervention" specifically affects the emotion/performance links. In any case, researchers may want to refrain from stressing accuracy in the future and, as suggested above, distract participants from the task-inherent achievement requirement of the VWM task in order to reduce any effects of incidentally induced achievement emotions on VWM performance.

Further, it may be fruitful to take another qualitative approach specifically as to why some participants were especially satisfied or dissatisfied with the VWM task design and what emotions they experienced here. This way, potential triggers of the VWM for achievement emotions can be identified and possibly eliminated. For instance, few participants in Study 1 noticed that the color wheel rotated randomly in each trial. This is common practice when adopting the continuous color-report task in order to reduce any influence of spatial memory (Zhang & Luck, 2008). However, this seemed to agitate some participants. It is possibly that

this factor reduced their sense of control over doing well on the task, which triggered (more) negative achievement emotions. Future research may want to weigh the effect of spatial memory on VWM performance against the effect of achievement emotions on VWM performance to make an informed decision as to whether the color-wheel can stay fixed.

In the studies presented here, the continuous color-report task was used as the measurement tool to assess VWM. As mentioned in Chapter 2.2.2, there are many other measurement paradigms adopted in VWM research and future research may want to establish, whether the findings obtained for the continuous color-report task here also hold true for other VWM measurement paradigms. For instance, the change detection task (e.g. Luck & Vogel, 1997) is also a commonly used measurement paradigm in VWM research, in which participants are required to recall a previously shown sample array and compare it to a test array. Participants then need to judge, whether the test array was identical to the previously shown sample array, which they can either get right or wrong. Thus they need to recall the entire array previously presented to them and there is a 50% chance of succeeding at this or, put differently, a 50% chance of failing. Therefore, it is likely that the change detection-task may trigger participants' achievement emotions more than the continuous color-report task does: If a participant performing the continuous color-report task cannot recall the exact color of the probed item but thinks they can remember the approximate shade and can therefore take a good guess, this still may be categorized as a success by the participant (i.e. it was some sort of shade of red, but definitely not green, blue or yellow). In the change detection task however, participants can either remember the sample array or not. There is a higher chance of failing. This characteristic of the change detection task may enhance the achievement requirement of the measurement paradigm in comparison to the continuous color-report task. In keeping with control value theory (Pekrun, 2006, 2018), this may reduce participants' feeling of control thus leading them to experience more negative achievement

emotions. Future research may want to explore this possibility. In doing so, one VWM measurement paradigm may prove to be more adequate in terms of reducing the tasks achievement requirements, therefore reducing the risk of incidentally induced achievement emotions distorting the VWM estimates.

As proposed in the registered report outlined above (see Chapter 6), future research should consider other variables in the relationship between achievement emotions and VWM performance. For instance, achievement goals are thought to be tightly linked with achievement emotions and have both been shown to influence academic performance (Pekrun et al., 2009). Further, research has found that achievement goals affect working memory (Crouzevialle & Butera, 2013; Avery & Smillie, 2013; Linnenbrink et al., 1999; Avery et al., 2013). However, this research is scarce. Further, there is currently no research on the potentially combined effects of both goal orientations and discrete achievement emotions on VWM performance but also, little is known as to the role of trait approach versus avoidance performance goals specifically and VWM. Looking into these research gaps may provide substantial findings for both achievement goal and VWM research.

Further aspects, which future research may want to investigate, are the possible strategies participants use in order to enhance their performance on the task. When classifying participants' thoughts in regards to their emotional experiences in Study 1, it became apparent that some participants hinted towards using certain strategies in order to enhance their performance on the VWM task such as grouping (Morey, 2019) and ensemble representations (e.g. Brady & Alvarez, 2015; Liesefeld et al., 2019). Also, what seemed to be a significant number of participants referred to internally repeating the colors of the items presented to them in the sample array, in order to recall the colors better. This strategy of verbalizing the colors is known in VWM research (e.g. Souza & Skóra, 2017). It does, however, raise the question, if VWM measurement paradigms only assess VWM, or if the verbal component of

working memory is also involved, as participants internally repeat the colors presented to them. As the strategies to enhance VWM performance were not the focus of the research presented here, these hints towards the strategies employed in this task were not investigated further. However, this incidental finding may be interesting to explore in more detail in future research.

As is mostly the case in psychological, laboratory-based research, the samples used in the studies presented here were mostly comprised of (psychology) students. Even though these overall homogenous samples still varied considerably in their emotional experiences on the between-person and within-person level, other groups may show different emotional patterns or emotion/performance links. For instance, achievement emotions were the most commonly experienced emotions mentioned by the participants during Study 1. However, this may be because students are regularly faced with achievement situations, thus being more sensitive to achievement requirements of a task (even when they are not in the foreground), which trigger achievement emotions in them. Further, students may be, as a group, more achievement orientated than other groups and may therefore strive to do well even on a task, which is not personally relevant to them. In keeping with Pekrun's (2006, 2018) control value theory student samples may value the (alleged) achievement situations more in general, thus boosting the intensity of their negative as well as positive achievement emotions, in comparison to non-student samples. Other groups may perceive the VWM task less as an achievement situation and more as a situation in which one can train their memory, for example, which may trigger mainly epistemic emotions (Brun, et al., 2008; Pekrun et al., 2017a; Pekrun & Stephens, 2012). Future research may want to explore this. Nevertheless, achievement emotions should still be considered potential confounds in future VWM research, as researchers at universities rely mainly on student samples for their studies.

Finally, the findings presented here also may be of interest for future research in educational psychology as well as applied education, as achievement emotions as well as VWM play an important role in educational settings: Achievement emotions have been shown to affect academic performance (Pekrun et al., 2017b), whereas VWM has been shown to relate to cognitive functions important for learning and academic performance, such as language comprehension, problem solving, fluid intelligence and processing speed (Daneman & Merikle, 1996; Epelboim & Suppes, 2001; Fukuda et al., 2010; Johnson et al., 2013). The findings from the current thesis demonstrate that achievement emotions affect VWM, and vice versa. Future research may want to establish the role of the achievement emotion/VWM performance links in learning outcomes and academic achievement. For instance, as deliberated above, negative achievement emotions may undermine participants VWM performance, especially if these participants have a lower VWM capacity, thus leading to poorer learning outcomes. Designing a learning environment where negative achievement emotions are reduced may enable students to use their full VWM potential, thus resulting in better academic performance. This may prove relevant for mental arithmetic, for example: VWM is required to maintain the information needed for these calculation skills (Imbo & LeFevre, 2010). In contrast, purposely facilitating positive achievement emotions in combination with exercising VWM also may positively influence learning outcomes. Future research should investigate these suggestions and test, which methods may be appropriate here in order to support learners in maximizing their performance.

7.5 Overall Conclusion

In the present thesis, the author acknowledged previous speculations that tasks designed to measure cognitive abilities, for instance VWM, may incidentally trigger certain emotions in participants, which in turn may affect the measurement outcomes. There is substantial

evidence that task-induced emotions and performance are correlated in academic settings. However, this link so far has not been shown for task-induced emotions and VWM performance in a laboratory setting.

In a three-study mixed-method approach, well-established findings from the field of educational psychology were generalized to VWM research. The results from these studies showed that the continuous color-report task, a commonly used paradigm in the field to assess VWM, induced an array of discrete emotions, which related to the achievement nature of the task itself, and, in turn, were linked to VWM performance both on the between-person as well as on the within-person level.

To the author's knowledge the role of task-induced emotions in VWM performance has not been established before. The findings obtained in the current thesis highlight the relevance of achievement emotions as a potentially confounding variable for interpreting an individual's VWM ability. At the most general level, these findings may also serve to alert the broader cognitive-experimental community that even in a controlled environment such as the laboratory, participants react to tasks emotionally and that this emotional reaction needs to be taken into consideration when interpreting task performance. As researchers, we would like participants to be more like machines sometimes, so we can examine their "hardware" most accurately. However, it seems that human functioning is more complex than that and we need to account for this in our research designs.

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Appendix 1: Transcription Guidelines

Information on Transcription of "Think Aloud" Protocols

- Use "P:" or "R:", respectively, to indicate that the participant/researcher is talking
- Transcribe verbatim, except when the participant recites colors. Summarize this by adding the following to the transcription: "recites colors"
- Pauses in participants' monologues are not noted
- Fillers such as "erm" do not need to be transcribed
- Include non-verbal utterances, such as laughing or coughing, in brackets and in italics
- Replace names of people, towns or any other such information with "XYZ"

Appendix 2: Booklet of paper-pencil Questionnaires for Study 3

Dear Participant,

Thank you for participating in this study. Before we start, we would like to ask you to give us some details about yourself:

How old are you? _____

What is your gender?
O male O female O other

Are you color blind?
O yes O no O I don't know.

Are you currently wearing any glasses or contact lenses?
O No, I don't require any visual aid.
O No, I am not wearing glasses or contact lenses, even though I normally do require visual aid.
O Yes, I am wearing glasses or contact lenses.

Thank you!

Now you can start the task on the computer. The task will take approx. 30 minutes. If you have any questions during the task, please don't hesitate to ask the experimenter. At the beginning, you will have the chance to practice the task in a short practice block. Please follow the instructions presented to you on the computer screen.
Now you can start the practice block. After you have finished the practice block, let the experimenter know.

Now you can start the actual block of the study. When you are ready, follow the instructions on the computer screen and hit the scroll wheel of the computer mouse to start the task. Let the experimenter know when you have finished.

Q1

How are you currently feeling?

	strongly disagree	disagree	partly agree	agree	strongly agree
I am enjoying the task.	O	O	O	O	O
I feel proud.	O	O	O	O	O
I feel angry.	O	O	O	O	O
I am frustrated.	O	O	O	O	O
I feel bored.	O	O	O	O	O

Now you can continue the task on the computer by hitting the scroll wheel of the mouse.

Q2

How are you currently feeling?

	strongly disagree	disagree	partly agree	agree	strongly agree
I am enjoying the task.	O	O	O	O	O
I feel proud.	O	O	O	O	O
I feel angry.	O	O	O	O	O
I am frustrated.	O	O	O	O	O
I feel bored.	O	O	O	O	O

Now you can continue the task on the computer by hitting the scroll wheel of the mouse.

Q3

How are you currently feeling?

	strongly disagree	disagree	partly agree	agree	strongly agree
I am enjoying the task.	O	O	O	O	O
I feel proud.	O	O	O	O	O
I feel angry.	O	O	O	O	O
I am frustrated.	O	O	O	O	O
I feel bored.	O	O	O	O	O

Now you can continue the task on the computer by hitting the scroll wheel of the mouse.

Q4

How are you currently feeling?

	strongly disagree	disagree	partly agree	agree	strongly agree
I am enjoying the task.	O	O	O	O	O
I feel proud.	O	O	O	O	O
I feel angry.	O	O	O	O	O
I am frustrated.	O	O	O	O	O
I feel bored.	O	O	O	O	O

Now you can continue the task on the computer by hitting the scroll wheel of the mouse.

Q5

How are you currently feeling?

	strongly disagree	disagree	partly agree	agree	strongly agree
I am enjoying the task.	O	O	O	O	O
I feel proud.	O	O	O	O	O
I feel angry.	O	O	O	O	O
I am frustrated.	O	O	O	O	O
I feel bored.	O	O	O	O	O

Now you can continue the task on the computer by hitting the scroll wheel of the mouse.

Q6

How are you currently feeling?

	strongly disagree	disagree	partly agree	agree	strongly agree
I am enjoying the task.	O	O	O	O	O
I feel proud.	O	O	O	O	O
I feel angry.	O	O	O	O	O
I am frustrated.	O	O	O	O	O
I feel bored.	O	O	O	O	O

Now you can continue the task on the computer by hitting the scroll wheel of the mouse.

Q7

How are you currently feeling?

	strongly disagree	disagree	partly agree	agree	strongly agree
I am enjoying the task.	O	O	O	O	O
I feel proud.	O	O	O	O	O
I feel angry.	O	O	O	O	O
I am frustrated.	O	O	O	O	O
I feel bored.	O	O	O	O	O

Now you can continue the task on the computer by hitting the scroll wheel of the mouse.

Q8

How are you currently feeling?

	strongly disagree	disagree	partly agree	agree	strongly agree
I am enjoying the task.	O	O	O	O	O
I feel proud.	O	O	O	O	O
I feel angry.	O	O	O	O	O
I am frustrated.	O	O	O	O	O
I feel bored.	O	O	O	O	O

Please indicate to the experimenter that you have finished answering these questions. Thank you for participating in this study.

Appendix 3: Booklet of paper-pencil Questionnaires for Registered Report

(Booklet example starting with retrospective measurement only)

Dear Participant,

Thank you for participating in the second half of our study. Before we start, please note down the code you already used for the online-questionnaire so we can match your answers with today's task (your mother's first name, the day (date) of your father's birthday, and the last two letters of your father's first name, e.g. your mother's name is Maria, your father's name is Peter and he was born on 02 June: MA02ER). Your personal code: _____

Next we need to know whether you are wearing any glasses or contact lenses:
O No, I don't require any visual aid.
O No, I am not wearing glasses or contact lenses, even though I normally do require visual aid.
O Yes, I am wearing glasses or contact lenses.

Now you can start the task on the computer. The task will take approx. 45 minutes. If you have any questions during the task, please don't hesitate to ask the experimenter. At the beginning, you will have the chance to practice the task in a short practice block. Please follow the instructions presented to you on the computer screen. Now you can start the practice block. After you have finished the practice block, let the experimenter know.

Now to the first block of today's experiment.

When you are ready, follow the instructions on the computer screen and hit the scroll wheel of the computer mouse to start the task. Let the experimenter know when you have finished.

When looking back across the entire last block: how well did you do at the task?

very poorly	poorly	moderately	well	very well
O	O	O	O	O

How were you feeling during the task?

	strongly disagree	disagree	partly agree	agree	strongly agree
I enjoyed the task.	O	O	O	O	O
I felt proud.	O	O	O	O	O
I felt angry.	O	O	O	O	O
I was frustrated.	O	O	O	O	O
I felt bored.	O	O	O	O	O
I felt ashamed.	O	O	O	O	O

Signal to the experimenter when you have finished filling in this questionnaire.

Now to the second block of today's experiment. From time to time, we will be asking you to respond to some questions. To do so, follow the instructions shown on the computer screen.

When you are ready, hit the scroll wheel of the computer mouse to start the task.

Q1

How well are you currently doing at this task?

very poorly	poorly	moderately	well	very well
O	O	O	O	O

How are you currently feeling?

	strongly disagree	disagree	partly agree	agree	strongly agree
I am enjoying the task.	O	O	O	O	O
I feel proud.	O	O	O	O	O
I feel angry.	O	O	O	O	O
I am frustrated.	O	O	O	O	O
I feel bored.	O	O	O	O	O
I feel ashamed.	O	O	O	O	O

Now you can continue the task on the computer by hitting the scroll wheel of the mouse.

Q2

How well are you currently doing at this task?

very poorly	poorly	moderately	well	very well
O	O	O	O	O

How are you currently feeling?

	strongly disagree	disagree	partly agree	agree	strongly agree
I am enjoying the task.	O	O	O	O	O
I feel proud.	O	O	O	O	O
I feel angry.	O	O	O	O	O
I am frustrated.	O	O	O	O	O
I feel bored.	O	O	O	O	O
I feel ashamed.	O	O	O	O	O

Now you can continue the task on the computer by hitting the scroll wheel of the mouse.

Q3

How well are you currently doing at this task?

very poorly	poorly	moderately	well	very well
O	O	O	O	O

How are you currently feeling?

	strongly disagree	disagree	partly agree	agree	strongly agree
I am enjoying the task.	O	O	O	O	O
I feel proud.	O	O	O	O	O
I feel angry.	O	O	O	O	O
I am frustrated.	O	O	O	O	O
I feel bored.	O	O	O	O	O
I feel ashamed.	O	O	O	O	O

Now you can continue the task on the computer by hitting the scroll wheel of the mouse.

Q4

How well are you currently doing at this task?

very poorly	poorly	moderately	well	very well
O	O	O	O	O

How are you currently feeling?

	strongly disagree	disagree	partly agree	agree	strongly agree
I am enjoying the task.	O	O	O	O	O
I feel proud.	O	O	O	O	O
I feel angry.	O	O	O	O	O
I am frustrated.	O	O	O	O	O
I feel bored.	O	O	O	O	O
I feel ashamed.	O	O	O	O	O

Now you can continue the task on the computer by hitting the scroll wheel of the mouse.

Q5

How well are you currently doing at this task?

very poorly	poorly	moderately	well	very well
O	O	O	O	O

How are you currently feeling?

	strongly disagree	disagree	partly agree	agree	strongly agree
I am enjoying the task.	O	O	O	O	O
I feel proud.	O	O	O	O	O
I feel angry.	O	O	O	O	O
I am frustrated.	O	O	O	O	O
I feel bored.	O	O	O	O	O
I feel ashamed.	O	O	O	O	O

Now you can continue the task on the computer by hitting the scroll wheel of the mouse.

Q6

How well are you currently doing at this task?

very poorly	poorly	moderately	well	very well
O	O	O	O	O

How are you currently feeling?

	strongly disagree	disagree	partly agree	agree	strongly agree
I am enjoying the task.	O	O	O	O	O
I feel proud.	O	O	O	O	O
I feel angry.	O	O	O	O	O
I am frustrated.	O	O	O	O	O
I feel bored.	O	O	O	O	O
I feel ashamed.	O	O	O	O	O

Now you can continue the task on the computer by hitting the scroll wheel of the mouse.

Q7

How well are you currently doing at this task?

very poorly	poorly	moderately	well	very well
O	O	O	O	O

How are you currently feeling?

	strongly disagree	disagree	partly agree	agree	strongly agree
I am enjoying the task.	O	O	O	O	O
I feel proud.	O	O	O	O	O
I feel angry.	O	O	O	O	O
I am frustrated.	O	O	O	O	O
I feel bored.	O	O	O	O	O
I feel ashamed.	O	O	O	O	O

Now you can continue the task on the computer by hitting the scroll wheel of the mouse.

Q8

How well are you currently doing at this task?

very poorly	poorly	moderately	well	very well
O	O	O	O	O

How are you currently feeling?

	strongly disagree	disagree	partly agree	agree	strongly agree
I am enjoying the task.	O	O	O	O	O
I feel proud.	O	O	O	O	O
I feel angry.	O	O	O	O	O
I am frustrated.	O	O	O	O	O
I feel bored.	O	O	O	O	O
I feel ashamed.	O	O	O	O	O

Please indicate to the experimenter that you have finished answering these questions.

When looking back across the entire last block: how well did you do at the task?

very poorly	poorly	moderately	well	very well
O	O	O	O	O

How were you feeling during the task?

	strongly disagree	disagree	partly agree	agree	strongly agree
I enjoyed the task.	O	O	O	O	O
I felt proud.	O	O	O	O	O
I felt angry.	O	O	O	O	O
I was frustrated.	O	O	O	O	O
I felt bored.	O	O	O	O	O
I felt ashamed.	O	O	O	O	O

Please turn to the next page.

Have you ever taken part in this kind of memory experiment at a university before?

O Yes.

O No.

O I'm not sure.

This is the end of the experiment. Thank you very much for participating in our study!

Appendix 4: Adapted Version of the Achievement Goal Questionnaire Revised

Adapted performance goal items of the AGQ-R (Elliot & Murayama, 2008). Responses will be given on a five-point Likert type scale ranging from *strongly disagree* to *strongly agree*.

Adapted performance-approach goal items:

- My aim is to perform well relative to others.
- I am striving to do well compared to others.
- My goal is to perform better than others.

Adapted performance-avoidance goal items:

- My aim is to avoid doing worse than others.
- I am striving to avoid performing worse than others.
- My goal is to avoid performing poorly compared to others.

Versicherung an Eides statt

Versicherung an Eides statt

(gemäß § 8 Abs. 2 Nr. 4 Promotionsordnung für die Fakultäten 09, 10, 11, 12 und 13 (2016) vom 15. September 2016)

Name, Vorname(n): *Laybourn, Sara*

Hiermit versichere ich an Eides statt, dass die Dissertation

„ Emotions in the Laboratory:
Task-induced Achievement Emotions and their Link with Visual Working Memory Performance"

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Holzkirchen, 16.03.2021, Sara Laybourn

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