# THE INFLUENCE OF MONETARY REWARDS ON PERFORMANCE AND ATTENTIONAL EFFORT MOBILIZATION IN A VISUAL SELECTIVE ATTENTION TASK

## Dissertation

zur Erlangung des akademischen Grades eines
Doktors der Naturwissenschaften (Dr. rer. nat.)

an der

Universität Konstanz

Mathematisch-naturwissenschaftliche Sektion
Fachbereich Psychologie

vorgelegt von
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im Mai 2011

Tag der mündlichen Prüfung: 10. Oktober 2011

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# Danksagung

Viele Personen haben mich während der Entstehung dieser Arbeit inhaltlich und persönlich unterstützt. Ihnen möchte ich an dieser Stelle meinen aufrichtigen Dank aussprechen:

An erster Stelle danke ich Herrn Prof. Dr. Ronald Hübner für die persönliche Betreuung dieser Arbeit und für die fachliche Unterstützung während der vielen Jahre in denen ich mit ihm zusammenarbeiten durfte.

Danken möchte ich außerdem Herrn PD Dr. Marco Steinhauser für die Übernahme der Zweitbegutachtung.

Desweiteren danke ich meiner Familie und meinen Freunden für ihre Ermutigung und Unterstützung während der Anfertigung dieser Arbeit.

# Zusammenfassung

Intuitiv gehen viele Menschen davon aus, dass das Inaussichtstellen von Belohnungen in Form von Geld ein adäquates Mittel darstellt um andere zu besserer Leistung zu motivieren. Im Gegensatz dazu zeigen jedoch Analysen, die den Effekt von Belohnungen in Form von Geld auf das Verhalten untersuchen, durch die Bank gemischte Effekte: Belohnungen verbessern zwar oft die Leistung, genau so oft verschlechtern sie diese jedoch auch. Das häufigste Resultat ist jedoch, dass diese Belohnungen schlichtweg keinen messbaren Effekt haben. Neuere Theorien versuchen diese gemischten Effekte dadurch zu erklären dass eine Vielzahl von Mediatoren auf die Beziehung zwischen Belohnung und Anstrengung einerseits und Anstrengung und Leistung andererseits einwirken. Zum besseren Verständnis werden die wichtigsten dieser Mediatoren aufgezählt und ihre Wirkung beschrieben. Anschließend werden exemplarisch einige neuere Studien vorgestellt die zum Ziel hatten das Zusammenspiel zwischen Motivation und Kognition zu untersuchen. Alle diese Studien zeigen eine Modulation des Verhaltens durch monetäre Leistungsanreize. Eine Frage die diese Studien jedoch meistens nicht beantworten können, ist ob die monetären Belohnungen auch die Leistung steigern, und wenn ja, über welchen Mechanismus diese Leistungssteigerung erreicht wird. Außerdem benutzen diese Studien durchgehend sehr hohe Belohnungen. Im Anbetracht der vorhergehenden Diskussion der Mediatoren stellt sich die Frage, ob nicht auch geringere Beträge eine ähnliche Wirkung erzielen, vorausgesetzt die verschiedenen Mediatoren sind adäquat eingestellt. Zur Untersuchung dieser Fragen werden 3 Studien durchgeführt. Studie I ist als Pilotstudie zu verstehen die der Determinierung der optimalen Methodik zur Untersuchung der Fragestellung dient. Studie II bestätigt dass bereits geringe Geldbeträge zur Leistungssteigerung führen können, und dass diese Leistungssteigerung über eine Verbesserung der Qualität der sensorischen Kodierung der Stimuli erreicht wird. In Studie III werden hauptsächlich zwei wichtige Mediatoren der Beziehung zwischen Belohnung, Anstrengung und Leistung untersucht, nämlich die Anordnung der Response-Deadlines sowie der Aspekt des Verhaltens der belohnt wird. Es zeigt sich dass eine absteigende Deadline-Reihenfolge zur größten Leistungssteigerung führt. Im Hinblick auf die belohnte Dimension des Verhaltens zeigt sich, dass es Menschen leichter fällt ihre Reaktionsgeschwindigkeit zu kontrollieren als ihre Genauigkeit, und entsprechend eine stärkere Leistungssteigerung zu erwarten ist wenn Langsamkeit stärker bestraft wird als Fehler zu begehen.

# Summary

Intuitively, most people assume that offering monetary rewards is a good way to motivate others to increase their performance. In contrast to this assumption, however, in analyses that examine the effects of monetary rewards on behavior, mixed results turn up: Although rewards do indeed often increase performance, they also decrease performance just as often. The most common result, however, is that these rewards simply do not have any measurable effect at all. Newer theories attempt to explain these mixed findings by stating that a host of mediators influence the relations between rewards and effort on the one hand and effort and performance on the other hand. For the sake of comprehension, the most important of these mediators are named and their effects are described. Following this, a bunch of newer studies that deal with the interactions between motivation and cognition is summarized. All of these studies report a modulation of behavior by monetary rewards. However, one question that these studies do not answer is whether monetary rewards also increase performance, and if so, by which mechanism they do so. Furthermore, almost all of these studies use very high rewards. Given the previous discussion of the various mediators the question arises if smaller rewards are capable of producing similar results, given that the various mediators are adjusted adequately. In order to investigate these questions, 3 studies are conducted. Study I is to be regarded as a pilot study that serves to determine the optimal methodology for the examination of these issues. Study II confirms that even small rewards are capable of increasing performance, and that this increase in performance is moderated by an increase in the quality of the sensory coding of the stimuli. In Study III, the main focus is on two important mediators of the relations between rewards, effort, and performance, namely, the ordering of the response deadlines and the rewarded aspect of behavior. As it turns out, a descending deadline order produces the largest increase in performance. Regarding the rewarded dimension of behavior, it turns out that it is easier for people to control their response speed rather than their accuracy, and consequently, a larger increase in performance is to be expected if slowness is punished harder than committing errors.

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# List of Abbreviations

In den Abbildungen und Tabellen dieser Arbeit finden die folgenden Abkürzungen Verwendung:

ACC = anterior cingulate cortex

ACh = acetylcholine

BF = basal forebrain

DLPFC = dorsolateral prefrontal cortex

EEA = environment of evolutionary adaptedness

FCE = flanker congruency effect

fMRI = functional magnetic resonance imaging

FPPFC = fronto-polar prefrontal cortex

LVF = left visual field

NAC = nucleus accumbens

OFC = orbito-frontal cortex

PFC = prefrontal cortex

RVF = right visual field

SATF = speed-accuracy tradeoff function

SPCN = sustained posterior contralateral negativity

VMPFC = ventromedial prefrontal cortex

VTA = ventral tegmental area

WM = working memory

# I.

# General Introduction

It is a common practice to offer rewards in order to motivate people to try harder and achieve better results in whatever domain: companies offer bonuses to their CEOs, bosses offer pay raises to their employees, parents offer candy or money to their children to motivate them to try to get good grades. Thus, it seems to be common knowledge that rewards are an effective way to motivate people to increase effort, and in turn, improve their performance. The most common form of reward offered is money – at least in the area of work and in laboratory research. Almost everybody seems to intuitively believe that money should be a highly effective motivator. The mechanism which is assumed to underly this positive effect is straightforward (and similar for any form of reward): money is supposed to be valued positively, and thus induce a motivation to perform the relevant task in order to gain it. This motivation is reflected in an increased effort, as compared to a situation where no money is offered. This increased effort ultimately pays off in an improved performance. However, as I will discuss later, this mechanism is vastly oversimplified and simply not valid for the majority of cases, despite its intuitive appeal. Contrary to popular belief, evidence for positive effects of monetary rewards is surprisingly sparse. However, this lack of evidence is probably due to a severe disregard for the contextual factors that mediate the effects of rewards on effort and performance. As I will show, there are sound reasons to expect postive effects of monetary rewards, given that sufficient attention is given to the relevant mediators.

As there is a certain level of confusion in the literature concerning the use of the terms incentive and reward, a brief clarification of what these terms refer to in the context of the present work is in order at this point. *Incentive* refers to a reward that has been announced to the potential recipient in some way (regardless of how complete his knowledge of the properties of that reward are), but has not yet been delivered. Hence, an incentive is a potential reward. Thus, 'incentive' refers rather to reward expectancy. *Reward*, on the other hand, refers only to rewards that have already been delivered, that is, to reward outcome. Notice that the only conceptual difference lies in time: before it has been delivered, the outcome of a behavior is called an incentive, but once it has been delivered, it becomes a reward (see figure I-1). Still, it is important to distinguish between these two concepts as it makes a large difference to an organism in its natural environment whether a reward has or has not been delivered yet. Consequently, largely overlapping - but not completely identical - psychological mechanisms and brain circuits are engaged (Breiter, Aharon, Kahneman, Dale, & Shizgal, 2001). Notice also that whereas a reward is by definition always positive (Schultz, 2007; the only exception being conceptualizing punishments as negative rewards), an incentive can also be negative. This is the case when a behavior aims at avoiding negative consequences of behavior, instead of seeking positive ones. For example, avoiding monetary loss constitutes a negative incentive.

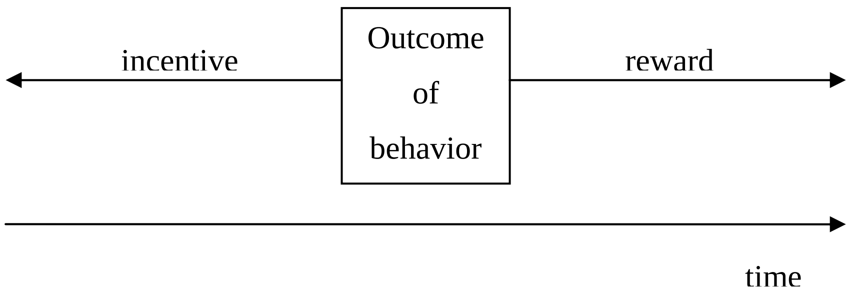


**Figure I-1** Relationship between incentives and rewards (see text for details)

These distinctions notwithstanding, for the sake of convenience, I will refer to both incentives and rewards simply as ‘rewards’, as the distinction is of no great significance in the context of this work. As incentives can be conceptualized as ‘potential rewards’, this simplification is justified. In the context of repeated decision making as it is employed in the present work, the distinction between incentives and rewards becomes blurred anyway. Furthermore, for the kind of behavioral (as opposed to neuroscientific) investigations which are the focus of the present work, that distinction plays only a minor role.

The remainder of this introduction is organized as follows: First, I will provide an overview and a summary of the existing literature on the effects of rewards on behavior. The most important of these mediators will then be discussed. They are organized into four broad categories: person variables (e.g., self-efficacy, skill level, reward responsiveness), environmental variables (e.g., time pressure, feedback), task variables (e.g., task complexity, intrinsic attractiveness), and reward variables (e.g., reward magnitude, framing as bonus or penalty, type of reward). Following this primer, I will discuss theories that attempt to explain how rewards can influence behavior. The focus will be on monetary rewards, as these are the most commonly used rewards in real life as well as in the laboratory (at least for human subjects). As it is my conviction that no behavior can be understood fully if it is not viewed in the larger evolutionary context, I will also briefly present an evolutionary psychological perspective. Furthermore, I will also briefly discuss the neural pathways that are assumed to moderate the effects of rewards on behavior, as a considerable amount of understanding can be gained from such a discussion. Finally, the reader will be introduced to the rationale and the hypotheses guiding my experiments presented in this work.

## I. 1 Review of the literature on rewards and performance

Searching the common databases for studies concerned with the effects of monetary rewards on performance yields a vast number of studies. It is beyond the scope of this dissertation to discuss them all, but to lay the foundation for an understanding of the experiments in the present work, it is necessary to consider what has been done before in this research area. Fortunately, there are some comprehensive summaries available that distill the findings from these studies. In the following, these summaries will be discussed in order to provide an overview of the current state of the art of the research on rewards and performance.

### I.1.1 Camerer and Hogarth, 1999

Perhaps the most relevant of these analyses is the one done by Camerer and Hogarth (Camerer & Hogarth, 1999). In their review of 74 studies, which included all studies known to the authors that reported substantially varying reward levels (that is, in a given experiment, participants received either zero, low, or high performance-based rewards), the following regularities emerged: first and foremost, the effect of rewards is not always positive. That is, rewards do not generally improve performance. There are studies that report beneficial effects, but at the same time, there are also studies that report the opposite. Maybe surprisingly, however, it turns out that the most common effect of rewards is that they do not have any measurable effect at all (especially in tasks that involve bargaining, market trading, or risky choices), apart from decreasing the variance in the data (see also Smith & Walker, 1993), especially when rewards are increased from a moderate to a high level. The authors attribute this surprising result to several factors: first, participants usually volunteer for participation in an experiment. Thus, their intrinsic motivation is supposed to be so high that additional rewards add little. Second, the match between the nature of the task and the effort invested by the participant is an important factor that determines the effects of rewards on performance (see the discussion of mediators below). When the task is either extremely simple or extremely difficult, effort does not pay off well in terms of mean performance.

According to the authors, the effects of rewards depend on the nature of the task (is an increase in effort easily transformed into an increase in performance?), the match between the abilities of the participants and those required in the task (or the ‘capital’ of the participants and the ‘production’ requirements of the task, to use the terms of the authors), and finally also on the magnitude of the reward.

As far as the nature of the task is concerned, rewards help most frequently in tasks in which investing more effort is actually an effective way to boost performance, such as recall tasks, or simple tasks like drawing or assembling objects. They also help in judgement and decision tasks, such as probability judgements, prediction tasks, binary choices, or easy problems. However, this is also the kind of task in which rewards have most frequently been reported to have negative effects. For example, when a participant is faced with a prediction problem, and there is a simple decision formula, participants receiving high rewards tend to increase their effort. By doing this, they tend to abandon the simple decision rule, which in turn leads to a decreased performance. This illustrates the fact that there has to be a good match between the task demands or task complexity on the one hand, and the resources invested by the participant or the skill level of the participant on the other hand. When too many resources are invested, the effects on performance are negative. Likewise, when there are rewards in a task that usually can be performed by automatic processes (that is, without having to invest conscious effort), offering rewards can be damaging. This effect is reminescent of the *Yerkes-Dodson law* (Yerkes & Dodson, 1908), and of the frequently reported phenomenon of *choking under pressure* (Baumeister, 1984). All experiments in which a decrement in performance as a result of rewards was reported used judgement and decision tasks. But, as the authors state, ‘many of the studies establishing these negative effects are likely to be controversial, and the effects are often unclear for various methodological reasons’ (p. 21). I agree with that speculation. As we shall see, there is a whole bunch of mediating factors that influence the effects of rewards.

There were also a couple of studies in which it was demonstrated that rewards do affect behavior, however, there was no standard against which to measure performance, so that it is not clear whether rewards actually improved performance (for example, choosing one among two possible gambles).

One final interesting aspect of the analysis is the suggestion that rewards can compensate for learning. Indeed, there are studies available that are concerned with strategic economic games, and which report that under certain circumstances, unexperienced participants who receive rewards perform just as well as experienced participants who receive no reward (Cooper, Kagel, Lo, & Gu, 1999).

All in all, Camerer and Hogarth conclude that rewards usually do not lead to a clear-cut increase in mean performance. However, it must be emphasized that their analysis does not constitute a proper meta-analysis. That being said, it is possible that there is an increase in performance when participants are offered rewards, but due to a lack of statistical power, the effect is hidden in the data. However, one effect that rewards undisputably have is reducing the variance in the response data, probably by priming unmotivated participants to try harder. In this way, rewards benefit the experimenter by increasing statistical power (although still a meta-analysis may be required to actually detect some of the effects of rewards). Thus, even if rewards do not affect the mean performance of a participant, they offer one possible way to conduct experiments that are both economically convenient, as well as producing high quality data with a low rate of response variance. Hence, in this view, rewards constitute yet another tool in the experimenter’s arsenal (see also Read, 2005). There is really nothing special about monetary rewards, compared to other manipulations. For example, carefully instructing participants how to optimally deal with a task can yield the same results as offering monetary rewards (Baker & Kirsch, 1991). Furthermore, as will be made clear later on, the effect of rewards strongly interacts with the effects of other person, environmental, and task variables.

Drawing on the results of Camerer and Hogarth, Rydval and Ortmann (Rydval & Ortmann, 2004) investigated the view that cognitive resources are at least as important as rewards. Examining the data of (Gneezy & Rustichini, 2000), they concluded that cognitive resources are even more important than rewards (about twice as important) in determining performance. This result again stresses the point that monetary rewards cannot be viewed as a magic bullet that every experimenter should use whenever possible, but instead only as one factor that can, but does not have to influence performance. If there are not enough or not the right cognitive resources to draw upon, monetary rewards will not increase performance. In a case like that, were the cognitive resources are deficient, building cognitive resources will be much more efficient in increasing performance.

#### I.1.2 Jenkins, Mitra, Gupta, and Shaw, 1998

As already pointed out, one weakness of the Camerer & Hogarth analysis is that they simply reviewed the results of a bunch of experiments, but did not conduct a proper meta-analysis, so that some reward effects might have passed below the radar. Luckily, there are other papers available that probe studies exactly for these hidden effects. Jenkins and his colleagues (Jenkins, Mitra, Gupta, & Shaw, 1998) looked at the effects that rewards have on two aspects of performance in a total of 39 studies: performance quantity and performance quality. Maybe a liitle surprisingly, although their analysis was conducted carefully, their results were just as mixed as those of Camerer and Hogarth.

Their general conclusion is that the effect of rewards on performance quantity is moderate at best (estimated effect size .34, covariation range between .24 and .56), with these effects being weakest in laboratory experiments, as compared to field experiments. They did not find any relationship between monetary rewards and performance quality. In contrast to the analysis by Camerer and Hogarth, they report that task type does not moderate that relationship. Given the results of other analyses and my own results, I doubt this claim. It seems questionable that, for example, a reward of a low magnitude should have the same effect in a perceptual discrimination task as in market bargaining task. However, it must be made clear that they included mainly experiments from applied areas in their analysis. One characteristic of these studies is that, unlike in laboratory studies, it is hard to detect subtle performance differences. Usually, the measures used in applied settings are not fine-grained enough to capture small increases in performance quality. In addition, Jenkins et al. based their conclusion that monetary rewards do not affect performance quality on a small sample of only 6 studies.

In contrast to task type, the theoretical framework used to interpret the results of the respective studies had a mediating effect in their analyis, presumably because it guided the design of the research.

What is missing in Jenkins & al.'s analysis is an examination of the effect of the magnitude of monetary rewards. However, they estimate that larger rewards do have a larger effect on performance than smaller rewards, thus accounting for the weak effects of rewards in laboratory settings (as the rewards used in laboratory experiments are typically rather small). The authors argue against the common claim that external rewards can substitute for intrinsic motivation, and thus decrease performance, stating that this happens only under very special conditions. Accordingly, they conclude that there is a 'generalizable positive relationship between financial incentives and performance' (p. 784).

### I.1.3 Bonner, Hastie, Sprinkle, and Young, 2000

According to the analysis of Bonner and her colleagues (Bonner, Hastie, Sprinkle, & Young, 2000), overall, financial rewards benefit performance in about 50% of all experiments included in their analysis. However, their premise is that whether rewards do or do not increase effort (and performance) is a matter of an abundance of variables within and outside of the person as well as of various task variables and the particular reward scheme employed. In their review, they particularly emphasize two variables: task type and reward scheme.

As for task type, their review reveals that as the complexity of the task increases, beneficial influences of monetary rewards on performance decrease. In a similar vein as Camerer & Hogarth (1999), they attribute this relation to the fact that effort can increase performance only if the individual is skilled in performing the task in question, so that the increased effort can readily be translated into an increased performance. That is, rewards cannot compensate for a lack of skill. They probably still increase effort, however, this increased effort is not translated into an increased performance, because the appropriate mechanism (skill or strategies) to do so is lacking. Bonner et al. define 'complexity', in terms of information-processing demands: a task is said to be the more complex the higher and the more elaborate the processing demands facing the proband. Furthermore, complex tasks usually require specific, specialized strategies that do not generalize to other tasks (for an example, consider the difference between the strategies required to win a match of chess and those required to win a match of Backgammon) and are not likely to be developed by the participants over the course of a standard experiment, which typical lasts only for about an hour or two.

Based on the results of their analysis, Bonner and her colleagues categorize common laboratory tasks into a hierarchy of complexity. Thus they provide a rough guideline that allows researchers to determine the expected impact of monetary rewards in various laboratory tasks (although it is doubtful that considering only task complexity will yield an accurate estimate of the impact of rewards, as a lot of other factors also moderate this impact). The tasks are arranged into five broad categories, in an ascending order of complexity: a) vigilance and detection (e.g., visual search, flanker task), with the key subtask being selective attention, b) memory (e.g., word list recall), with the key subtask memory search, c) production and (simple) clerical (e.g., assembling a jigsaw puzzle), with the key subtask being information integration, d) judgment and choice (e.g., probability estimates, forecasts), e) problem solving, reasoning, and (economic) game playing (e.g., iterated ultimatum game, solving equations, diagnosing diseases), with the key task being finding a solution/finding the best solution.

The findings of all of the analyses above can be summarized as follows:

1. The effects of rewards on performance are highly variable. All possible results from positive to negative and to zero effect have been reported in the literature.
2. The only consistent effect of rewards on behavior is decreasing the variance in behavior.
3. There is nothing ‘special’ about rewards. Their effect is similar to other manipulations.
4. The effect of rewards is dependent on a whole lot of contextual factors like task complexity or the participant’s skill level.
5. There are factors that exert a much more powerful influence on behavior than monetary rewards. One such factor are the cognitive resources of a participant.

## I.2 Mediating factors and their impact on effort and performance

As the discussion in the previous paragraphs revealed there are a lot of mediating factors that influence the effect of rewards on effort and performance. However, that knowledge alone is of little value. It is also necessary to describe those factors in order to be able to make accurate predictions regarding the effects of reward manipulations. In a follow-up paper, Bonner & Sprinkle (2002) provide helpful insights concerning this issue. They group these mediating factors into four broad categories: person variables, task variables, environmental variables, and reward scheme variables. In the following, I will describe not only the mediators identified by Bonner and Sprinkle, but also some of those identified by other authors. Still, I will keep the categorization scheme of Bonner and Sprinkle, as it is a handy one. Note, however, that the following description is necessarily incomplete, because of the sheer number of mediators.

### I.2.1 Person variables

Person variables are defined by Bonner & Sprinkle as 'attributes that a person possesses prior to performing a task, such as knowledge content, knowledge organization, abilities, confidence, cognitive style, instrinsic motivation, cultural values, and risk preferences' (Bonner & Sprinkle, 2002, p. 312). Some of the most important person variables and their influence on effort and performance are described in the following.

#### *I.2.1.1 Skill level*

One of the most important variables – if not the most important - in this category is the individual skill level of a person regarding a given task. As skill is related to many aspects of performance, it is one of the most eminent mediators of the relationship between rewards, effort and performance. Specifically, if a person's skill level is too low to perform a task adequately, the increased effort that should be induced by the presence of rewards does not translate into an enhanced performance, as skill is the most important link by which effort is translated into performance. If that link is weak, however, even the highest rewards will not affect performance, although the person may demonstrate a considerable increase in effort. There is empirical evidence to confirm this line of reasoning. For example, Awashti and Pratt

(1990) demonstrated that participants performing a decision task under performance-contingent rewards consistently exhibited more effort than participants who received only a flatrate payment. However, only those participants that were highly skilled in the task actually increased their performance relative to the control group. In more complex tasks, the effect of rewards increases over time, as the individual gets more skilled at the task (Sprinkle, 2000). That is, the increased effort can be transformed more and more efficiently into an increased performance to the same degree as the individual builds his or her skills. Furthermore, for simple tasks that do not require a high skill level to be performed well, or for which individuals already possess the necessary skill, the effect of rewards on performance is expected to be constant over time. In this case, skill level is already high enough for an increased effort to be readily translated into an increased performance.

One issue that is not fully settled yet is to what extent effort does or does not substitute for a lack of skill. It is clear, however, that these two factors cannot be complete substitutes. That is, a person has to exert some degree of effort in order for his or her skill to have an effect on performance. The question is: to what degree can a person compensate a lack of skill by exerting more effort, especially in more complex tasks? As rewards are supposed to have a direct effect only on effort, but not on performance (see the conceptual model of Bonner and Sprinkle (2002) below), resolving this question is important in order to be able to estimate the effects that rewards have in a given task.

Skill can influence the reward-effort-performance relationship in a second way. Because an individual’s perception of his or her skill at a given task is an integral component of his or her self-efficacy regarding that task (Bandura, 1997), skill influences the self-selection of individuals. This is so because an individual’s self-efficacy strongly influences his or her decision to participate in an experiment or to take on a task. A corollary of this fact is that individuals who are confident to have the necessary skill to perform well, tend to prefer a performance-contingent payment over a flatrate payment, if given the choice (Farh, Griffith, & Balkin, 1991).

#### *I.2.1.2 (Intrinsic) motivation*

One factor that clearly affects the influence of rewards on effort and performance is the intrinsic motivation of a person. A person with a high intrinsic motivation to perform a given task naturally exerts considerably more effort than a person whose intrinsic motivation is lower. Thus, as highly motivated individuals by default already exert a high degree of effort, most of the time their performance is not influenced remarkably by monetary rewards. Vecchio, for example, conducted an experiment in which students were hired to conduct surveys (Vecchio, 1982). There were two experimental groups: one group was paid a (performance-incontingent) flat rate, while the other group was paid a piece-rate in which the payment was contingent on the number of completed surveys. Furthermore, Vecchio measured the intrinsic motivation of his participants. As it turned out, performance-contingent rewards had a positive effect on performance only for those individuals who were low in intrinsic motivation.

Naturally, intrinsic motivation is higher for interesting or funny tasks than for boring tasks. In contrast to popular belief, however, the evidence for the hypothesis that external monetary rewards can decrease intrinsic motivation and performance is not unequivocal. Rather, this effect seems to occur only under specific conditions. First, a reduction of intrinsic motivation due to external rewards is supposedly limited to tasks or activities for which the intrinsic motivation is high. As boring tasks are by definition not intrinsically motivating, a reduction in intrinsic motivation can hardly occur (Deci, Koestner, & Ryan, 1999; see also Gneezy & Rustichini, 2000). However, other reviews conclude that it does not matter whether the task is boring or interesting (Jenkins, et al., 1998; Rummel & Feinberg, 1988; Tang & Hall, 1995; Wiersma, 1992). Second, not all types of external rewards are detrimental to intrinsic motivation. For example, several analyses have shown that verbal rewards (or verbal feedback) increase rather than decrease intrinsic motivation as measured by the attitude towards the task and the time spent performing the task in the absence of external rewards (e.g., Cameron & Pierce, 1994; Deci, et al., 1999; Eisenberger & Cameron, 1996). Third, at least one analysis (Eisenberger & Cameron, 1996) concludes that the reduction in intrinsic motivation is dependent on the reward scheme: according to that analysis, external rewards diminish intrinsic motivation only when the reward is delivered independent of the performance of the participant. In contrast, other analyses (Deci, et al., 1999) conclude that this reward scheme is exactly that which does not reduce intrinsic motivation, whereas performance-contingent, completion-contingent (reward is dependent on the completion of the task, for example, completion of a puzzle), or engagement contingent (reward is dependent on engagement, but not completion of the task, for example, engaging in the puzzle, but not completing it) rewards do reduce intrinsic motivation.

In conclusion, the issue of how external rewards affect intrinsic motivation and performance is controversial and far from being resolved. There are studies that show that rewards decrease intrinsic motivation, but there are also studies that show the exact opposite result. Part of the problem is that there are multiple ways to operationalize (and thus multiple ways to measure) intrinsic motivation, and sometimes these measures are in conflict with one another (Wiersma, 1992), suggesting that the concept of intrinsic motivation is still ill-defined. What is generally true, however, is that the *removal* of monetary rewards can decrease intrinsic motivation, and hence, performance (Bonner, et al., 2000). Thus, monetary rewards and instrinsic motivation clearly seem to interact rather than to substitute for each other as is sometimes hypothesized. In any case, intrinsic motivation is an important factor to keep in mind when investigating the effects of rewards on performance.

#### *I.2.1.3 Goals*

The effect that goals have on effort and performance is a vigorously investigated area. In an excellent review, Locke and Latham (Locke & Latham, 2002) summarized the ways in which goals influence performance. They identified four general ways: first, goals help directing effort and resources towards activities that are goal-relevant and away from activities that are goal-irrelevant. Second, goals can have an energizing function if they are set sufficiently high and specific, so that people invest more effort to attain them. Third, goals increase effort duration, or persistence. Last, goals promote the discovery and use of knowledge and strategies which are relevant to task-fulfillment. Furthermore, the effects of goals on performance are the stronger the more committed people are to their goals. Another interesting finding is that goals interact with self-efficacy in mediating performance. For example, people higher in self-efficacy tend to set higher goals for themselves, be more committed to goals, and develop better strategies to reach their goals.

Rewards can interact with goals in at least three ways (Bonner & Sprinkle, 2002; Locke, Shaw, Saari, & Latham, 1981): first, they can lead people to set goals that they otherwise would not set. Second, people might set more challenging goals when there are rewards for achieving them. Third, rewards can increase goal commitment. However, the reward scheme has to be adapted to the difficulty of a goal. For example, if a goal is extremely difficult and challenging, rewards should be delivered in a piece-rate scheme rather than a quota scheme (under a quota scheme, rewards are not performance-contingent until a certain level of performance has been reached), in order to have an effect on performance.

Goals do not directly influence performance, but they influence all dimensions of effort (see below): effort direction, effort duration, effort intensity, and strategy development. And their efficiency in doing so is clearly influenced by the presence of rewards as well as reward scheme variables, as the analysis of Locke and Latham revealed.

#### *I.2.1.4 Impulsiveness*

In laboratory studies, monetary rewards are usually delivered in close temporal succession to the behavior that produced them (directly after a trial, or a block, or at the end of the session). In ‘real life’, however, rewards are often delivered with a considerable temporal lag. This is especially true for behaviors that have to be exerted for a considerable amount of time (and thus require sustained attention) before they begin to yield rewards. Naturally, some people are more impulsive than others and thus prefer rewards that are delivered immediately over rewards that are delivered with a delay, even if the delayed reward is higher than the immediate one. That is because rewards become less attractive the longer the delay is that has to expire before they are delivered. This is referred to as *delay discounting*. It is usually operationalized by so-called delay discounting tasks (Ainslie, 1975; Kirby & Marakovic, 1996): people have to choose repeatedly between two rewards (usually hypothetical money) that are more or less separated temporally. For example, one could be asked to choose between 50€ in 2 days or 100€ in 2 weeks. From this data, one can then determine – for each individual – a hyperbolic function that describes when the person begins to choose the smaller but more immediate reward over the longer but delayed reward (a phenomenon known as *preference reversal*, see Kirby & Marakovic, 1995). Typically, this function is steeper for more impulsive persons (as it is for drug addicted as opposed to healthy persons, see Kirby, Petry, & Bickel, 1999), meaning that the discount rate is higher for these persons. Thus, it is reasonable to assume that a person’s impulsivity (operationalized by the discount rate) interacts with reward magnitude and the temporal proximity of the reward in determining effort and performance, so that less impulsive persons are more willing to exert effort and increase performance than more impulsive ones. To reiterate, this mediator can probably be neglected when considering laboratory studies. But of course, that does not make it a less important mediator in any way, only one that is more relevant for practical applications in the life outside of the laboratory.

### *I.2.1.5 Self-efficacy*

Although there are supposedly many factors within the personality that may affect the relations between reward, effort and performance, the most prominent among these is certainly self-efficacy. Self-efficacy is roughly defined as a person's belief in his or her ability to accomplish a given task (Bandura, 1977). The importance of this concept for the present research is reflected in the fact that a whole theory is built around it to explain how it influences effort and performance (see below). Presumably, it is a main determinant of how much effort a person generally invests. Thus, at least for tasks for which the gap between the individual skill level and task complexity is small, it is supposed to be a main determinant of performance. Furthermore, self-efficacy influences other mediators too, such as goal setting and goal commitment, as people who are more confident in their skills tend to set higher goals and to be more committed to their goals.

Self-efficacy probably mediates the relation between reards, effort and performance in the following way: at the beginning of an experiment, participants assess their self-efficacy with regard to the respective task via their perceived ability to deal with the task demands. If the gap between task complexity and their own perceived ability is large, their self-efficacy for the task will be low, and they should prefer a comfortable level of performance to the cost of expending more effort, as they should not expect that this effort would pay off in a better performance anyway. In contrast, if the gap between skill level and task complexity is small, a participant's self-efficacy should be high, and thus he or she will expend considerable effort, as he or she is confident that this will pay off in increased performance. When there are performance-contingent rewards present in the task, this person will be even more motivated to perform well, given that the rewards are high enough.

So far, my review suggests that higher self-efficacy should always have a positive effect on performance. Indeed, a meta-analysis conducted by Stajkovic and Luthans (Stajkovic & Luthans, 1998) found that a positive relation is the most common result in the literature by far. However, there are studies that actually found a decrease in performance due to higher self-efficacy. Vancouver and his colleagues (Vancouver, Thompson, Tischner, & Putka, 2002) reported that, when self-efficacy is manipulated and measured within an individual instead of between individuals, it turns out that it is detrimental to performance in an analytic game. They maintain that high self-efficacy can lead to overconfidence concerning one's personal skill level, which in turn increases the number of errors. Nevertheless, they acknowledge that self-efficacy might still be beneficial in other ways. For example, the fact that individuals with higher self-efficacy seek out more difficult goals is not affected by these results. Thus, the bottom line is that self-efficacy may not be beneficial to performance in every single regard, but overall, higher self-efficacy seems to be connected to higher performance.

#### *I.2.1.6 Reward sensitivity*

Another person variable that likely influences the impact of rewards on behavior is a person's sensitivity to rewards. Previous research has shown that one particular motivational subsystem seems to underlie reward sensitivity, namely, the *behavioral activation system* (BAS), that is supposed to guide behavior based on reward signals that are received via the dopamine system (Carver & White, 1994). Carver and White developed self-report questionnaires that are designed to assess individual BAS activation. In particular, the 'BAS drive' subscale has been proposed to be strongly related to positive affective responses to reward (Beaver et al., 2006). Empirical results generally support this proposition. For example, Engelmann and his colleagues (Engelmann, Damaraju, Padmala, & Pessoa, 2009) correlated BAS drive scores with the activation of various brain areas in response to changes in reward magnitude and found significant relations, particularly between BAS scores and various areas in the frontal lobe. Using a flanker task, van Steenbergen and his colleagues (van Steenbergen, Band, & Hommel, 2009) found out that individuals who scored high on the 'BAS drive' subscale demonstrated a strong decrease in conflict adaptation following gains. That is, the participants focused their visual attention less on the target stimulus in trial x if there had been an incongruent stimulus in the previous trial x-1 and their response on that trial had been rewarded (for a more detailed account of this study, see below). Finally, Locke and Braver (Locke & Braver, 2008) found that BAS scores correlated moderately with the percentage of trials in which a reward was obtained in the context of a continuous performance task. They also correlated this percentage with the scores on another scale that is supposed to tap into an individual's reward sensitivity, the *Generalized Reward And Punishment Expectancy Scale* (GRAPES, (Ball & Zuckerman, 1990). However, that correlation was not significant. Yet, GRAPES scores (as well as BAS scores) were correlated with state-dependent activity in various regions involved in reward processing and cognitive control, as observed via an fMRI scan.

In conclusion, overall, at least some aspects of reward sensitivity can definitely be considered important mediators of the effect of rewards on performance.

#### *I.2.1.7 Sex*

Evolutionary psychology suggests that there should be sex differences regarding decisions that involve monetary rewards. For men, social status is major determinant of reproductive success (Buss, 1989). In our Western culture, money is regarded as an indicator of social status. Therefore, men in general invest considerably more effort than women in order to get ahold of it. Furthermore, access to resources that indicate a high social status (such as money) is a source of intrasexual competition among men but not women (Daly & Wilson, 2001). But these sex differences go even further: as Ermer and her colleagues (Ermer, Cosmides, & Tooby, 2008) have demonstrated, there are pronounced sex differences in risky decision making about resources, mediated by the social surroundings. In their experiment, when men were faced with a decision problem that involved choosing between a high-risk/high-gain option and a no-risk/low-gain option, their choices varied with their perception of the social environment. If they thought that other men of equal status were observing and evaluating them, they chose the risky option significantly more often than when they thought that the men observing them had either a lower or a higher social status. Furthermore, this pattern was only observed when the decision involved a culturally valued resource (money) as opposed to a medical decision. None of these results were observed with female participants. Thus, sex clearly is a mediator of behavior and performance when it comes to rewards in the form of money.

## I.2.2 Reward variables

The definition of what is a reward variable and what is not is less clear-cut than it is the case for person variables. Reward variables include, for example, the timing of rewards, the nature of rewards, and the reward scheme.

### *I.2.2.1 Reward scheme*

Regarding the effects of the reward scheme on effort and performance, Bonner and her colleagues provide a good summary (Bonner, et al., 2000). There are generally five possible schemes that the authors discuss: flat-rate scheme, piece-rate scheme, variable-ration scheme, quota scheme, and tournament scheme. As the authors note, these reward schemes do not only differ in financial but also in nonfinancial attributes. Financial attributes concern the question of whether a person’s performance is linked to the reward globally (that is, the performance has to be above a certain performance threshold) and locally (i.e., performance on the level of each individual piece of performance, for example, a single trial in a laboratory experiment). Nonfinancial attributes concern the issues of whether a reward scheme implicitly also implements a goal, and also social aspects of reward schemes, such as whether the scheme leads to competition between various performers or not. According to the authors, financial and nonfinancial aspects of a reward scheme combine to determine its relative efficiency. The characteristics of the various rewards schemes are as follows:

With a *quota scheme*, an individual’s payment is not linked to performance before a prespecified performance-level is attained. Once the individual’s performance reaches that level, he or she is rewarded with a bonus, or he or she is allowed to continue with a piece-rate scheme (see below). Thus, under a quota scheme, an individual’s payment is linked to performance globally, but not locally. What is special about the quota scheme is that it also has a nonfinancial attribute: it implicitly assigns a goal to the performing individual, namely, reaching the pre-specified performance level. As it turns out, of all reward schemes, the quota scheme is most likely to produce positive effects of rewards on performance. The fact that it includes an implicit performance goal might well be responsible for this superiority.

A *piece-rate scheme* links an individual’s payment to his or her performance both globally as well as locally, as he or she receives payment for each individual piece of performance (this could be, for example, an assembled toy, or a correct response that is faster than a deadline). However, in contrast to a quota scheme, a piece-rate scheme does not implement a performance goal. Hence it is less likely to produce positive reward effects than a quota scheme.

A *variable ratio (or VR) scheme* can be considered a subclass of the piece-rate schemes, or a stochastic piece-rate scheme. Just like under a piece-rate scheme, the participant is rewarded on the level of individual performance units. However, under this scheme, he or she is rewarded only part of the time. For example, under a VR5 scheme, a participant would be rewarded one out of five times, on average. Consequently, the scheme is linked to performance globally, but only partially locally. It is about as likely to produce positive effects of rewards on performance as a piece-rate scheme.

Under a *tournament scheme*, only the best performer or the best performers receive a bonus, while all other participants receive a flat-rate (see below). Thus, a tournament scheme links performance to pay only globally, not locally. Just like the quota scheme, the tournament scheme has nonfinancial attributes to it. It is easy to see that it prompts a competition among the participants. As a consequence, weak performers might just give up as they do not see any chance of earning the bonus. Furthermore, uncertainty as to how other participants are performing could consume a good deal of an individual's cognitive resources, thus lowering performance. The same uncertainty could also diminish the amount of effort that is spent. On the other hand, a tournament scheme could prime participants to behave more strategically than under each of the other reward schemes. However, that presumes that the individual already has some skill in performing the task at hand. In accordance with that assumption, the authors' analysis of the effect of the tournament scheme on performance show that beneficial effects are limited to those individuals that are most skilled in the respective task. However, as the tasks employed in laboratory experiments are usually new to a participant, the skill level they bring to the table is usually low. Therefore, the tournament scheme is expected to have a lower probability of producing positive reward effects than both the quota scheme and the piece-rate scheme. This is valid with one exception: if the individuals are allowed to self-select their reward scheme, the tournament scheme is likely to attract very highly skilled individuals who are confident in their skill and their ability to win the tournament. In that case, the tournament scheme may be more likely to produce positive reward effects.

Finally, under a *flat-rate scheme*, an individual receives a fixed payment, regardless of his or her performance. Thus, performance is linked to payment neither locally nor globally, and therefore this reward scheme is expected to be the least likely to produce positive reward effects.

In their review of studies, Bonner et al. determined the number of studies in which rewards benefitted performance and in which they did not, split up for a variety of task types. In some cases, it was unclear what effects rewards had on performance, because, for example, there was no clear performance standard. Therefore, the authors additionally report a best-case scenario in which ambiguous results are interpreted as speaking in favor of a positive effect of rewards, as well as a worst-case scenario, in which they are interpreted as speaking against a positive effect. Furthermore, when positive reward effects were found, the authors determined the reward scheme that was employed. The flat-rate scheme usually did not affect performance at all, therefore it is not reported in the following. As the reward scheme closely interacts with the task type, both factors are reported together here, although of course task type belongs in the category of task variables (see below).

For vigilance and detection tasks (the least complex task type), in the best-case scenario, 83% (10 out of 12 studies) of the results speak in favor of a positive effect of rewards on performance. In the worst-case scenario, still 42% (5 out of 12) of the results are positive. However, at least the remaining studies do not report negative results. That is, for tasks within this category, the worst thing rewards can do is not affecting performance, but they don't seem to lead to a decrement in performance. As for the reward scheme, a quota scheme delivered positive results in 2 out of 3 cases, a piece-rate scheme in 5 out of 6 cases (best-case), or 3 out of 6 (worst case). All in all, for vigilance and detection tasks, rewards are beneficial for performance about 50% of the time.

When it comes to memory tasks, rewards are less effective in boosting performance: 62% of the time in the best-case scenario, and 23% of the time in the worst-case scenario. Piece-rate schemes yielded positive effects 69% of the time (best-case) or 31% of the time (worst-case). Tournament schemes were beneficial 25% (best-case) or 0% (worst-case) of the time. Again, no negative results are reported, apart from one that compared a flat-rate payment with an unpaid control condition.

For production and clerical tasks, the numbers are as follows: rewards are beneficial in 67% (best-case) or 43% (worst-case) of the studies in the sample. Quota schemes proved to be the most efficient reward scheme again: it led to positive results 85% of the time (best-case) or 54% (worst-case). Piece-rate schemes are a little less efficient, as they yielded positive reward effects in 67% of all studies (best-case) or 43% (worst-case). There were two studies that used a tournament scheme: both reported positive effects. Again, no negative effects of rewards were found.

In experiments that employed judgement and choice tasks, rewards yielded positive effects 42% of the time (best-case) or 21% (worst-case). Again, quota schemes proved effective at increasing performance: three out of four studies (best-case) or two out of four (worst-case) using quota schemes reported positive effects. Of the six studies using piece-rate schemes, only one (best-case) or in the worst-case scenario even none, reported positive effects. In contrast, tournament schemes led to positive effects of rewards four out of eight times (best case) or two out of eight times (worst case). Four studies using tasks of this category reported negative effects of rewards on performance.

For the category of the presumably most complex tasks (problem-solving, reasoning, game-playing), even in the best-case scenario, only five out of 24 studies (21%) report positive effects of rewards on performance (in the worst-case scenario, the corresponding figures are 4 out of 24, or 17%). Quota schemes yielded positive results 38% of the time, piece-rate schemes 13%, and tournament schemes 20% of the time. Five studies reported negative effects of rewards on performance.

Using a cross-classification analysis, the authors were able to confirm that the positive effects of rewards on performance are most pronounced for vigilance and detection tasks, and least pronounced for judgement, choice, problem-solving, reasoning, and game-playing tasks. Thus, as tasks become more complex, the gap between the requirements of the tasks and the skill level of the typical experimental participant becomes wider, thus attenuating the effects of rewards. Furthermore, the analysis revealed that the type of reward scheme used is significantly related to the likelihood of obtaining positive effects of rewards. When one arranges the five classes of reward schemes from most likely to yield positive results to least likely, one gets the following hierarchy (in descending order): quota scheme, piece-rate scheme/variable ratio scheme, tournament scheme, flat-rate scheme.

What is surprising about the analysis of Bonner & al., especially in the light of the findings of Camerer and Hogarth (1999) is that virtually no study in their sample reported negative effects of rewards. Those few studies that reported negative effects all used tasks from the two task categories that were judged to be the most complex. One possible explanation for this surprising result is that the magnitude of the rewards used in the studies summarized by Camerer and Hogarth was too low to yield positive effects in these tasks. For example, in a study by Arkes and colleagues (Arkes, Dawes, & Christensen, 1986), the participants had to judge whether various students would graduate with honors. For this rather complex judgement, however, they received only 0.10$ for a correct judgement. Given the findings of Gneezy and Rustichini (2000), this payment might have been too small. However, there are other studies in the sample of Bonner, et al. (2000) in which it is not as easy to make a judgement regarding the appropriateness of the reward magnitude offered to the participants, so it is not completely clear how this striking difference to the analysis of Camerer and Hogarth comes about.

#### *I.2.2.2 Timing of reward*

In the area of classical conditioning, it is a well-known fact that the timing of a reward has a major influence on its effect on learning (Lieberman, 2000): generally, the more closely in time a reward is delivered after a behavior has been executed, the stronger it influences learning. An analogue seems to hold for rewards: a reward is the more effective in influencing performance the smaller the time window between the information about the reward and the rewarded behavior. For example, Libby and Lipe (1992) investigated the effect of monetary rewards on information encoding and retrieval. One of their manipulations consisted of varying the time at which participants were informed of the reward. There were three groups: one group received only a flatrate payment (baseline group), another group was told prior to encoding that their payment would be contingent on their recall performance (encoding group). A third group received this information only after they had completed the encoding phase (recall group). The results indicated that presenting rewards before the information was encoded increased both the effort invested in encoding (as measured in number of times cycled through the four lists of items on the computer screen) compared to the other two groups, as well as recall performance compared to the baseline group. Furthermore, this measure of effort was correlated stronger with recall performance for the encoding group than for the other two groups, indicating that the rewards increased the efficiency of stimulus encoding. Presenting information about the rewards just before recall increased the effort invested in recall (as measured in mean time spent on each individual item) compared to both the baseline and the encoding groups, as well as recall performance compared to the flat-rate group. These results indicate that the timing of effort mobilization is contingent on the timing of information about rewards; effort is greatest directly after this information, as evidenced by the encoding group: they spent significantly more encoding effort than the other two groups, but less recall effort than the recall group. That is, the timing of rewards determines *when* a person invests effort.

*I.2.2.3 Framing of reward as bonus or penalty*

The term *loss aversion* was originally coined by Kahneman and Tversky (Kahneman & Tversky, 1984). It references the fact that people tend to value losses heavier than gains (by a factor of about two). That is, it makes a difference whether a reward is framed as a potential gain or as a potential loss, even if they are equal economically (both yield the same net gain/loss for the person). A natural extension of this concept is the prediction that because of loss aversion, people should prefer rewards that are framed as bonusses to rewards that are framed as losses. However, when it comes to effort investment, one would predict that people should expend more effort when rewards are framed as losses rather than bonusses, because due to loss aversion, they should be more motivated to avoid losses than to earn gains. Although compelling experimental data to support this claim is yet missing, there is preliminary evidence that could confirm it. For example, Hannan and her colleagues (Hannan, Hoffman, & Moser, 2005) investigated just this issue. However, the design of their experiment did not require their participants to actually expend effort, but only to indicate how much effort they would be willing to expend. Nevertheless, the results indicate that, on the one hand, people prefer a bonus contract over a penalty contract, yet, they are willing to expend more effort under a penalty contract than under a bonus contract. Of course, these results need to be replicated and extended, but it does not seem too bold to expect that experiments with a refined design would come to the same conclusion.

A yet open question is whether the increased effort due to loss aversion would also result in an increased performance, and if so, under which circumstances. In any case, the framing of a reward as bonus or penalty is expected to mediate the relation between rewards and effort.

*I.2.2.3 Nature of the reward*

Money as a reward has different properties than other rewards. This is corroborated by studies that compare different categories of rewards directly. The results of Heyman and Ariely (2004) demonstrate that the effort invested in a task depends on the nature of the rewards used. Presumably, the nature of the reward determines the perception of the situation. When money is used as a reward, the task situation is perceived rather as some kind of market interaction, and effort increases proportionally to the amount of monetary compensation offered. However, when non-monetary compensation such as candy is used, the situation is perceived rather as a social interaction, and effort is high and steady, irrespective of the amount of compensation. In one experiment, participants performed a simple task (repeatedly drawing a ball to a certain position on the computer screen) and were offered either a low (0.10$) or a medium (4.00$) monetary payment, a low (5 Jelly Bellies) or a medium (0.5 lb Jelly Bellies) candy payment, or no payment at all. As a result, effort (as measured by the number of times the ball was drawn to the designated area on the screen; note, however, that this measure could also be conceived of as a measure of performance) was significantly smaller in the low pay condition than in either the no pay, medium pay, or any of the candy pay conditions. Thus, clearly money evokes a particular view on the nature of the task situation, namely, as a market interaction, were effort is invested in proportion to the compensation offered. Conversely, when no payment is mentioned or (either low or medium) candy is offered as compensation, the interaction is perceived as social and the level of effort invested is decoupled from the amount of compensation. Thus, money really is a special kind of reward.

*I.2.2.5 Magnitude of the reward*

Until recently, there was (and still is, sometimes) a good deal of confusion in the scientific community regarding issues like: should compensation in laboratory experiments be tied to the participant's performance? And if so, do the rewards have to be of a certain magnitude, or do small rewards suffice to motivate the participants to do their best? Specifically, researchers in the field of economics have been strongly at odds with researchers in the field of psychology: economists presumed that people are motivated purely by their economic interest, and thus will not expend more than a minimal amount of effort lest this effort is rewarded according to his or her performance. Therefore, if a participant in an experiment receives only a flatrate payment, the results of this experiment would be flawed. Implicit in this view is that effort is regarded as something unpleasant. In contrast, psychologists argued that, as people who participate in an experiment usually volunteer for it, they should be intrinsically motivated to follow the instructions and spend effort as needed. As we shall see, both parties are partially correct, but only if important qualifications are taken into consideration.

Intuitively, almost everybody assumes that effort should be proportional to the magnitude of the offered reward. Hence, a small reward should be better than no reward at all. This is (or rather was) the standard economic view. However, a closer look at the recent literature reveals that in reality the picture looks a little different. The study of Gneezy and Rusticchini (2000) was probably the first to bring this issue to the attention of researchers. In a nutshell, the authors argue that the relation between reward magnitude and performance is not linear, at least not over the full range. They reviewed a couple of studies to corroborate their claim. In one study, participants solved a number of tasks taken from an IQ test. Regardless of their performance, all participants received 60 New Israeli Shekel (NIS) as a compensation for their participation. However, they were divided into four groups that differed in the magnitude of the reward that was offered for good performance: the first group was not offered any monetary reward, but was simply told to answer as many questions as possible. The second group was offered a small reward (10 cents of a NIS) for each item they solved correctly. The third group was offered a medium reward (1 NIS), and the fourth group a comparably large reward (3 NIS). The results are irreconcilable with the view of a linear relation between reward magnitude and performance. On average, participants solved 28.4 (first group), 23.07 (second group), 34.7 (third group) and 34.1 (fourth group) items correctly. Various other experiments yielded the same pattern of results. What these results suggest is a pronounced discontinuity between 'no reward' and 'small reward'. What is the reason for this discontinuity? The explanation offered by Gneezy and Rusticchini revolves around the notion of incomplete contracts. In brief, the assumption is that participants enter the laboratory with incomplete information on what they are supposed to do and what they will receive in return. That is, both sides of the bargain are not completely clear. In such a scenario, mentioning rewards serves as information to complete the contract. If no rewards are mentioned at all, participants perceive the situation in such a way that it is their part of the deal to perform the task reasonably well in exchange for the flatrate payment. Presumably, they adjust their level of effort and performance to the perceived magnitude of the flat-rate. However, once rewards are mentioned (regardless of their magnitude), the perception shifts. Now, the flatrate is perceived as the fee received in exchange for showing up. Performance on the task itself, however, is now perceived as being paid independent of the show-up fee. Therefore, participants adjust their effort/performance according to their perceived magnitude of the rewards. If rewards are perceived as very low, effort and/or performance will be very low too. Thus, the incomplete contracts theory explains the disconituity in the continuum of effects of reward magnitude of performance.

Heyman and Ariely (2004) further elaborated on that theory by investigating the nature of this perceptual shift. They maintain that the introduction or the mentioning of monetary rewards inevitably shifts the perception of the situation towards a monetary market/bargain perception, regardless of how people perceived the situation before the rewards were introduced. If no rewards are mentioned, the perception of the situation is that of a social market, in which people are motivated to exert effort without being paid money for it (an example would be helping a friend moving to a new house). That perception remains unaffected as long as non-monetary rewards, such as candy, are offered.

Interestingly, there is another discontinuity on the continuum of the effects of reward magnitude on performance. Several research groups (Ariely, Gneezy, Loewenstein, & Mazar, 2009; Mobbs, et al., 2009) reported that performance declines when the reward magnitude becomes exceptionally high. This phenomenon – which may seem a little paradox at first glimpse – was dubbed *choking on the money* by Mobbs and his colleagues, as an analog to the well-known phenomenon of choking under pressure (Baumeister, 1984). To understand this phenomenon, it is helpful to remember the Yerkes-Dodson law, according to which performance is best when the organism's arousal is at a medium level (Yerkes & Dodson, 1908). Rewards increase arousal, and extremely high rewards can be expected to increase arousal rather dramatically, which according to Yerkes-Dodson law should decrease performance. In agreement with this hypothesis, Ariely and his colleagues found (in an experiment conducted in India) that performance-contingent rewards that equal an average monthly payment of an Indian worker led to a performance decrement in a number of tasks (Ariely, et al., 2009). Similar results were reported by Mobbs (Mobbs, et al., 2009) using a task in which the participants of the experiments had to catch an artificial prey in a maze game. In this study, the rewards were considerably lower than in that of Ariely et al., yet the findings were similar.

In conclusion, as I said at the beginning of this paragraph, both the economist and the psychologist views on the use of rewards are correct up to a certain point: If rewards are offered, they have to be high enough to be beneficial to effort and performance, because people adjust their level of effort and performance to the magnitude of the rewards. What is ‘high enough’, however, is a completely different question. If no rewards are offered (or rather, not mentioned), participants perceive the situation rather as a social interaction, and exert a reasonable amount of effort by default. The relationship between the magnitude of the monetary reward and effort mobilization is summarized in figure I-2.

### I.2.3 Task variables

Presumably, the characteristics of a task are of enormous importance to the question of whether rewards can increase performance in that task. In fact, they are of such an eminent importance that Kahneman advanced the view that task demands are the sole determinators of the amount of attentional effort spent by a person (Kahneman, 1973). There are a lot of task variables that affect the relationships between rewards, effort, and performance: task type, the intrinsic attractiveness of the task, and task complexity, just to name a few. However, among those variables, task complexity is the most prominent. Bonner and Sprinkle (2002) define task complexity in terms of the amount of information processing that is required by the task, and the structure and clarity of the task. It is not to be confused with the sensitivity to effort. While the latter concept refers to the directness of the relationship between effort and performance, task complexity refers to the amount and quality of information processing that is required in order to perform the task.

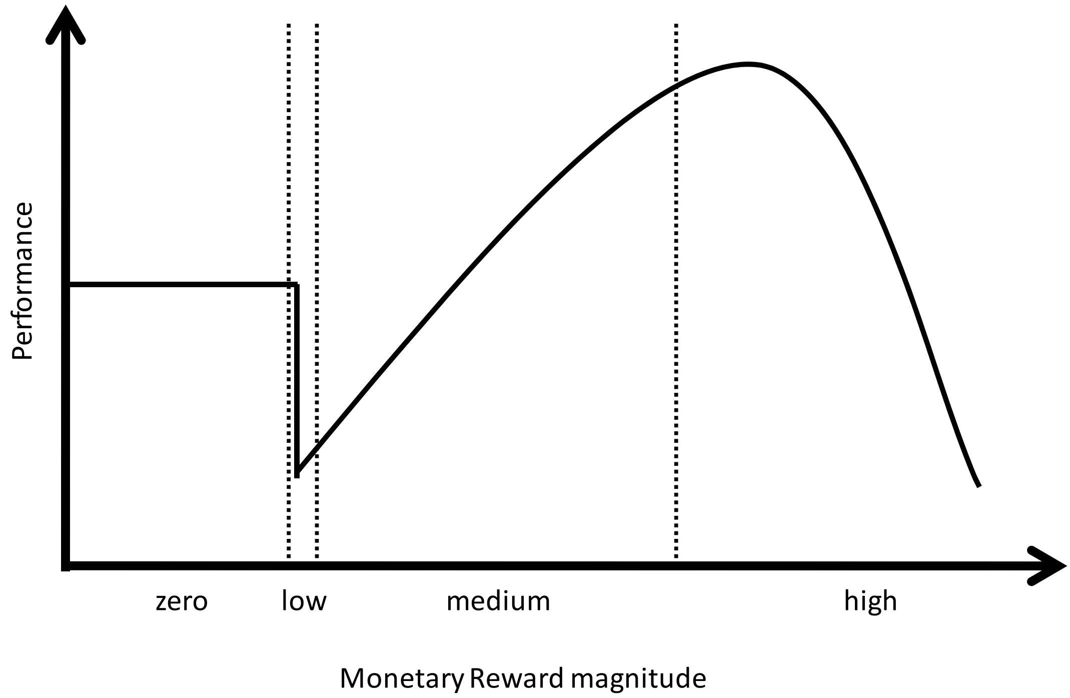


**Figure I-2** Relationship between monetary reward magnitude and performance (see text for details)

Theoretically, task complexity can affect task performance in three ways: first, because an overly complex task may appear daunting to a participant, effort duration and/or effort intensity (see below) might be reduced by an increase in task complexity. Second, since the processing requirements for complex tasks are naturally very high, effort towards strategy development – and thus learning – can be affected by task complexity. Third, individuals require a higher skill level for performing complex tasks than for performing simple tasks. Thus, if an individual is lacking an appropriate skill level, the relationship between effort and performance will be attenuated for him or her. This is particularly true for the typical short-run laboratory experiment, where the participants do not have enough time to learn and adapt to the complexity of the task.

One fact that may seem surprising is that, as task complexity – and thus effort requirements – increase, the actual effort spent by a person declines. Bonner and Sprinkle (2002) suggest a number of possible explanations for this phenomenon. Their first suggestion is derived from expected utility theory and holds that individuals assess the expected costs (effort that needs to be spent) and rewards associated with performing the task. If the costs are perceived as too high (which highly complex task should be prone to), the participant may respond by trading off a decrease in performance for a decrease in effort. In other words, he or she accepts a decrement in the performance level for the reward of a largely stress-free performance session.

The second suggestion of Bonner and Sprinkle refers to the increase in arousal that is caused by complex tasks as compared to simple tasks. As performance is typically best for medium levels of arousal (Yerkes & Dodson, 1908), performance may decline if the increase in arousal caused by task complexity is too high. Additionally, if rewards – which also increase arousal - are present simultaneously, this effect may be even more pronounced. However, since the perceived task complexity depends heavily on an individual's skill level, this relationship should be true only for low-skill individuals, or people who perceive their skill as low, or, more generally, people low in self-efficacy. Self-efficacy influences the expected benefits for good performance. However, when assessing their own self-efficacy with regard to performing a certain task, people base this assessment – among other factors – on their perception of their own skill.

The third suggestion of Bonner and Sprinkle regarding the effects of task complexity on effort and performance concerns the fit between an individual's skill level and task complexity. Typically, laboratory tasks are made up deliberately and only remotely resemble tasks in the real world. Therefore, experimental participants are likely to have a low skill level with regard to a complex laboratory task. However, if this fit is not good, effort cannot readily be translated into an increase in performance.

The overall conclusion is that, as task complexity increases, beneficial effects of rewards decrease. This is particularly true for short-run experiments in which individuals do not have the opportunity to increase their skill (and thus their self-efficacy). An increasing task complexity can thus attenuate both the relationship between rewards and effort and the relationship between effort and performance.

Othe task variables – namely task type – were already dealt with in earlier paragraphs, in particular in I.1.1 and I.2.2.1. The reader thus might want to revisit these paragraphs.

## I.2.4 Environmental variables

Environmental variables encompass, for example, time pressure, assigned goals, and feedback. Rewards in and of themselves, are an environmental variable too, but due to their relevance to the purpose of the present work, they are dealt with separately (see above). Of course, there is an infinite number of environmental variables that could potentially influence the effects of rewards on behavior. Therefore, I will focus only on two variables: one that is particularly important in the context of the present work (time pressure), and one that tends to be underestimated as a mediator (culture).

### *I.2.4.1 Time pressure*

In principle, time pressure could also be regarded as a task variable, depending on the configuration of the task. However, as it is not a general task feature, it is regarded as an environmental variable here. Time pressure can be technically defined as the difference between the time required to complete a task and the amount of time that is available (Rastegary & Landy, 1993). Time pressure can be operationalized by imposing response deadlines on the participants in an experiment. People are usually able to adapt their performance to time pressure by accepting a higher error rate for the benefit of increased response times, resulting in the typical speed-accuracy tradeoff (Wickelgren, 1977). That is, people adjust their response criterion, a process that can be simulated with formal models that successfully predict the distributions of – for example - errors and response times (e.g., Ratcliff, 1978; Ratcliff & Rouder, 1998; Usher & McClelland, 2001). Thus, as long as either accuracy but not response speed or response speed but not accuracy are rewarded, the only mediating effect of time pressure would consist of causing people to adjust their response criterion accordingly. However, that strategy becomes problematic when accuracy and speed are both rewarded, because you cannot simply trade speed for accuracy in such a setup. Thus, in this case, one has either to accept a decline in performance, or one has to mobilize additional resources (i.e., try harder). This is were rewards come into play: as we shall see below, rewards could function as a motivator to increase effort in order to deal with the task demands (Sarter, Gehring, & Kozak, 2006). In contrast, if no rewards are present, people tend to increase response speed and produce more errors than they would without time pressure (Slobounov, Fukada, Simon, Rearick, & Ray, 2000). Thus, time pressure is clearly expected to be an important factor to keep in mind when judging the effects of rewards on performance.

*I.2.4.2 Culture*

It is reasonable to assume that the values of the culture into which a person is born should influence how highly one values money, and thus, how one reacts to the presence of monetary rewards. However, to my knowledge, no study has directly investigated this question experimentally so far. It has been shown that cultural values explain a great deal of the variance in economic growth among nations (Franke, Hofsteede, & Bond, 1991), but it is yet unclear whether these values also influence how strongly people of a given culture are motivated by monetary rewards. It can only be speculated, that, for example, people living in masculine cultures in which money is regarded as a resource and an indicator of social status are more willing to work hard and take higher risks in order to get access to more money, but experimental data is needed to confirm this speculation. Nevertheless, it is at least highly probable that cultural values influence the relations between rewards, effort, and performance.

When it comes to culture, it is necessary to talk about intracultural differences, too. Although I am not aware of any data that would support this claim, it is likely that the socio-economic status of a person also influences the effects that rewards have on effort and performance. The reason for this can be understood by recurring to Brehm's (Brehm & Self, 1989) concept of *potential motivation* (see also below). According to Brehm, how much effort one actually invests (the *motivation intensity*) is not primarily determined by how much effort one would in principle be willing to invest (one's potential motivation) but rather by how much effort is really necessary. However, if the required motivation intensity exceeds one's potential motivation, effort is withheld. As people with a lower socio-economic status are by definition less wealthy than those with a higher socio-economic status, their potential motivation regarding monetary rewards should be higher, as they have a greater need for it. Consequently, their motivation intensity should be higher, too (see also Wright, 2008). Thus, one would expect people with a lower socio-economic status to invest more effort and to persist longer in the face of detrimental task manipulations when it comes to monetary rewards than people with a higher socio-economic status. However, as stated above, to my knowledge no study has directly examined this claim, yet. Still, preliminary results with hungry versus satiated subjects may provide an indication that the above hypothesis may be accurate (Biner, Hua, Kidd, & Spencer, 1991).

## I.3 A conceptual model of the effects of rewards on effort and performance

Having listed a large number of factors that mediate the effects of rewards on behavior, it is now necessary to organize them into a conceptual scheme in order to be able to understand how one can increase performance via monetary rewards.

Again, Bonner and Sprinkle (2002) developed a model that comes in handy here. According to their model (see figure I-3), monetary rewards work by increasing effort, which in turn leads to an enhancement in the dimension of task performance that is rewarded (e.g., quantity of assembled objects). However, whether rewards really do increase effort and performance in a given case or not is a different question and depends on the interplay and the specifications of the mediating factors that are depicted in figure I-3. However, although this model draws attention to the fact that there are really a lot of mediators, there is an objection against it: it is far too general to allow any more specific predictions. It merely lists mediators, but is tacit when it comes to ordering these factors and their relative influence. Does skill level exert a larger effect than self-efficacy? Does reward influence mainly the relationship between reward and effort or rather the one between effort and performance? Does skill level interact with self-efficacy to determine effort? Based only on this model, it is impossible to tell. Furthermore, although Bonner and Sprinkle distinguish between various dimensions of effort, they fail to distinguish between the effort that a person would be willing to expend and the effort that he or she actually does expend (Brehm & Self, 1989; Wright, 2008). This distinction, however, is vital when it comes to predicting behavior in the face of monetary rewards, as rewards exert their influence primarily not on the effort actually spent (the motivation intensity in the terms of Brehm), but on the effort that one would be willing to spent (the potential motivation). Of course, motivation intensity depends on potential motivation, but also on factors such as task difficulty. For example, if task difficulty exceeds a person's ability, effort is withheld (i.e., motivation intensity is low), although the potential motivation may still be high.

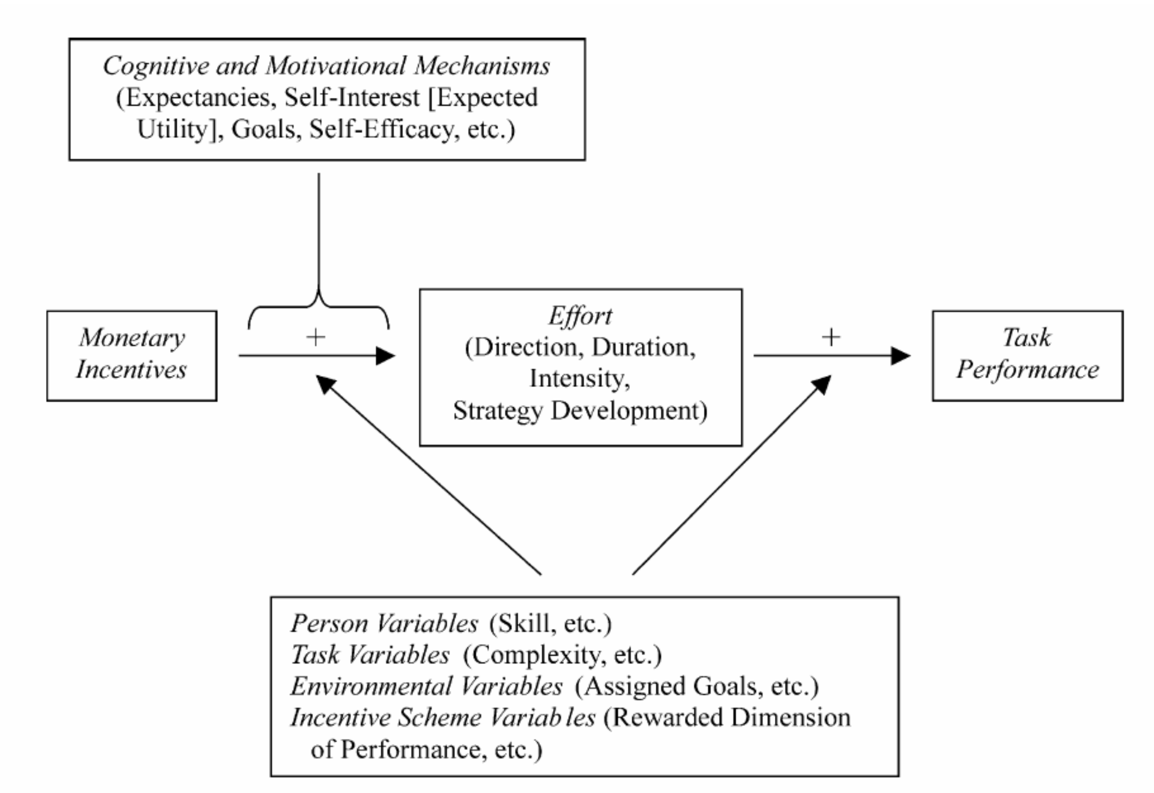


**Figure I-3** Bonner and Sprinkle's conceptual model for the effects of performance-contingent monetary rewards on effort and performance (reprinted from Bonner & Sprinkle, 2002)

However, despite the shortcomings of this model, the paper of Bonner and Sprinkle is valuable for another reason: the clarification of the various aspects of effort that could potentially be influenced by monetary rewards. The authors distinguish four different aspects: Effort direction, effort duration, effort intensity and strategy development (i.e., learning effort). The fourth aspect is different from the other three in that effort is not directed towards current performance of the task, but rather towards learning, so as to perform better in the future.

## I.3.1 Dimensions of effort

### *I.3.1.1 Effort direction*

*Effort direction* refers to the question of on which of several possible activities a person chooses to spent time. When rewards are introduced, they are presumed to push effort direction towards that task or activity that yields the largest payoff relative to the invested effort. However, this facet of effort is relevant only in more practical domains like work psychology, where phenomena like absenteeism are thought to reflect the effect of rewards on effort direction (Kanfer, 1990). In laboratory experiments, the participants usually have no alternative other than the task which they were assigned to do. However, as Bonner and Sprinkle note, a participant can always choose on which dimension of the task he or she focuses (for example, emphasizing speed over accuracy), or he or she can choose to daydream instead of focusing on the task, both of which can be considered equivalent to choosing which task to perform.

### *I.3.1.2 Effort duration*

*Effort duration* refers to the amount of time during which an individual chooses to invest resources (either cognitive or physical) to a certain task. Rewards could influence effort duration in such a way that individuals spent more time performing an activity that is rewarded. For example, in laboratory experiments, subjects could choose to perform an additional task after the original task is completed, if this additional task is rewarded, or he or she could take fewer breaks between blocks.

### *I.3.1.3 Effort intensity*

*Effort intensity* refers to the amount of cognitive resources (e.g., attention) an individual chooses to invest in a given activity within a fixed period of time. This aspect of effort is roughly similar to what Sarter and his colleagues (Sarter, et al., 2006) refer to as *attentional effort*. Presumably, the introduction of rewards prompt people to increase effort intensity on the rewarded task. The authors suggest time limits for performing a task as a good method for measuring increases in effort intensity. Increased effort intensity would then be reflected, for example, in shortened response latencies of rewarded participants compared to non-rewarded participants, while accuracy remains constant (or vice versa).

#### *I.3.1.4 Strategy development*

Finally, rewards may motivate people to increase learning effort, in order to become more proficient in performing the task at hand, so that the payoffs of the task become higher than they would be without investing learning effort. This effect of rewards on effort is called *strategy development*. In essence, it is effort directed towards skill acquisition. It involves, for example, planning, conscious problem solving, or innovation. Importantly, strategy development may decrease performance in the short run, but pay off later, when the participant's newly developed skill allows him or her to perform at a high level. According to Bonner and Sprinkle, this aspect of effort is most likely to be affected by rewards when an enhancement of more automatic mechanisms (e.g., focusing visual attention on the target item) does not suffice to reach the person's desired performance level.

### I.3.2 How do monetary rewards influence behavior?

In the last paragraph, it was described what aspects of effort can potentially be influenced by monetary rewards. The next question that needs to be answered is: how, or by what mechanism, do rewards increase these aspects of effort, and ultimately performance? A number of theories have been proposed to answer this question. Typically, these theories are relatively coarse-grained and generally lack a neuropsychological foundation, except for the theory of Sarter and his colleagues (Sarter et al., 2006). Still, the former theories are a good starting point for understanding how rewards modulate effort and performance. Again, Bonner and Sprinkle (2002) provide a good overview that is summarized in the following.

According to *Expectancy theory* (e.g., Vroom, 1964), individuals adjust the effort they invest (be it effort direction, effort intensity, or any other dimension) according to the satisfaction they expect from the outcome of the task. According to the theory, this is because people are motivated to maximize their expected satisfaction. Hence, two factors determine the effort spent on the task: first, the expected satisfaction of the reward (i.e., its attractiveness), and second, the expectancy about the relationship between effort and reward.

If this relationship is reasonably balanced or even promises a relatively high reward for relatively little effort, an individual is motivated to invest the effort.

Several predictions regarding the effect of rewards on effort and performance can be inferred from expectancy theory: first, as money has both instrumental as well as symbolic value (as an indicator of social status, for example), it is supposed to have a reasonably high attractiveness for participants, given an appropriate amount of it. Its attractiveness should be higher than that of no pay, thus effort should be higher when money is offered as pay than when there is no pay at all. However, it cannot be ruled out that non-monetary rewards have an equal or even higher attractiveness than money. Second, when payment is performance-contingent, the expectancy about actually getting the reward should be higher than under either non-performance-contingent (flatrate) rewards or no payment at all. In turn, effort and possibly performance, should be higher, too.

*Agency theory* (e.g., Eisenhardt, 1989) is the theory that used to implicitly underlie most of economic theories. It adopts a rather classical, normative view on human behavior. According to this theory, people are expected utility maximizers who are perfectly rational, and have well-defined preferences. They are motivated by nothing but self-interest, meaning their motivation aims at maximizing wealth and maximizing leisure (that is, minimizing effort). Therefore, in the view of this theory, rewards are absolutely necessary, because people are not motivated to spend effort on an activity if there is no reward to do so. There is no such concept as intrinsic motivation (the motivation to engage in an activity because doing so is rewarding in itself) in the framework of agency theory. Furthermore, in order to maximize performance, the reward should be contingent on performance. An additional assumption of this theory is that individuals are generally risk-averse. That means, if an individual cannot control the performance of an activity fully (for example, because there is some random intervening variable outside of the individual's control), he or she has to be paid a risk-premium, so as to keep the performance level constant.

Both Expectancy theory and Agency theory are oblivious to the question by which mechanism rewards actually increase effort. All they state is that monetary rewards increase the desire to perform well. However, there are other theories which are more explicit in this regard.

*Goal-setting theory* (Locke & Latham, 1990) takes a less normative view on human nature and states that the primary motivator for investing effort are personal goals, not necessarily maximizing wealth and leisure. As research indicates, setting challenging but realistic goals can indeed increase the effort invested to attain that goal (see above). Furthermore, goals seem to have an effect on effort and performance that is independent from expectancy, and thus probably mediated by different cognitive processes. Within the framework of goal-setting theory, monetary rewards can influence the effort invested in a task only via their influence on personal goals. There are several ways in which this could happen. First, when there are monetary rewards that are tied to a goal, people may choose to pursue this goal, although they would not do so if there were no such rewards. That is, monetary rewards can influence goal-setting. Second, goal-tied rewards may also drive people to adopt more challenging goals which in turn would elicit greater effort investment. Third, they may increase goal-commitment, which is known to increase the effort a person invests in reaching a goal.

*Social-cognitive* (or *self-efficacy*) *theory* (e.g., Bandura, 1991) extends the earlier theory by adding a further factor alongside expectancy (expectancy theory) and goals (goal-setting theory). Specifically, it states that the confidence of an individual regarding his or her ability to execute the actions required to successfully perform a task (that is, his or her self-efficacy) influences the effort invested in that activity to a large degree. Self-efficacy is thought to influence a whole array of emotional, cognitive, and motivational mechanisms. For example, self-efficacy influences the perception of how challenging a goal is that one sets, as well as goal commitment. For example, people who score high in self-efficacy tend to set themselves more challenging goals than people low in self-efficacy. However, the theory allows for rewards to come into play, too. Generally, rewards are expected to increase interest in a task, which should then transform into an increased effort (Bandura, 1997). This increased effort should then lead not only to an enhanced task performance, but also to an increase in the skill necessary to perform the task at hand. Presumably, this increased skill then feeds back in the form of an increased self-efficacy regarding that task.

The theories outlined above are all valuable as frameworks for understanding the relationship between rewards, effort, and performance. However, to make specific predictions regarding the influence of monetary rewards in, for example, a selective attention task like the flanker paradigm (Eriksen & Eriksen, 1974), they are located at an explanatory level that is too general. It would be more interesting to have a theory that is sound from a neuropsychological perspective and aimed at cognitive behavior. The following theories provide just that.

Kahneman and his colleagues (Kahneman, Peavler, & Onuska, 1968; Kahneman, 1973) investigated the role of rewards in a digit transformation task. In his view, attention has a limited capacity, and how much of this capacity is devoted to the execution of a task depends mainly on the demands of that task. The person performing the task can do little to increase the amount of devoted capacity. In other words, how much effort he or she invests in a task has little to do with his or her motivation to achieve a given goal, but much more so with the task demands. Furthermore, this effort varies from second to second due to momentary changes in demands. Technically, a performance goal is selected and the mental machinery then works to achieve this goal, thereby drawing on (attentional) resources as they are required in a given moment. Behaviorally, corresponding fluctuations in effort can be observed, as measured, for example, by changes in pupil dilation.

However, this conception of *attentional effort* seems to miss half the truth. As Sarter and his collegues note (Sarter et. al, 2006), whether or not further capacity is devoted to the performance of a task depends largely on the costs and benefits of maintaining a steady performance level versus letting performance deteriorate. Evolution programmed humans in such a way that they are motivated to rest when the potential rewards do not justify investing effort in an activity. Not any goal once chosen justifies its own attainment. If the investment of capacity/resources becomes too high during the process of working towards that goal, the person might well accept a deterioration of performance if the goal is of a rather small value. This could happen, for example, in experimental settings, where the cost of abondoning an assigned performance goal is rather neglible from the participant’s point of view. However, if the goal is of a reasonably high value to him, he might invest effort to keep performance at a sufficient level. Such a situation would be given in an experimental setting where the financial compensation for the participant is performance-contingent, and at the same time high enough to be of value to the participant. In such a situation, the participant would be likely to try to mobilize additional cognitive or attentional resources. This top-down modulation of cognitive mechanisms (summarized in figure I-4) would clearly be more dependent on the motivation of the participant to attain the performance goal than on the task demands. In accordance with this prediction, Pochon and his colleagues (Pochon, et al., 2002) found in their fMRI study that - as suggested by Kahneman - an increase in task demands led to an increase in activity in the dorsolateral prefrontal cortex (DLPFC), an area that is known to represent goals and rules that are important for the performance of a current task, and thus is critical for top-down control of behavior (Miller & Cohen, 2001). However, the same pattern of activity was observed when a reward was offered - in accordance with Sarter's suggestion. As Locke and Braver (Locke & Braver, 2008) suggested, reward could be maintained as a superordinate goal in the fronto-polar prefrontal cortex (FPPFC) of the brain, thereby coordinating the sub-goals and rules in the DLPFC, a process referred to as *branching* (see Koechlin, Basso, Pietrini, Panzer, & Grafman, 1999). In both cases (that is, an increase in task demands or the introduction of rewards), this mobilization of additional resources is effortful, therefore Sarter refers to it as *attentional effort.* Compared to stimuli that attract attention in a bottom-up manner by virtue of their behavioral significance, goals which participants are motivated to pursue are able to exert a top-down influence on attentional and cognitive mechanisms, thus compensating for increasing task demands such as prolonged duration of the task.

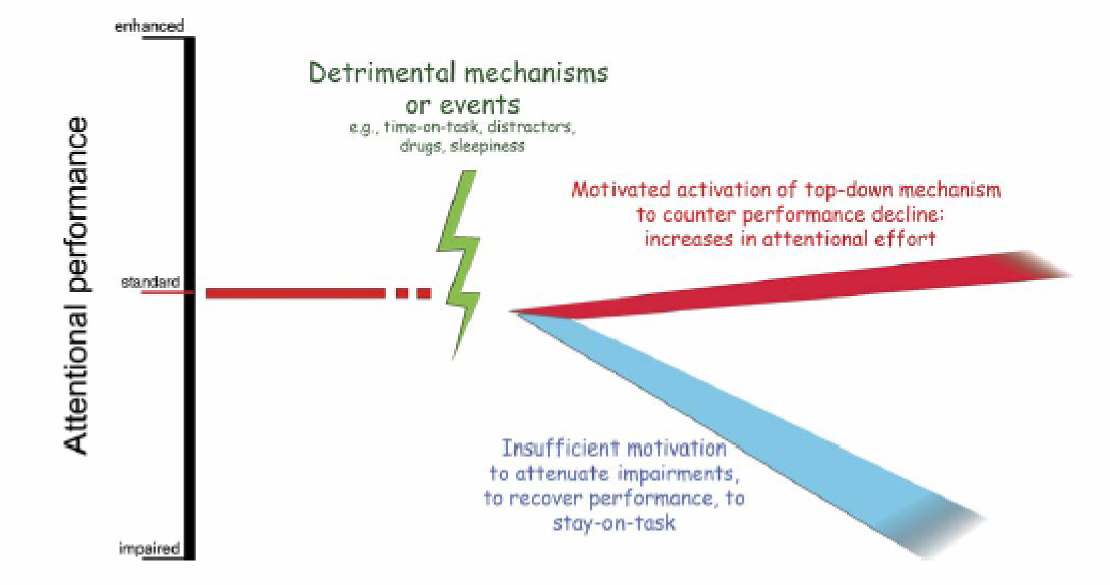


**Figure I-4** Illustration of the role of attentional effort (see text for details). Reprinted from Sarter et al. (2006)

These increases in attentional effort are probably mediated by frontoparietal circuits and their effects are numerous. They include, for example, modulations of the firing rate of sensory neurons (Engel, Fries, & Singer, 2001), activity changes in areas that process target features (O'Connor, Fukui, Pinsk, & Kastner, 2002; Serences et al., 2005), as well as attenuation of activity in areas that process non-target features (O'Connor, et al., 2002), and increases in the quality of sensory coding of stimuli in the visual cortex (which are not due simply to changes in neuronal firing rate, cf. Goard & Dan, 2009).

Neurologically, increases in attentional effort seem to be mediated by cholinergic projections that originate in the basal forebrain (BF). They innervate literally the whole brain, however, not in a diffuse manner, but in distinct bands (Zaborsky, 2002). Such an organization suggests a certain degree of specifity, so that specific areas could be activated by increasing cholinergic inputs. The PFC is special in that it – unlike other brain areas - also sends projections back to the BF. As the PFC is heavily involved in cognitive control (Miller & Cohen, 2001; Ridderinkhof, van den Wildenberg, Segalowitz, & Carter, 2004) and top-down selective attention (Corbetta & Shulman, 2002), this suggests that the PFC is responsible for increases in attentional effort, and that it does so by recruiting specific brain areas via the cholinergic projections of the BF (Sarter, Hasselmo, Bruno, & Givens, 2005). For example, an increase in cholinergic transmissions in a sensory area leads to an enhanced cortical processing of thalamic inputs to that area, thereby enhancing sensory processing, and thus, for example, detection performance (Hasselmo & McGaughy, 2004). Thus, cholinergic projections originating from the BF are an important component of PFC-mediated top-down attention.

All in all, one can describe the sequence of events that lead to an increase in attentional effort due to the presence of rewards as follows: first, a decline in performance has to be detected (in terms of, for example, errors or reward loss) by a performance-monitoring system. In the human brain, that system is most likely located in the PFC, or more specifically, in the ACC (Holroyd & Coles, 2002; Yeung, Botvinick, & Cohen, 2004), which has also been implicated in the adaptation of response strategies due to performance decrements (Holroyd & Coles, 2002). Thus, the ACC could either act as the performance monitor or as the controller, or both. In any case, it is heavily involved in the processes that are the focus here. The activity of the ACC and thus the mobilization of attentional effort is contingent on motivational manipulations such as the presence of rewards (Hajcak, Moser, Yeung, & Simons, 2005). Whenever the actual outcome of an action differs from the predicted outcome, an error signal is generated which is sent to the nucleus accumbens (NAC), a structure that has been shown to be involved in integrating motivation and changes in behavior (Robbins & Everitt, 1996), including the recruitment of resources that are necessary for an increase in attentional performance (Christakou, Robbins, & Everitt, 2004). In line with these results, the NAC projects to the BF, where it modulates the cholinergic inputs of the BF to other brain areas (Neigh, Rabenstein, Sarter, & Bruno, 2004). A similar modulatory role is played by the ventral tegmental area (VTA) (Smiley, Subramanian, & Mesulam, 1999). Thus, as already stated above, an increase in prefrontal ACh release is responsible for the top-down activation of mechanisms and brain-circuits that counteract a decline in (attentional) performance, such as the anterior attention system (Posner & Dehaene, 1994). The regional specifity of these ACh inputs, however, is not completely clear yet (Sarter, et al., 2006).

Although the details of the process that leads to increases in attentional effort due to rewards are not understood very well yet, and the above description of the process is, consequently, rather general, these findings nevertheless justify predictions that the presence of monetary rewards should have positive effects on attentional effort, and consequently also on performance.

## I.4 Linking motivation and cognition: an evolutionary psychological perspective

As should have become clear in the previous paragraphs, motivation, cognition, and attention are closely linked in the human central nervous system. However, traditionally, cognition and motivation have been treated as if they were completely distinct. Cognitive psychologists were oblivious to the obvious interactions between motivation and cognition. The decision making theories they developed were evocative of a perfectly rational human being in the sense of a Laplacean demon. However, from personal experience, everybody can tell that, for example, the decision which car to buy is never driven by rational reflection alone. In fact, a case can be made for the claim that decisions are guided primarily by emotions, not cognition (e.g., Bechara, 2004). Still, efforts to integrate motivation and cognition have begun to emerge only rather recently. One major theoretical framework that has driven these integratory efforts is Evolutionary Psychology (Buss, 2005; Cosmides & Tooby, 1994; Gaulin & McBurney, 2003). In the view of Evolutionary Psychology, motivation and cognition co-evolved, because both proved to be indispensable for the vital task of goal-directed action, thus serving the ultimate purpose of reproduction and genetic propagation. Emotions provide the organism with a kind of a ‘goal compass’, without which it would be impossible to select a goal from the infinite host of possible goals. That is because only emotions provide value, or standards, for evaluating the adequateness of goals, as they are intricately linked to what benefits our biological fitness and what does not. Conversely, cognition provides the means and mechanisms necessary to achieve that goal. To see that this is true you only have to look into the area of social decision making, such as mate choice. In this area, emotions (in the form of feelings) provide indispensable information. Presumably, they represent the output of a variety of unconscious computations regarding the value of the potential mate for one’s own reproductive success (Tooby & Cosmides, 2008). Thus, emotions assist in deciding which potential mate to charm, wheras the action sequence of charming itself depends mainly on cognition.

Stated more technically, according to the account of Evolutionary Psychology, there is a variety of internal regulatory variables in our central nervous system that constantly monitor the internal and external environment. For example, there is a regulatory variable that monitors the level of blood glucose. Once this level falls below a certain threshold, a signal is sent out that regulates the direction of behavior. This signal triggers the motivation to find something to eat, which is accompanied by the feeling of hunger. So we stop reading the newspaper and get up to get something to eat. Note that in this view, motivation and emotion are really two sides of the same coin. Gaulin and McBurney (Gaulin & McBurney, 2003) express this view explicitly when they assert that ‘emotion is the affective component of motivation’ (p. 122). But notice the priority relation: emotion is a component of motivation, not vice versa! That means that there can be motivations without emotions (such as the unconscious motivation that causes you to breathe when you have been holding your breath for a certain amount of time, whether you like it or not, which makes it impossible to commit suicide by holding your breath; another example are species that clearly do have motivations, but that are very unlikely to have emotions, such as insects for example), but no emotions without motivation. Presumably, emotions kick in when the motivational problem cannot be handled by unconscious mechanisms alone.

Within the framework of Evolutionary Psychology, the general theory of motivation is as follows: Humans evolved in the environment of evolutionary adaptedness (EEA, a statistical composite of the environmental pressures acting on humans, see Tooby & Cosmides, 2005) in such a way that they prefer objects, environments, and actions that contribute to their fitness. For example, salt was scarce, but absolutely indispensable for the survival of our ancestors. Thus, individuals that had a special craving for salt and therefore consumed more salt compared to other members of their species who did not have this craving produced more offspring. Therefore, over the course of many generations, the craving for salt became a standard in the motivational architecture of our species. The bottom line is that we evolved to like what contributes to our fitness, and as a consequence, we are motivated to approach objects and situations that contribute to our fitness, and to engage in actions that contribute to our fitness, but to avoid objects, situations and actions that are detrimental to our fitness. This is the essence of motivation. The truth of this statement can be observed in action every day: We react with positive emotions to the sight of an attractive member of the other sex and begin to engage in approach behavior, whereas we react with disgust and avoidance behavior towards, for example, putrid food.

It is now easy to see that motivation necessarily has to be closely linked to cognition. The nature of this link is different from the link between motivation and emotion, however: whereas emotion can be considered an inseperable component of motivation, cognition is conceptually distinct from the motivational system, but interacts closely with it, and probably also co-evolved with it. One reason is that the actions we carry out to meet our motivational goals used to take place in a world that is highly complex and highly dangerous. One single wrong move could have eliminated our ancestors from the gene pool. Furthermore, every action requires energy, which is usually not a big deal in the modern, western world, but was a major problem for our ancestors: had they carelessly spent their energy, they would not have survived long enough to reproduce. Because of the dangerousness of our ancestors' environment and the scarcity of energetical resources, Natural Selection favored individuals that had developed the ability to plan action sequences in advance, before carrying them out in the real world, or the ability to assess the likelihood of getting the desired object and to weigh this likelihood against the chances of being eaten or dying of exhaustion, to name only two functions of cognition. Adapting a quotation by Karl Popper, one can argue that, ultimately, cognition provides not only the architecture necessary to meet our motivational goals, but also the ability to meet them most efficiently, by allowing our hypotheses to die in our place (quoted in Dennett, 1995), an obvious and enormous advantage in the pursuit of maximum genetic reproduction. There you have the link between motivation (and emotion) and cognition.

The close interaction between motivation and cognition is further reflected in the fact that it is hard, if not impossible, to clearly differentiate between ‘affective’ and ‘cognitive’ areas of the brain (Pessoa, 2008), as has often been attempted to do in early imaging studies. ‘Affective’ regions are also involved in cognition and vice versa. This is because complex behavior is always mediated by dynamic interactions between widely distributed neuronal networks, rather than by one single, circumscribable brain region. In fact, there is strong evidence that both functions are tightly integrated in the brain, so that the distinction may be unreal both biologically and psychologically (Duncan & Barrett, 2007). For example, the amygdala, once a prototypical ‘affective’ region (Aggleton, 2000) has been repeatedly shown to be heavily involved in attention and cognition, too (Anderson & Phelps, 2001; Holland & Gallagher, 1999; Schaefer & Gray, 2007). Conversely, the PFC is a classical ‘cognitive’ area (Corbetta & Shulman, 2002; Miller & Cohen, 2001), but nevertheless, many of its subregions such as the ACC, OFC, and VMPFC are also involved in emotion (Rolls, 2005). The bottom line is that when an affectively valenced stimulus is processed, it is impossible to distinguish which contributions to the processing stem from ‘affective’ areas and which stem from ‘cognitive’ areas, because the sensory and perceptual modulation is the product of both (Pessoa, 2008). It follows that no behavior is purely ‘cognitive’ or purely ‘emotional’: it is always both. It also follows that the still prevalent function-to-brain area-mapping approach to affect and cognition is fundamentally flawed. Behavior is always a product of an interacting network of areas, in which the distinction between the influence of more emotional and more cognitive areas becomes effectively blurred by information integration in so-called hubs (brain areas with a high connectivity that integrate information from a large number of brain areas, see Sporns, Honey, & Kotter, 2007). Whereas a specific (non-hub) area might be categorized as more concerned with cognitive or more concerned with emotional aspects, the individual contribution of these areas to the information processing that drives behavior is integrated with the contributions from other areas, which makes them virtually impossible to isolate. Any functional specialization that might exist is lost at some point during processing (Gray, Braver, & Raichle, 2002).

### I.4.1 Bottom-up and top-down processing in the context of the interactions between motivation and cognition

As I tried to clarify in the previous paragraphs, motivation and cognition cannot be separated. But how does motivation (and thus valuation) enter into the cognitive system? Generally, there are two general routes: either bottom-up or top-down. Bottom-up means that information flows from lower to higher centers, beginning with sensory stimulation. The presence of an affectively valenced stimulus (or a neutral stimulus that has acquired affective value via its previous pairing with an aversive stimulus such as an electric shock) will automatically draw processing resources such as attention to itself in a bottom-up manner (e.g., Schupp et al., 2004). For example, stimuli with an erotic content draw attention to themself automatically. Conversely, top-down means that information flows from higher to lower centers. For example, a personal goal that is kept active in WM (for example, maximizing reward) will modulate incoming sensory information and can lead to an increased alottment of processing resources to stimuli and tasks that are relevant to that goal. In accordance with that, it has been demonstrated that people are better at detecting a stimulus if they know something about its properties in advance, such as the location at which it will appear (e.g., Dosher & Lu, 2000).

One particularly interesting motivator that could serve to influence behavior in a top-down manner is money. It is far too recent an invention to have become hardwired into the brain as a naturally motivating stimulus like food or sexual stimuli. Yet it is clear that it does influence motivation. It is remarkable in that it has little inherent, material value (materially, money is either a disc of metal or a slice of paper), and in that it does not satisfy any direct needs of the organism. In and of itself, it is useless. Yet everybody accepts it in exchange for any other good. So what is money? And what is the source of its motivational power?

As to the first question, Iwai (Iwai, 2001), concluding a highly formal analysis of the evolution of money states that ‘money is money simply because it is used as money by everybody in the community. Wheter it is made of a useful commodity or of a useless token, money is a pure “social entity”’ (p. 423). It is beyond the scope of this work to go into more detail here, but as a brief summary, it can be put on record that money is so persistent and widespread in human society because it is both simpler than, and superior to other economic systems such as gift exchange systems, for example. Its power as a motivator presumably derives from the fact that it is a fitness-promoting resource in so many regards: it can be exchanged for food, breeding space, and almost anything else that is beneficial to individual and kin fitness. Furthermore, its nature as a means of exchange for all kinds of resources turns it into an indicator of high fitness, especially for males (Ermer, et al., 2008): a man who is capable of amassing a lot of money proves his worth as a provider for his and his mate’s offspring. But even independent from its worth as a signal of high fitness, a person who possesses a lot of money is regarded as standing high in the social hierarchy, at least in the Western culture, regardless of whether the individual is male or female. Thus, it can be reasonably expected that in societies in which a monetary economy is dominant, almost anybody should be motivated by money, but males even more so.

#### *I.4.1.1 Bottom-up and top-down activation of motivated attention*

As I said above, there are certain categories of stimuli that are capable of attracting attention in a bottom-up manner. These tend to be stimuli that are behaviorally relevant from an evolutionary psychological perspective, such as erotica, pictures of violence (Bradley, Codispoti, Cuthbert, & Lang, 2001), food (LaBar et al., 2001), or faces (Hunt, Cooper, Hungr, & Kingstone, 2007). Typically, these stimuli lead to large late positive potentials, that are the more pronounced the more emotionally arousing the stimuli are (Schupp et al., 2000).

In a recent article, Luiz Pessoa presented a framework for understanding the way in which motivation (e.g. rewards) directs attention and executive control (Pessoa, 2009). In his so-called *dual competition model*, the core assumption is that there is competition for attentional and processing resources at both the perceptual and the executive levels, and that the competition is modulated by both positively (e.g. reward) or negatively (e.g., reward loss) motivating stimuli. A second assumption is that all areas of executive functioning (that is, inhibition, shifting, and updating, see Miyake et al., 2000) draw on common but capacity-limited mechanisms, so that if one executive function draws heavily on these resources, there are less resources left for the other functions. To reiterate, affective significance is supposed to modulate processing in two general ways: first, in a stimulus-driven (bottom-up) fashion, such as when the stimulus itself has emotional significance, for example an angry face or a neutral stimulus that has been paired previously with a negative event. Sensory representations of stimuli that are emotionally significant are enhanced in the visual cortex (Vuilleumier, 2005). These enhanced representations in turn receive a larger amount of attention, which is why executive functions are affected by emotional stimuli. The amount of emotional significance determines the nature and strength of the influence of the stimulus on behavior. Negative emotional significance, e.g. threat usually provides the clearest results. If the level of threat is relatively low, the stimulus receives priority in processing.

The second way in which affective significance modulates processing is in a state-dependent (top-down) fashion, that is, dependent on things like anxiety or motivational manipulations. Pessoa suggests that reward will lead to a sharpening of executive functions so that, for example, detection sensitivity is increased. Furthermore, reward should modulate the allocation of processing capacities of the executive functions, so reward can be maximized.

As the focus of the present work is on top-down modulation of attention due to monetary rewards, it is important to examine whether these supposed effects of rewards and motivational states on behavior can actually be observed. In recent years, a number of studies have been published that were concerned with this and similar questions. Various cognitive functions have been probed with regard to their susceptibility to top-down motivational manipulations. Because of their relevance to the present worked, they are described in a little more detail below.

*Working memory*

Pochon and his colleagues (Pochon, et al., 2002) provided the first evidence that motivational manipulations in the form of monetary rewards have a similar effect on brain activation as an increase in task demands. In their experimental design, participants were presented with rewarded and non-rewarded trials in a randomized order. The task consisted of an *n*-back task (Cohen et al., 1997) that varied in difficulty (i.e. in the number of items that have to be kept in WM). In difficult as well as in rewarded trials, the FPPFC was recruited in addition to areas that mediate WM. This is in line with the branching hypothesis as suggested by Koechlin et al. (1999). In addition, additional activation specific to the medial FPPFC was observed in rewarded trials as compared to non-rewarded trials. Furthermore, deactivation of paralimbic structures was observed as a consequence of both increased task demands and rewards. However, no increase in performance was observed in rewarded trials as compared to non-rewarded trials. Nevertheless, this study justifies the view that both an increase in task demands as well as the presence of monetary reward can induce an increase in (attentional) effort. Additionally, the FPPFC qualifies itself as a promising candidate for the integrated concertation of motivation and WM, with the medial portion being concerned primarily with the processing of value, and the lateral portion with the branching aspect of cognition. Surprisingly, the modulation of processing was not accompanied by an increase in performance. Results comparable to those of Pochon et al. were obtained by Taylor and his colleagues (Taylor et al., 2004) using a slightly different paradigm.

In contrast to Pochon et al., Locke and Braver (Locke & Braver, 2008) reported an increase in performance as a result of rewards, in terms of speed. Participants performed a task that required the maintenance of a cue in WM as well as selective attention to a probe under three reward conditions: baseline (no reward), reward, and penalty. As said before, in the reward condition, participants demonstrated an improved performance in terms of speed, but no significant differences in terms of accuracy, as compared to the other two conditions. In the penalty condition, participants showed a reduced error rate as compared to the reward condition. An interesting minor result is that participants who faced the penalty condition before the reward condition responded significantly slower in the reward condition than those participants who experienced the reward condition first. This highlights the important role that learning plays in mediating reward effects on performance. Failing to withhold a response was costly under the penalty condition, so participants who encountered that condition first learned to withhold it until sufficient information for the response had been accumulated. In contrast, participants who faced the reward condition first learned that responding quickly pays off, as rewards were awarded for high response speed in that condition.

Additionally, fMRI analyses showed an increase in sustained activity in a variety of brain regions during task performance in the reward condition. The host of these regions was also active during the baseline condition, however, activity was increased during the reward condition (probably reflecting increased cognitive control), whereas event-related activity associated with task-performance decreased during the reward condition (but nonsignificantly).

Taken together, Locke and Braver were able to demonstrate a clear positive effect of monetary rewards (but not penalties) on behavioral performance in terms of response speed as well as on sustained brain activity during task performance in a cognitive control/WM task. Remarkably, monetary penalties did not lead to an increase in performance. However, a closer look at the reward scheme reveals that it differed between the reward and penalty conditions: under the reward scheme, participants were rewarded depending on their response speed, whereas under the penalty scheme, they were rewarded for accuracy. One interpretation of this result is that response speed is easier to control than response accuracy. This interpretation is in line with the view that the evolved behavioral structure of humans favors quick responses over accurate responses, as it was often more vital in the EEA to react quickly (e.g., when it comes to flight responses).

Heitz and his colleagues (Heitz, Schrock, Payne, & Engle, 2008) found that monetary rewards increase performance in the reading span task, another WM measure (Daneman & Carpenter, 1980). Also, rewards increased effort as measured by pupil dilation. Furthermore, the increase in effort due to monetary rewards was similar for individuals with a high reading span and individuals with a low reading span, although performance differed between these two groups. Similarly, the benefit in performance due to increased effort was similar. Thus, in this case, monetary rewards did not interact with individual skill level to determine performance.

Altogether, compelling evidence has already been gathered that supports the claim that monetary rewards can and do influence WM, one of the most central mechanims of cognitive control.

*Orienting of visual attention and the breadth of visual attentional selectivity*

The earliest studies in this regard stem from Douglas Derryberry (for a review, see Derryberry, & Tucker, 1994). In several studies, he investigated the effects of motivation on visual attention by using stimuli that were differentially valenced. However, this different valence was not implemented by monetary rewards, but merely by points that could be earned, but that carried no further value (hence, symbolic rewards). Nevertheless, he found that these symbolic rewards affected the orienting of visual attention (Derryberry, 1989; Derryberry, 1993). For example, in one experiment (Derryberry 1989, Experiment 2), participants had to discriminate between a target and a non-target, both of which could either appear in a location that was positively valenced (points could be won but not lost if the participant reacted fast enough) or negatively valenced (points could be lost but not gained if the participant was too slow) in a variant of the Posner task. There were also neutral trials in which points could neither be gained nor lost. A cue that was presented before the actual trial informed the participants about which location was more likely to be targeted. After the participant's reaction, feedback concerning the performance on the respective trial was presented. The results indicated that rewards did influence behavior, but only in interaction with the feedback from the previous trial: costs in attention orientation were larger after cues that cued the negative location after positive feedback than after negative feedback, and costs were also larger after cues that cued the positive location after negative feedback than after positive feedback. Later experiments (Derryberry, 1993) indicated furthermore that the same mechanism might also influence the diameter of the zoom lens of visual selective attention (it becomes narrower after negative outcomes/feedback), and, finally, that positive rewards might be more effective than negative rewards, in contrast to what you would expect given the phenomenon of loss aversion (Kahneman & Tversky, 1984).

Although there are some methodological weaknesses to Derryberry's approach (for example, reward attainment depended only on response speed, not accuracy), his experiments nevertheless provide reasons to assume that rewards influence visual attention.

More recent studies using actual monetary rewards often investigate even more specific mechanisms, more often than not in the context of imaging studies. In a now already classic study, Small and her colleagues (Small et al., 2005) investigated the motivational effects of monetary rewards on two aspects of top-down attentional orienting (visual-spatial expectancy and spatial disengagement). The participants performed a variant of the Posner task under three different reward-conditions: depending on the condition, they could either win money, lose money, or neither win nor lose money. The behavioral data indicated that, while accuracy was unaffected by the rewards, response times were faster in the lose money-condition as compared to the neither win nor lose-condition. For the win money-condition, the same trend was observed, but this effect was not significant. As for visual-spatial expectancy, rewards speeded up only directionally cued trials (valid and invalid). Furthermore, rewards enhanced responses in areas associated with visuaospatial expectancy and also in areas that are associated with the disengagement of attention.

In a later study (Bagurdes, Mesulam, Gitelman, Weintraub, & Small, 2008) using the same paradigm it was shown that the attentional orienting of elder people suffering from mild cognitive impairment (i.e., beginning Alzheimer's disease) could be enhanced by the prospect of losing money. In contrast, healthy elder control participants reacted better towards the prospect of winning money.

In a related vein as Small et al., but focusing more on the effect of rewards on perceptual sensitivity, Engelmann and Pessoa (Engelmann & Pessoa, 2007) probed the nature of the interaction between motivation and attention. They also used a Posner task variant similar to that of Small et al., and manipulated motivation by offering the chance to win money or to avoid losing money. In order to achieve these rewards or avoid losing them, the participants had to maintain adequate levels of speed and accuracy. The detection sensitivity of the participants as measured by d' (pronounced as d-prime) increased with the magnitude of the reward offered. The authors conclude that the motivational system informs the endogenous attentional system about the magnitude of the reward, which then in turn results in a fine-tuning of attention. This fine-tuning then results in process-specific improvements, for example, in an increase in detection sensitivity. In a follow-up study (Engelmann, et al., 2009), Engelmann and his colleagues further investigated the effects of motivation on evoked brain responses, in order to disentangle these specific effects from unspecific effects like effort or arousal. Using the same task as in their previous study in a fMRI setting, they replicated their previous result that detection sensitivity increases as rewards increase. Furthermore, they observed brain-responses to rewards that were transient and cue- and target-specific. Sustained-state effects of, for example, arousal or effort, could not account for these response-modulations.

Seifert and his colleagues (Seifert, Naumann, Hewig, Hagemann, & Bartussek, 2006) studied the link between motivation and attentionally controlled conflict resolution in a flanker task. In their variant of this task, a cue was delivered before each stimulus that informed the participant about the reward valence in the respective trial. There were three reward conditions: participants could either win 20 Eurocent if they responded correctly and fast enough, or lose 20 Eurocent if they responded incorrectly or too slow. Furthermore, there was a neutral reward condition were the participants could neither win nor lose money. After their response, participants received a feedback regarding their performance and the outcome of the respective trial. The results indicated speeded responses in the negatively valenced as well as in the positively valenced reward conditions, but no significant effect of the rewards as far as error rates were concerned. Furthermore, the *flanker congruency effect* (FCE) (in terms of errors) was larger in trials were participants could win money than in neutral trials, indicating a wider zoom lens in these trials. EEG data indicated a stronger activation of the incorrect response hand in reward trials. The authors concluded that the participants responded to the motivational manipulation with a decrease in controlled processing, thereby increasing the breadth of the attentional zoom lens.

Van Steenbergen and his colleagues (van Steenbergen et al., 2009) used the flanker paradigma to investigate the effects of monetary rewards on the so-called *conflict-adaptation effect* (Gratton, Coles, & Donchin, 1992). This effect can be observed when participants are focusing stronger on the target in a given flanker trial after incongruent trials, thereby reducing the FCE in these trials as compared to trials that follow congruent trials. Van Steenbergen started from the assumption that conflict is perceived as an aversive event that subsequently triggers adjustments in the cognitive control system. Given this, he hypothesized that monetary rewards should be able to decrease these adjustments, as they represent rewarding events. If this is the case, the conflict-adaptation effect should be smaller after rewarded trials than after trials that are not rewarded. That is exactly what was found. Thus, their results are consistent with those of Seifert (Seifert, et al., 2006), as the latter research group also found that monetary rewards decrease controlled processing.

All in all, evidence is accumulating that attentional orienting and focusing mechanisms are susceptible to motivational influences generated by monetary rewards.

*Negative Priming*

Negative priming occurs, for example, when an item that had to be ignored on a given trial because it was used as a distractor becomes the target on the following trial. Using such a negative priming paradigm, Della Libera and Chelazzi (2006) found that monetary rewards increased the suppression of irrelevant information (see also Della Libera & Chelazzi, 2009). That is, after highly rewarded trials, negative priming was amplified as compared to negative priming after lowly rewarded trials. In fact, in one experiment (Della Libera & Chelazzi 2006, Experiment 1) a positive priming effect was observed after lowly rewarded trials. The authors interpret their results in terms of an increase in visual attentional selectivity. However, this interpretation might not be justified, as the results merely show that rewarding the response on trial *n* has negative effects on trial *n*+1 for the processing of information that had been irrelevant on trial *n*. A further weakness of these experiments is that rewards were not dependent on the participants' performance, but instead delivered randomly. Accordingly, it cannot be concluded safely whether reward really improves performance in such conditions, as one would expect if the attentional selectivity had really been increased. However, although they may not increase performance, clearly monetary rewards influence processing in this kind of tasks.

*Performance: Visual search*

Navalpakkam and his colleagues (Navalpakkam, Koch, & Perona, 2009) investigated the effects of rewards on target detection rate in a visual search task. In their experiment, an array of lines of which one was oriented slightly differently than all others was presented to the participants. However, they manipulated how often the target was present in the array in the first place, and noted a significant drop in detection performance when this frequency was decreased to very rare occurences of the target. Surprisingly, their results indicated that this drop in detection performance cannot be counteracted by a reward scheme that rewards target detection massively, or by a scheme that extremely punishes misses. Only when participants entered a contest among each other where the best one gained an additional 50$ did these rewards schemes have an effect. This highlights the fact that there is no such thing as a 'best' reward scheme. If anything, the reward scheme can be more or less suitable to the specific task type, reward magnitude, etc.. In this contest, the sum of each participant's gains and losses served as the criterion which decided who was the winner of the contest. Presumably then, when there was no contest, the participants weigthed the gains and losses differently, depending on the amount they had already gained or lost (Kahneman & Tversky, 1979). However, when they were in the contest, they could never be sure if their performance would be good enough, that is, whether their gains were large enough to win the contest, so they could not afford to weigh the gains and losses differently.

Altogether, then, the study of Navalpakkam et al. clearly shows an increase in performance due to monetary rewards. However, this effect was mediated by the reward scheme, as measurable effects of rewards on performance were observed only under the competition scheme.

Kiss and her colleagues (Kiss, Driver, & Eimer, 2009) investigated visual search performance in a paradigm similar to that of Navalpakkam et al.. Participants had to indicate which one of two possible features a target item in a visual search array had by pressing one of two response buttons. There were two reward levels (high and low), each corresponding to a pre-determined target color. For a response that was correct and fast enough, they received either a high or a low bonus, depending on the condition. The results indicated a speeding-up of response times in the high reward condition as compared to the low-reward condition. Error rates did not differ between the two reward conditions, so this clearly indicates an increase in performance. Furthermore, the EEG data revealed that the amplitude of the N2pc component (an indicator of the time course of attentional selection during visual search, see (Woodman & Luck, 1999) and the SPCN component (reflecting processing after attentional selection) were significantly larger in the high reward condition than in the low reward condition, indicating better attentional selection as well as better processing in the high reward condition. Also, the onset of the N2pc occured earlier in the high reward than in the low reward condition.

## I.5 Introduction to the present experiments

Summarizing the research reviewed above, one can safely state that there are clear effects of monetary rewards on behavior in a variety of domains of cognitive control. However, important gaps still remain to be addressed. First and foremost, although all the studies cited above reported a modulation of behavior, most of them leave it open to speculation whether these modulations also entail an increase in performance. Only the study of Navalpakkam et al. demonstrates a clear increase in performance after administering monetary rewards. However, they dealt with a pre-cognitive domain (signal detection).

Secondly, except for the experiments of Douglas Derryberry, in all the studies reported above, researchers offered relatively large rewards. For example, in the study of Small et al. (2005), participants could gain up to 50$. In the study of van Steenbergen et al. (2009), they could win or lose 20 cents per trial. Although it's easy to see that large rewards should be more effective than small rewards, such kind of common sense thinking is notorious for being flawed. Not many studies have varied reward size and analyzed the behavioral data, so it remains open to speculation whether small rewards could be effective enough for certain types of tasks.

Third, it would be interesting to know if it is possible to influence the zoom lens of visual attentional selectivity with monetary rewards. It is rational to assume that focusing visual attention requires effort. Given the framework provided by Sarter et al. (2006), an interesting hypothesis is to suggest that participants whose rewards are performance-contingent are more willing to invest this additional effort than participants who receive only a flatrate payment.

The goal of my work was to address these issues. In order to do so, a variant of the flanker task (Eriksen & Eriksen, 1974) was developed that included monetary rewards. In the following, the issues described above are addressed over the course of three studies. In the first study, various methodological problems will be solved. Study II will investigate whether monetary rewards are capable of increasing performance in the flanker task. As it turns out, they do. Furthermore, this study will allow suggestions regarding the question of exactly what mechanisms are responsible for the increase in performance. Finally, Study III will examine how the positive effect of monetary rewards that was observed in Study II is affected by the arrangement of the response deadlines. Furthermore, it will be probed how rewarding different aspects of performance influence the effect of rewards on performance. Finally, this study will also investigate how flexibly participants can switch between two reward schemes of which each rewards a different aspect of performance.

# II.

## Study I:

## Pilot Study: Determining the optimal methodology

## II.1 Introduction

The goal of this pilot study was to investigate if – and under what conditions - performance-contingent monetary rewards lead to an increase in performance in a visual selective attention task at all. To this end, a variant of the flanker task (Eriksen & Eriksen, 1974) was developed that included a response deadline as well as a response feedback. The response deadline was necessary in order to prevent participants from accumulating stimulus information for too long, which would result in a typical speed-accuracy trade-off where response speed is traded for a high accuracy. Although it was clear from the outset that parameters such as the length and arrangement of the response deadlines would mediate the effect of the rewards on behavior (see General Introduction), it was not entirely clear how these parameters should ideally be configured. Therefore, as you will see, some methodological adaptions will be made after the initial pilot study (Experiment 1): the main difference is that, whereas a within-subjects design was used in Experiment 1, I resorted to a between-subjects design in Experiment 2, which was necessary in order to exclude differences in the learning rate as a possible cause for the differences seen between the rewarded condition and the unrewarded condition.

## II.2 Experiment 1

Experiment 1 was designed to test the hypothesis that monetary rewards increase performance in the flanker task, a paradigm that is used to study visual selective attention. In a typical flanker task, a stimulus array consisting of 3 or more stimuli is presented to the participant. The task of the participant is to categorize the central stimulus, and to ignore the lateral stimuli. Typically, participants are faster and more accurate if the central stimulus and the lateral stimuli are mapped to the same response (congruent stimuli) than when they are mapped to different responses (incongruent stimuli). The difference in response time or accuracy between incongruent and congruent stimuli is known as the flanker congruency effect (FCE). It can serve as a measure for the diameter of the attentional zoom lens: if the FCE is small, the participant successfully ignored the lateral distractors and focused his or her attention mainly on the central stimulus. However, if the FCE is large, the lateral distractors were co-processed to a large degree together with the target stimulus, thus resulting in a response conflict that leads to more errors and prolonged response latencies. Thus, in that case, the participant's attentional zoom lens was rather relaxed, as compared to the case of a small FCE (Eriksen & St James, 1986).

The general idea of the present experiment was to have the participants perform a variant of the flanker paradigm under two conditions: a deadline condition, in which there was only a response deadline but no rewards, followed by a reward condition in which there were both rewards and a response deadline. If the hypothesis that monetary rewards increase performance in the flanker task is correct, participants should respond either faster or more accurate (or both) in the reward condition as compared to the deadline condition. As this was the first study ever to investigate this issue, a few more variables than would have been necessary were manipulated, in order to collect as much information as possible. First, the stimuli were presented lateralized, as it could have been – although this would have come rather as a surprise - possible that monetary rewards are more effective in one visual field than in the other. Second, I wanted to know whether rewards would be equally efficient for congruent and for incongruent stimuli, although this forced me to postpone the investigation of possible effects of rewards on the zoom lens of visual selective attention to a later experiment (see Study II). Third, I wanted to observe the normal learning rate in that task by having the participants complete a condition in which there was only a response deadline but no rewards before they encountered the rewards. This ordering of conditions was also motivated by previous studies in applied setting that demonstrated a marked decline in productivity following the removal of a reward scheme (Greene & Podsakoff, 1978; Rothe, 1970), thus indicating a decline in the motivation to perform the task.

## II.2.1 Method

### *II.2.1.1 Participants*

10 students of the University of Konstanz participated in this experiment (6 male, mean age 23.8). All had normal or corrected to normal vision. All participants were paid a base payment of 12€. When they got to the first block in which rewards were given, they were informed that they would have the chance to additionally gain up to 5€ depending on their performance. All participants were given a capital of 100 Euro cent.

*II.2.1.2 Apparatus*

Stimuli were presented on a 18” color-monitor with a resolution of 1280x1024 pixels and a refresh rate of 60 *Hz*. Participants responded by pressing one of two buttons of a computer mouse. Stimulus presentation as well as response registration was controlled by the same personal computer (PC).

*II.2.1.3 Stimuli*

Target items were odd and even numerals (2, 4, 6, 8, and 3, 5, 7, 9). Incongruent stimuli were constructed by using response incompatible numerals as flankers. Target and flankers were arranged horizontally at the center of the screen. Each single character extended a visual angle of 1.0° horizontally and 0.76° vertically; the spacing between the items (center to center) was 1.08° of visual angle. Stimuli were presented in white against a black background.

*II.2.1.4 Procedure*

Participants were seated at a viewing distance of 45 *cm* in front of the screen. A trial started with the presentation of a fixation cross at the center of the screen for 400 *ms*. After a cue-stimulus interval of 600 *ms,* the stimulus array appeared for 165 *ms*. The screen remained blank until the participant responded. After the response, a feedback screen appeared for 1500 *ms* (see figure II.1). After a blank screen of 1000 *ms* duration the next trial started. The course of a trial is summarized in figure II.1.

The task of the participants was to indicate whether the target numeral was odd or even by pressing a corresponding response button of the mouse with their index or middle finger of the right hand. Response errors were signaled by a short sound. The participants performed 18 blocks of 64 trials each. The experiment started off with 3 baseline blocks in which there was neither a response deadline nor monetary rewards present. Following this, there were 6 blocks in which there was a response deadline but no rewards (deadline condition). The response deadline decreased from block to block in 3 steps (starting over again with the longest deadline once the block with the shortest deaadline had been completed). Starting with a deadline of 650 *ms* in the first block (long deadline), the deadline decreased to 525 *ms* in the second block (medium deadline), and finally 450 *ms* in the third block (short deadline). After these three blocks, 6 further blocks followed that were exactly the same, except for the fact that there were rewards (reward condition) for responses that were both accurate and fast enough (see below). Finally, another 3 baseline blocks were administered.

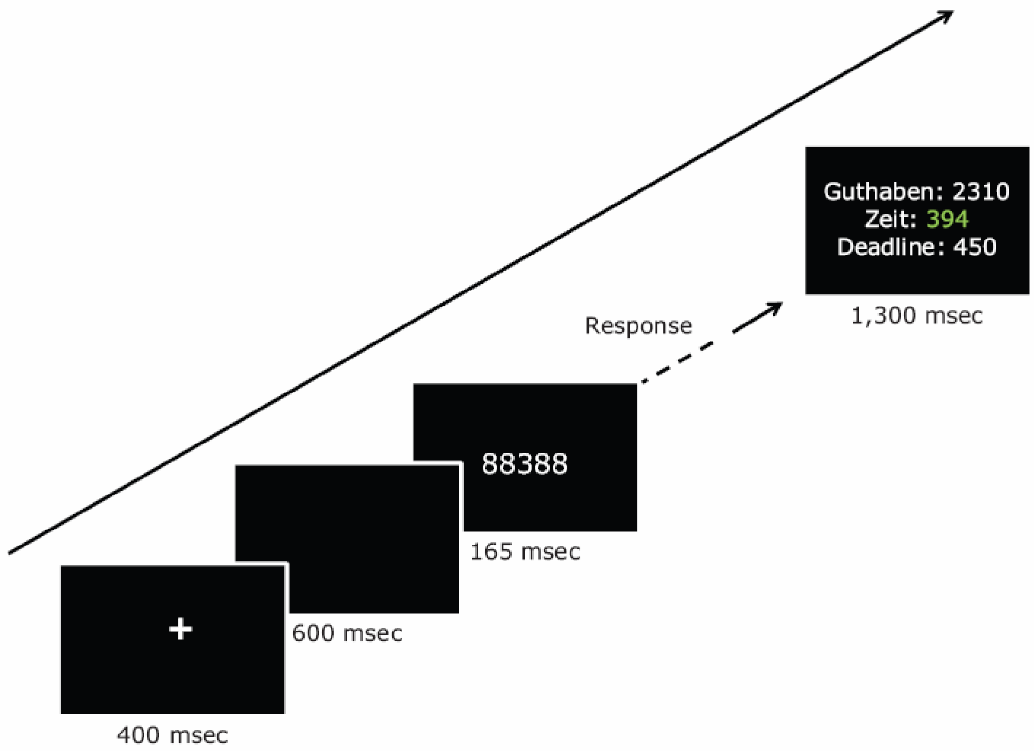


**Figure II.1:** Course of a trial. Note: In Experiment 1, a participant's assets ('Guthaben') increased in steps of 1 for each response that was correct and fast enough. In all experiments that followed, the assets increased in steps of 10. In the deadline condition of Experiment 1, the feedback screen included only the response time of the participant ('Zeit') and the response deadline ('Deadline').

*Feedback*

In the deadline- and reward blocks, after each response, a feedback screen was displayed for 1500 *ms* (see Figure II.1, right) informing the participants about their performance in the current trial. In the deadline blocks, this feedback included the deadline in the current block as well as the response time in the respective trial. It was displayed in green color if the response was correct and faster than deadline, in red if the response was an error but still faster than the deadline, and in yellow if the response had missed the deadline, regardless of whether it was correct or not. In the reward condition, the feedback also included the participant's current amount of money. After each block, an additional feedback screen was shown for maximally 60 seconds that displayed information about their overall performance. It informed again about the money gained so far (accumulated over all blocks), the mean response time for the last block, the error rate in the last block, and about the percentage of missed deadlines in the last block.

In the reward blocks, the participants received 1 Euro cent when their response was faster than the deadline *and* correct. If their response was faster than the deadline but incorrect, they lost 1 cent. If they missed the deadline, they lost 2 cents.

## II.2.2 Results

Mean latencies of correct responses were entered into a three-factor analysis of variance (ANOVA) for repeated measurements on the factors: *Condition* (deadline or reward), *Deadline* (long, medium, or short), and *Congruency* (congruent or incongruent). Accuracies were computed by entering percent correct values into a similar three-factor ANOVA as that for response times.

For the purpose of qualitative analyses, a speed-accuracy trade-off function (SATF) is shown in Figure II.2. For illustrative purposes, Figure II.3 shows the speed, accuracy and FCEs for each block of the experiment.

### *II.2.2.1 Response Times*

All three factors in this experiment had a significant main effect. The main effect of *Condition*, $F(1, 9) = 82.04$, $p < .001$, indicated that participants were faster in the reward-condition than in the deadline-condition (427 *ms* vs. 461 *ms*). The main effect of *Deadline*, $F(2, 18) = 59.96$, $p < .001$ indicated decreasing response times with faster deadlines. The main effect of *Congruency* was also significant, $F(1, 9) = 114.58$, $p < .001$. This means that responses to congruent stimuli were faster than responses to incongruent stimuli (430 *ms* vs. 458 *ms*). There was also a significant interaction between *Condition* and *Deadline*, $F(2, 18) = 5.01$, $p < .05$. This reflects the fact that response times decreased more dramatically with faster-growing deadlines in the reward condition than in the deadline condition. No further interactions were significant or approached significance.

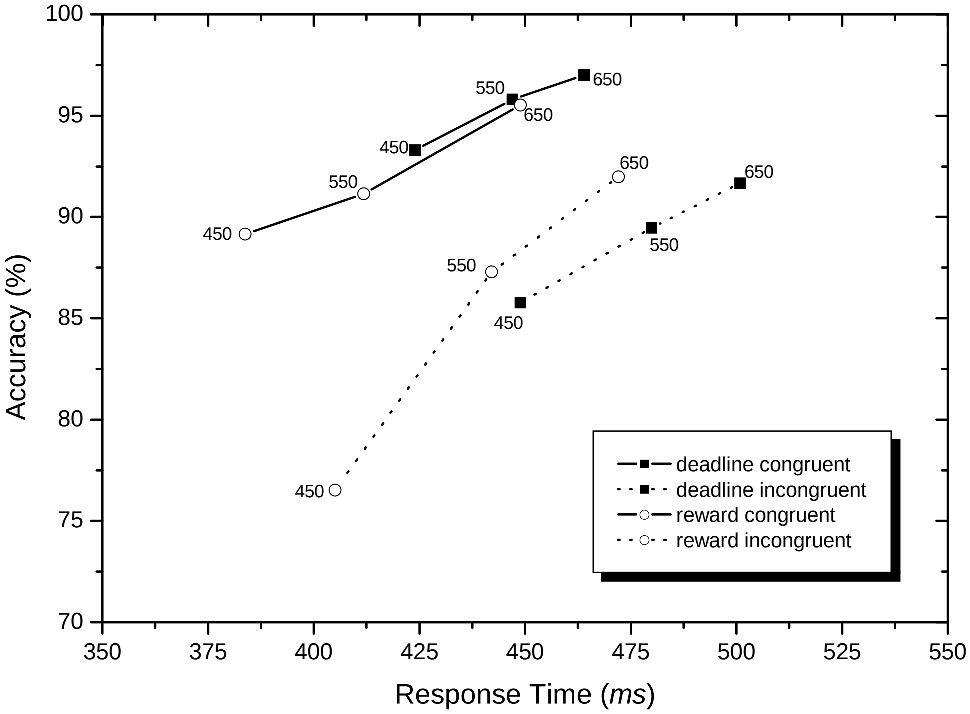


**Figure II.2:** Speed-accuracy trade-off functions of the two reward conditions (reward and deadline) in Experiment 1. Numbers at the data points indicate the corresponding deadline.

*II.2.2.2 Accuracy*

Only two factors had a significant main effect: *Deadline*, $F(2, 18) = 25.29$, $p < .001$, indicating decreasing accuracies as the deadlines grew faster, and *Congruency*, $F(1, 9) = 49.87$, $p < .001$, with better accuracies observed for congruent than for incongruent stimuli (93.69% vs. 87.16%). The main effect of *Condition*, however, was not significant. The two-way interaction between *Condition* and *Deadline* was significant, $F(2, 18) = 5.20$, $p < .05$ which indicated a more pronounced drop in accuracies as the deadlines grew faster for the reward condition compared to the deadline condition. The two-way interaction between *Deadline* and *Congruency* was also significant, which was mainly due to a larger FCE under the short deadline as compared to the medium and long deadlines (10.1%, 5.07%, and 4.44%, respectively). Furthermore, the three-way interaction between *Condition*, *Deadline*, and *Congruency* was significant, $F(2, 18) = 3.92$, $p < .05$. This indicated a smaller FCE in the reward group, but only under the medium and long deadlines.

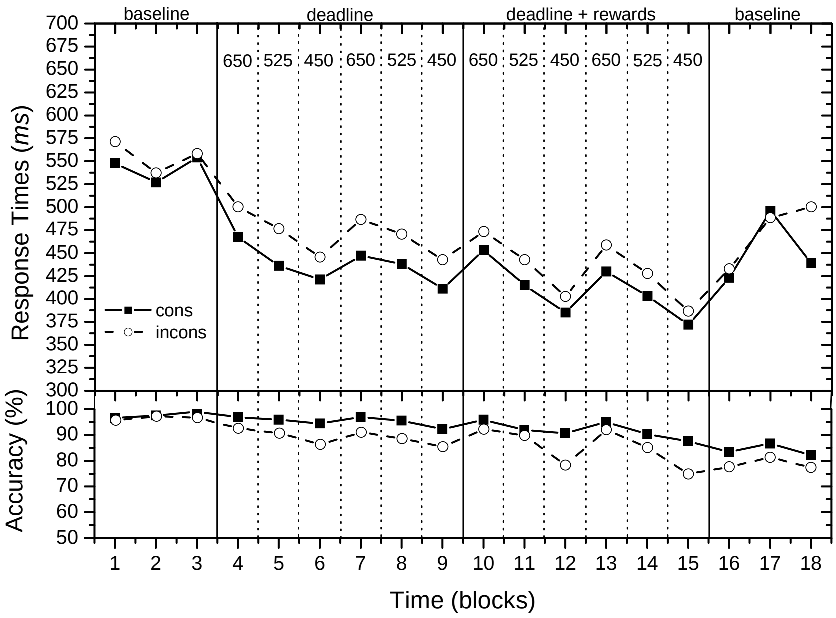


**Figure II.3:** Course of Experiment 1: speed, accuracy, and the FCE for each block

II.2.3 Discussion

Experiment 1 was designed as a pilot experiment that aimed at investigating the hypothesis that monetary rewards increase performance in a visual selective attention task. Although the experimental design undoubtly has its weaknesses, overall, the results are in line with the hypothesis. Compared to the deadline condition, participants responded faster in the reward condition, without significantly trading this increase in speed for accuracy. There is also a hint at the possibility that participants increased attentional selectivity in the reward condition, although this interpretation of the result requires further evidence.

One obvious problem is that learning was unequal in the two conditions: all the participants encountered the deadline condition before they encountered the reward condition. Hence, it would be plausible to assume that considerably more learning took place in the deadline condition than in the reward condition. Consequently, the speed-up in response times that can be observed in the second half of the experiment could have been due simply to the fact that the participants were not as experienced in performing the task during the deadline-part as they were during the reward-part. It is possible to get a hint regarding whether this presupposition is true by comparing the performance of the participants in the last three blocks of the deadline condition to the first three blocks of the reward condition. Although this comparison has to be considered with caution, it hints at the interpretation that the differences between the deadline and the reward conditions are unlikely to be due to the effects of learning: if they were, the difference between the groups should be less pronounced in this comparison than when you consider the whole experiment. However, the opposite is true: in terms of RTs, the difference remains highly significant, $F(1, 9) = 24.55$, $p < .001$, whereas in terms of accuracy the difference remains non-significant, $F(1, 9) = 1.34$, $p = .28$. Therefore, although it cannot be excluded, I suggest that learning did not play any significant role in bringing about the differences between the reward condition and the deadline condition. Nevertheless, to definitely exclude this possibility, learning will be equated between the conditions in future experiments.

An interesting feature of the SATFs is that their overall form differs considerably: compared to those of the deadline condition, the SATFs of the reward condition are stretched considerably. This is another good indicator that the participants did in fact try to adjust their performance to the requirements of the task once they were confronted with the rewards: given that the rewards were rather small, this is not a trivial observation. It hints at the possibility that the excessive rewards usually offered in other studies that investigate the effects of rewards on performance might be unnecessary and in fact, a waste of money.

In conclusion, it is fair to say that rewards did indeed improve performance in the present experiment. An open question is by what mechanism this increase in performance was achieved. Generally, there are three possible mechanisms: a general speeding-up of sensory coding or motor responding, an improvement of the quality of sensory coding, or an improvement in spatial selectivity. However, the preliminary data that was obtained in Experiment 1 does not allow any definitive statement regarding this issue. As already mentioned, there are hints that the spatial selectivity was improved in the reward condition, but more robust evidence is needed to confirm that conclusion. In any case, it is highly likely that participants did not simply shift their response criteria in the reward condition, but rather mobilized attentional effort.

One potential problem of the present experiment remains to be discussed: the fact that congruent and incongruent stimuli were used might in fact have obscured a possible effect of rewards on the zoom lens of attentional selectivity. Think about it: there is no cue or anything similar that would signal to the participants if they have to expect a congruent or an incongruent stimulus in the upcoming trial. However, if you do not know what stimulus you have to expect, you cannot adjust the zoom lens. In fact, it might be wiser to use either congruent stimuli alongside neutral stimuli, or incongruent stimuli alongside neutral stimuli if the goal is to examine possible effects of rewards on the focus of visual attention. Alternatively, it might be interesting to use only neutral stimuli, in order to examine the baseline of the effect of rewards.

All in all, considering that Experiment 1 was a pilot study, the results are pretty encouraging. Yet, a number of methodological refinements are in order, first and foremost regarding the comparison between the two reward conditions.

## II.3 Experiment 2

The results of Experiment 1 indicated that the hypothesis that monetary rewards increase performance in a visual selective attention task could be true. Nervertheless, there were reasons to assume that there is room for improvements on the methodology. Therefore, I conducted another pilot experiment in which I implemented a number of modifications.

First and foremost, it was necessary to equate the factor ‘learning’ between the two conditions. One way to achieve this would be to alternate between blocks in which there is only a deadline and blocks in which there are also rewards. However, there is one major drawback to this approach. As already mentioned earlier, if a reward system is established, performance in a task declines considerably once that system is removed (Greene & Podsakoff, 1978; Rothe, 1970). Therefore, a safer way is to use a between-subjects design: one group that deals only with the deadline condition, and another group that deals only with the reward condition.

Second, I wondered whether the results would be any different if the response deadlines were presented in a blocked fashion, rather than changing them from block to block. It is reasonable to assume that this modification would promote learning, as it gives the participants more time to adapt to the task requirements, and gradually increases task difficulty, thus supposedly fostering self-efficacy and task motivation. Therefore, using deadlines in a blocked manner could decrease the variance in the data due to unmotivated participants, particularly in the deadline group, and increase overall performance.

Third, although it is unlikely to be a major factor given the results of Experiment 1, individual participants reported to be discouraged rather than encouraged by the feedback in Experiment 1. Particularly, the feedback regarding the current assets after each trial was experienced as discouraging, because even if your performance was perfect, the asset counter counted upwards in a painfully slow manner (1 point for each response that was correct and fast enough). Therefore, for Experiment 2, I revised the feedback in such a way that participants gained and lost more points, although the reward rate was still the same (for more details, see the methods section below).

Fourth, I used only neutral stimuli in this experiment. There are two reasons for this. First, I aimed at establishing a baseline regarding the effects of rewards. Second, and more important, using only neutral stimuli in an experiment was the first step towards addressing another problem of Experiment 1. That problem is that confronting the participants with both congruent and incongruent stimuli could discourage them from using a strategy that modulates the scope of selective attention. Introducing neutral stimuli could help alleviating this problem. However, it is important to know beforehand how rewards affect performance when there are only neutral stimuli. Like this, one would have a good baseline regarding the effects of rewards in a categorization task.

As the nature of this experiment was very explorative, the hypothesis was simple and straightforward: performance should be better in the reward group than in the deadline group. I expected that the methodological refinements that were applied would at the very least reduce the variance in the data, which would be particularly important considering that a between-subjects design was used.

## II.3.1 Method

### *II.3.1.1 Participants*

36 students of the University of Konstanz participated in this experiment. They were randomly assigned to the deadline group (7 male, mean age 21.8) or to the reward group (5 male, mean age 22.6). All had normal or corrected to normal vision. Members of the deadline group were paid 8€ per hour. Members of the reward group were paid a base payment of 6€ and, at the beginning of the experiment, they were informed that they would have the chance to additionally gain up to 5€ depending on their performance. They were given a capital of 1000 points.

### *II.3.1.2 Apparatus*

The apparatus was the same as in Experiment 1.

### *II.3.1.3 Stimuli*

Target stimuli were odd and even numerals (2, 4, 6, 8, and 3, 5, 7, 9). The characters $, &, ?, and # served as flankers. To increase perceptual noise, 4 flankers were used, in contrast to Experiment 1 were there were only 2 of them. Target and flankers were arranged horizontally at the center of the screen. Each single character extended a visual angle of 1.27° horizontally and 0.89° vertically. The spacing between the items (center to center) was 1.27° of visual angle. Stimuli were presented in white against a black background.

*II.3.1.4 Procedure*

Participants were seated at a viewing distance of 45 *cm* in front of the screen. A trial started with the presentation of a fixation cross at the center of the screen for 400 *ms*. After a cue-stimulus interval of 600 *ms*, the stimulus array appeared for 165 *ms*. The screen remained blank until the participant responded. After the response, a feedback screen appeared for 1500 *ms*, just as in Experiment 1. After a blank screen of 1000 *ms* duration, the next trial started. The task of the participants was to indicate whether the target numeral was odd or even by pressing a corresponding response button of the mouse with their index or middle finger of the right hand. Response errors were signaled by a short sound. The participants in both groups performed 9 blocks of 64 trials each. The response deadline was decreased in two steps: in both experimental groups, the participants first encountered 3 blocks with a response deadline of 650 *ms* (long deadline), followed by 3 blocks with a response deadline of 525 *ms* (medium deadline), and finally 3 blocks with a response deadline of 450 *ms* (short deadline).

*Feedback*

The feedback procedure was similar to that used in Experiment 1 except for one detail: The assets of the participant were presented in the form of points, not Euro cent. Thus, in the reward group, the participants received 10 points when their response was faster than the deadline *and* correct. If their response was faster than the deadline but incorrect, they lost 10 points. If they missed the deadline, they lost 20 points. At the end of the experiment, the points were converted into money at a rate of 10:1.

For the deadline group, the feedback procedure was similar except for the fact that there was no information about their current assets, since they did not receive any reward.

As in the previous experiments, an additional feedback screen was shown for maximally 60 seconds that displayed information about participants' overall performance. For the deadline group, the only difference was that there was naturally no information regarding their assets.

## II.3.2 Results

Mean latencies of correct responses were entered into a two-factor ANOVA on the between-subjects factor *Group* (deadline, or reward) and the within-subjects factor *Deadline* (long, medium, or short). Accuracies were computed as in Experiment 1. A SAF for the results is displayed in figure II.4.

### *II.3.2.1 Response Times*

The main effect of the factor *Group* was not significant. The main effect of *Deadline,* however, was significant, $F(2, 68) = 235.61$, $p < .001$. Response latencies decreased as response deadlines decreased (473 *ms* for the long deadline, 434 *ms* for the medium deadline, and 403 *ms* for the short deadline). The two-way interaction between *Group* and *Deadline* was significant, too, $F(2, 68) = 4.20$, $p < .05$. It indicates that participants in the deadline group responded faster than participants in the reward group under the long and medium deadlines, whereas under the short deadline, the participants in the reward group responded faster. Response times were as follows: for the deadline group, 469 *ms* for the long deadline, 431 *ms* for the medium deadline, and 408 *ms* for the short deadline; for the reward group, 477 *ms* for the long deadline, 437 *ms* for the medium deadline, and 399 *ms* for the short deadline.

### *II.3.2.2 Accuracy*

The main effect of *Group* was not significant, although responses were slightly more accurate in the reward group (90.8%) than in the deadline group (88.9%). The main effect of *Deadline*, however, was significant, $F(2, 68) = 116.19$, $p < .001$, which indicated decreasing accuracies with faster-growing response deadlines (93.79% for the long deadline, 91.18% for the medium deadline, and 84.58% for the short deadline). There was a significant interaction between *Group* and *Deadline*, $F(2, 68) = 3.91$, $p < .05$, indicating a better accuracy in the reward group than in the deadline group for the long and medium deadlines, but not for the short deadline. Accuracies were as follows: for the deadline group, 92.32% for the long deadline, 89.74% for the medium deadline and 84.64% for the short deadline; for the reward group, 95.25% for the long deadline, 92.61% for the medium deadline, and 84.53% for the short deadline.

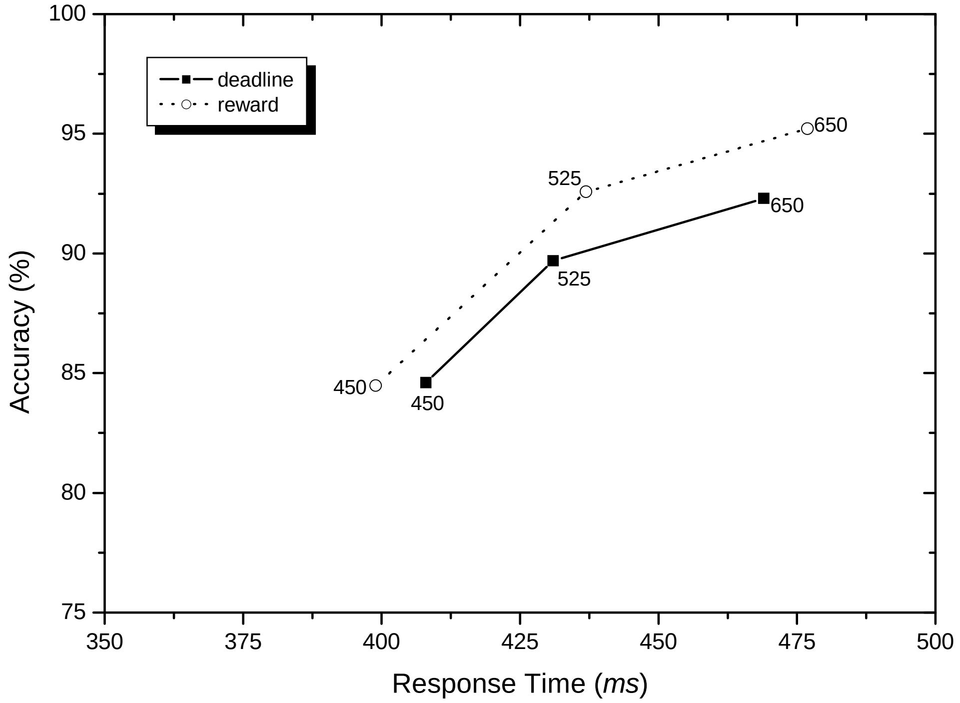


**Figure II.4:** Speed-accuracy trade-off functions of the two groups of Experiment 2. Numbers at the data points indicate the corresponding deadline.

## II.3.3 Discussion

Experiment 2 was designed to refine the methodology of Experiment 1, and to observe the effects of rewards on performance in a baseline variant of the flanker task were there are only neutral stimuli. The results are generally in line with the hypothesis that monetary rewards increase performance, although the difference in performance between the two groups is far from significant. However, actually the fact that the difference is non-significant is not as surprising as it may seem at first glimpse. Remember that the task was merely an easy categorization task that did require attentional resources only to the extent that they are required for filtering out the perceptual noise of the flankers. The general claim, however, is that in this kind of task, monetary rewards increase performance by increasing attentional effort. As not much attentional effort was needed, any increase in attentional effort was unlikely to affect performance notably.

Of course, these results are no convincing evidence, but at least they allow for suggestions regarding the mechanism that is affected by monetary rewards: presumably, more or less specific attentional mechanisms are affected, rather than early sensory or late motor mechanisms. Thus, one would suggest that monetary rewards do not simply lead to a general increase in processing- or response speed, but that they indeed affect visual selective attention.

Regarding the methodological adjustments that were applied in this experiment compared to Experiment 1, it can be stated that they worked out fine. Particularly, the between subjects-design eliminated any learning differences between the deadline and the reward groups and thus solved a major problem of Experiment 1. Regarding the other refinements, there are no reasons to assume that they were anything else than improvements.

There is one remaining problem, though: One could argue that the improvements seen in the reward group was not due to the monetary rewards, but rather to the feedback. Whereas the reward group gained points, the deadline group received only feedback on whether they beat or did not beat the deadline. Therefore, it could well be that symbolic rewards (that is, rewards that are not transformed into actual money) would produce the same results as actual rewards. To deal with this problem, one would have to compare the performance of a group that receives points and monetary rewards with the performance of a group that receives only the points without the reward. This confounding of feedback and reward will be addressed in the next experiment.

## II.4 Intermediate conclusion

The two experiments reported in Study I are to be regarded as pilot experiments. Given this, the results they produced are rather encouraging: in Experiment 1, the rewards led to an increased response speed as compared to a condition in which there were no rewards. However, this result might be confounded by a differential learning rate in the two conditions. Experiment 2 dealt with this problem by implementing a between-subjects design, thus eliminating any learning differences between the rewarded and the non-rewarded condition. Additionally, some minor methodological adjustments were applied. The results again were encouraging. However, that experiment was also not flawless. A major objection that could be raised is that mere feedback or symbolic rewards could have produced the same results.

Although the results of this pilot phase are encouraging, clearly more evidence is needed. First and foremost, it would be desirable to observe a significant difference between a rewarded group and a group that receives only a flatrate payment in a between-subjects design. Furthermore, it would be interesting to catch a glimpse at the mechanism that is affected by the rewards. That is, by what mechanism would an increase in performance come about? These issues will be addressed in Study II.

# III.

## Study II:
## „Rewards increase attentional effort“

# III.1 Introduction

Although the results of the pilot phase encourage the view that rewards most likely do have a positive effect on performance in the flanker task, the results are not yet completely convincing, and more evidence is definitely needed. Furthermore, more insights regarding the mechanisms by which rewards increase performance in the flanker task would be desirable. In order to address these issues, the current experiment was conducted.

Regarding the mechanism that is affected by the rewards, before we can actually begin asking ourselves what mechanisms could theoretically be improved by attentional effort due to monetary rewards, we need a tool that allows us to differentiate between the various candidates. One such tool is the form of the SATF: it is possible to compute theoretical SATFs by means of a diffusion model (Ratcliff & Rouder, 1998). Depending on what mechanism is affected, the simulated SATF takes on a different form. It is then possible to infer what mechanism is affected by monetary rewards by comparing these simulated SATFs with the empirical SATFs.

What mechanisms could theoretically be improved in the flanker task? There are three possible candidates: First, one effect of an increase in attentional effort could be that it generally speeds up stimulus processing and/or responding in an unspecific manner, e.g. by increasing arousal. This would save time that could then be used to extend the response selection phase. As a result, accuracy is increased for a given deadline condition, relative to a baseline condition. A corresponding SATF is shown in figure III.1. However, as is also shown in Figure III.1, this improvement vanishes with an increasing deadline, because the SATFs finally converge to a common asymptotic value. In other words, if reward simply speeds up processing, then the observed SATF should be a leftward shifted version of the baseline SATF. The results of Experiment 2 yielded preliminary evidence that speaks against this account. However, it cannot be completely dismissed yet.

Another and more specific effect of reward could be that it mobilizes attentional resources that improve the *quality* of sensory coding (Goard & Dan, 2009; Sarter et al., 2006). The better quality would then increase the available information for response selection, which, in turn, would lead to a higher accuracy. In the corresponding SATF this is reflected by a steeper function that approaches a higher asymptotic level (see again Figure III.2).

Finally, an even more specific effect of reward would be to improve spatial selection, e.g. by preventing flanker processing. To not discourage the participants from using such a strategy, congruent stimuli were excluded in the present experiment. Because the flankers of congruent stimuli activate the correct response, a narrow focus of spatial attention on the target might impair performance. However, if there are only incongruent and neutral stimuli, a narrow focus should improve performance in either case, or at least not impair it. Thus, if reward improves selective attention, then the performance for incongruent stimuli should mainly be improved, whereas that for neutral stimuli should remain relatively unchanged. Consequently, the difference between the SATFs for incongruent and neutral stimuli should be reduced.

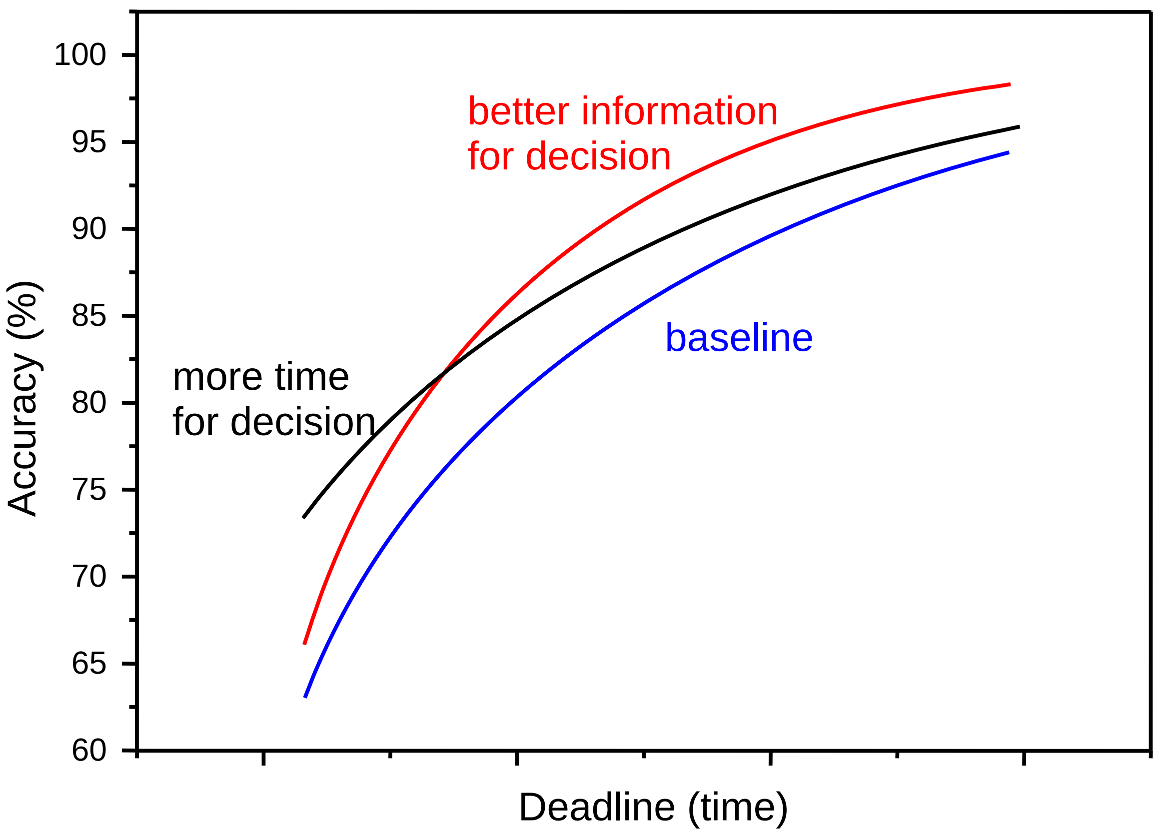


**Figure III.1:** Theoretical SATFs. The two upper SATFs show possible effect of an increased attentional effort, relative to a baseline condition (see text for details).

## III.2 Experiment 3

In this experiment, the between-subjects approach was maintained. However, the confounding of the feedback with reward that was a problem in Experiment 2 made it necessary to drop the deadline group and add another group that received the exact same feedback as the reward group, but no monetary rewards. This group will be labeled as *payoff group*.

### III.2.1 Method

#### *III.2.1.1 Participants*

104 students from the Universität Konstanz participated in the experiment. All had normal or corrected-to-normal vision. The participants were randomly assigned to the payoff group (mean age 23.2, 12 males), or to the reward group (mean age of 22.5, 16 males). Members of the payoff group were paid 8€ per hour, whereas members of the reward group were paid a base payment of 6€ per hour, and were informed in advance that they could additionally earn up to 5€ depending on the gained points in the experiment. Members of the payoff group and of the reward group started with a ‘capital’ of 1000 points.

#### *III.2.1.2 Apparatus*

Stimuli were presented on a 18” color-monitor with a resolution of 1280x1024 pixels and a refresh rate of 60 *Hz*. Participants responded by pressing one of two buttons of a computer mouse. Stimulus presentation as well as response registration was controlled by the same personal computer (PC).

#### *III.2.1.3 Stimuli*

Target items were numerals from 2 to 9. Incongruent stimuli were constructed by using response incompatible numerals as flankers. For neutral stimuli, the characters $, &, ?, and # served as flankers. Target and flankers were arranged horizontally. The target was presented at the center of the screen. Each single character extended a visual angle of 0.9° horizontally and 1.27° degrees vertically, the spacing between the items (center to center) was 1.27° of visual angle. Stimuli were presented in white on a black background.

#### *III.2.1.4 Procedure*

Participants were seated at a viewing distance of 45 *cm* in front of the screen. A trial started with the presentation of a fixation cross at the center of the screen for 400 *ms*. After a cue-stimulus interval of 600 *ms,* the stimulus array appeared for 165 *ms*. The screen remained blank until the participant responded. After the response, a feedback screen appeared for 1300 *ms*. After a blank screen of 1000 *ms* duration the next trial started. The task of the participants was to indicate the parity of the target numeral by pressing a corresponding response button with their index or middle finger of the right hand. Response errors were signaled by a short sound. One half of the participants started by performing 3 blocks in which the response deadline was 650 *ms* (long deadline). Then followed 3 blocks with a response deadline of 525 *ms* (medium deadline), and then 3 blocks with a response deadline of 450 *ms* (short deadline). To counterbalance possible practice effects, the other half of the participants cycled through the deadlines in reverse order, that is, they began with the short deadline and finished with the long deadline. All blocks of 64 trials each were administered in one session that lasted for 1 hour.

*Feedback*

After each response, a feedback screen was displayed for 1300 *ms*, informing the participants about their performance in the current trial. Additionally to the deadline in the current block, the response time (RT) was shown. It was displayed in green color if the response was correct and faster than the deadline, in yellow if the response was an error but faster than the deadline, and in red if the response had missed the deadline, regardless of whether it was correct or not. Members of the payoff group and of the reward group were additionally informed about the current sum of their points. After each block, an additional feedback screen was shown for maximally 60 seconds that displayed information about their overall performance. It informed about the points gained so far (accumulated over all blocks), the mean response time for the last block, the error rate in the last block, and about the percentage of missed deadlines in the last block.

Members of the payoff and of the reward group received 10 points when their response was faster than the deadline *and* correct. If their response was faster than the deadline but incorrect, they lost 10 points. If they missed the deadline, they lost 20 points. At the end of the experiment, the points of the reward group were converted into Euro-cents with a rate of 10:1.

## III.2.2 Results

Mean latencies of correct responses were entered into a three-factor ANOVA with the between-subjects factor *Group* (reward or payoff), and the within-subjects factors *Deadline* (long, medium, or short) and *Congruency* (neutral or incongruent). Accuracies were computed by entering percent correct values into a similar ANOVA as that for response latencies. SATFs for the results are presented in figure III.2.

### *III.2.2.1 Response Times*

The analysis revealed significant main effects of the factors *Deadline*, $F(2, 204) = 105.9$, $p < .001$, and *Congruency*, $F(1, 102) = 328.7$, $p < .001$. There was also a significant two-way interaction between *Deadline* and *Congruency*, $F(2, 204) = 9.9$, $p < .001$. This interaction indicated that the FCE in RT increased with an increasing deadline (14 *ms*, 17 *ms*, and 23 *ms*). The factor *Group* was not significant, but there was a slight trend of 5*ms* towards faster responses in the reward group.

### *III.2.2.2 Accuracy*

The analysis revealed significant main effects of *Deadline*, $F(2, 204) = 144.6$, $p < .001$, *Congruency*, $F(1, 102) = 158.9$, $p < .001$, and *Group*, $F(1, 102) = 6.2$, $p < .05$. Thus, accuracy was higher in the reward group than in the payoff group (89.5% vs. 86.9%). There was also a significant three-way interaction between *Deadline* and *Congruency*, $F(2, 204) = 6.79$, $p < .01$. A further analysis showed that this interaction was due to the fact that the FCE was significantly larger for the reward group than for the payoff group, but only for the longest deadline (1.043% versus 0.400%), $F(1, 74) = 7.73$, $p < .01$.

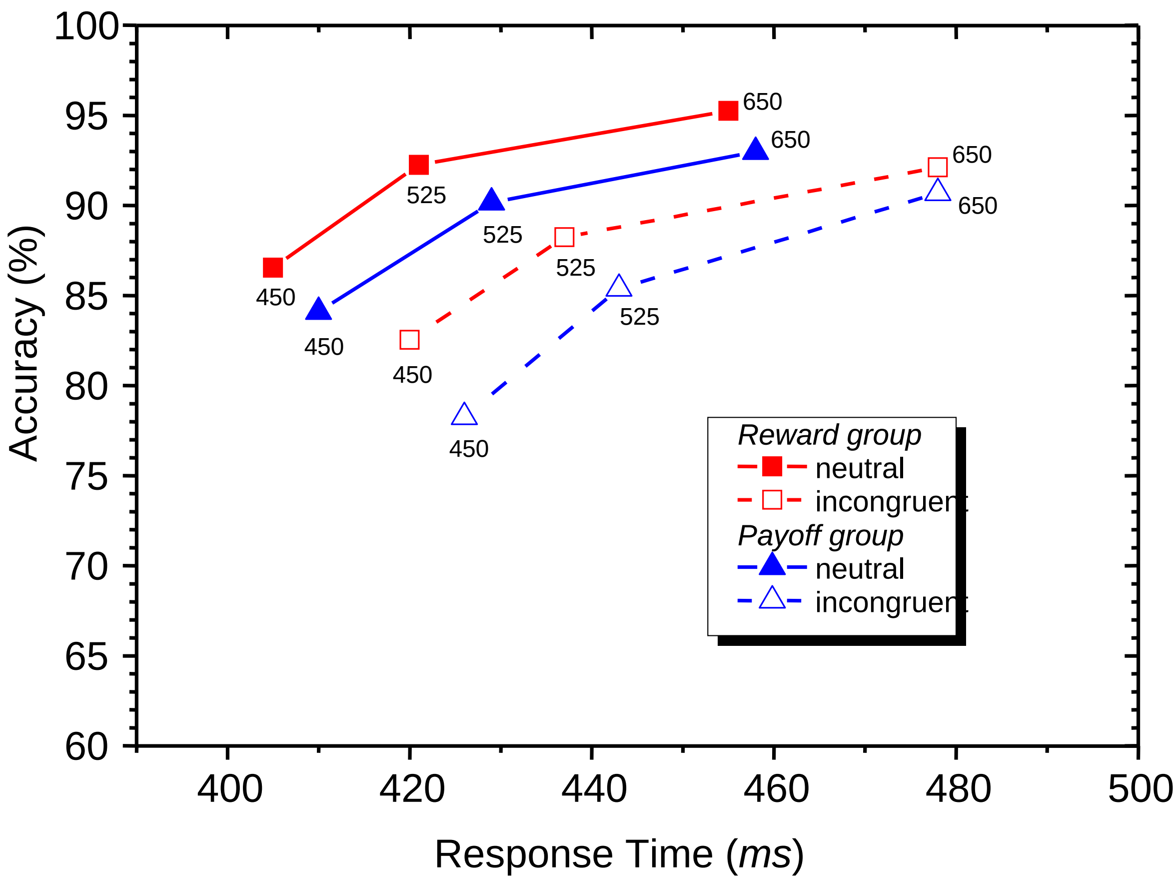


**Figure III.2:** SATFs of the two groups of Experiment 3. Numbers at the data points indicate the corresponding deadline.

III.2.3 Discussion

The results of this experiment show that - in line with the hypothesis - shorter deadlines systematically speeded up responding, but at the expense of accuracy, which led to typical SATFs (see Figure III.2). The analysis left no doubt that monetary rewards led to an increase in performance: compared to the payoff group, the reward group responded significantly more accurate. As there were no differences between these two groups other than the fact that one group received money for good performance and the other group did not, the only possible interpretation of the results is that the increase in performance was due to the monetary rewards.

However, the empirical SATFs allow us to draw further conclusions regarding the mechanism that was affected by the monetary rewards. If you consider the SATFs for the neutral condition, you will see that the performance improvement is similar for all three deadlines. According to the reasoning in the introduction of the present study, this indicates that the monetary rewards improved the quality of sensory coding and the corresponding cortical representations (Goard & Dan, 2009; Sarter et al., 2006). In the context of the diffusion model, this improved quality is reflected in an increased drift rate of evidence accumulation.

Furthermore, this increased quality of sensory coding was unselective, which is reflected in the fact that the improvement was similar for both neutral and incongruent stimuli. Accordingly, monetary rewards increased the sensory quality of both the target and the flankers. Had the effect been selective, one would have seen a smaller FCE in the reward group as compared to the payoff group. Thus, rewards did not influence the focus of visual attentional selection. However, there is a small hint that attentional selectivity was affected: whereas the FCE remained constant across the range of response deadlines in the reward group, it increased in the payoff group. This could mean that participants in the payoff group not only lowered their decision criterion, but also relaxed their spatial selectivity, whereas participants in the reward group maintained spatial selectivity. Although this account is rather speculative, it is nevertheless a possibility that warrants further investigation.

Thus, altogether, these results provide clear evidence for the hypothesis that performance-contingent monetary rewards can increase attentional effort in order to increase performance. Obviously, reward mobilizes attentional resources that improve stimulus coding which, in turn, increases accuracy. Hence, these results are in line with other studies showing that monetary reward can improve performance in tasks that tap visual attention (Engelmann & Pessoa, 2007; Engelmann et al., 2009; Kiss et al., 2009). Furthermore, the results also hint at the possibility that – as suggested by Della Libera and Chelazzi (2006) - selective spatial attention is affected by monetary rewards. However, more convincing evidence is most definitely needed for that latter proposition.

## III.3 Intermediate conclusion

Experiment 3 addressed the weaknesses of the experimental design that were left over from the pilot phase: in this experiment, there was no difference whatsoever between the two experimental groups, except for the fact that one group received a performance-contingent payment, whereas the other group received a flatrate payment. As a result, the performance of the reward group was clearly superior to that of the payoff group. Furthermore, the results also allowed drawing conclusions regarding the mechanism that is enhanced by the rewards.

What remains to be addressed is the question of how stable this result is. For example, if one would punish making errors rather than responding too slowly, would that change the results? After all, it seems reasonable to assume that the effects of rewards depend also on the question of what aspect of performance is rewarded (e.g., speed versus accuracy). Furthermore, it would be interesting to know how the results are affected by the order in which the response deadlines are presented. It could well be that task learning is different when your first encounter with the task is under a harsh deadline than when it is under a more generous deadline. These and some other related questions will be addressed in Study III.

# IV.

## Study III:
## „The mediating influence of deadline order and the rewarded dimension of behavior on the mobilization of attentional effort“

## IV.1 Introduction

In the previous study, it was demonstrated that monetary rewards are capable of enhancing attentional effort, and along with that, performance. Compared to the payoff group which received the same feedback as the reward group but was paid only a flatrate, the latter group responded equally fast but significantly more accurate than the payoff group. It was concluded that monetary rewards exert their influence by enhancing the quality of sensory coding of the stimuli, but in an unspecific manner, i.e. the scope of visual selective attention remained unaffected. Thus, the last experiment successfully demonstrated a beneficial effect of monetary rewards on performance.

However, the experiment also produced several new questions. These will be addressed in the present study. First, in Experiment 3, we combined two deadline orders, one ascending, progressing from the shortest response deadline to the longest, and the other one descending, progressing from the longest to the shortest deadline. This was necessary in order to exclude the possibility that practice effects would confound our results. However, it is highly likely that these two orders have different effects on the behavior of the participants, and the question is how these differences can be characterized. Investigating this issue is important, because the common modus operandi when response deadlines are used in an experiment is to present them in a randomized order. Of course, from the point of view of experimental design, this is rational. However, as said before, the order of response deadlines may well influence the way in which rewards influence behavior. Therefore, if the participants' performance is the focus of an experiment, a randomized deadline order might not be the smartest solution. This issue will be dealt with in Experiment 4.

Second, the reward scheme we used in Experiment 3 was special insofar as slow responses were punished more harshly than erroneous responses: whereas participants lost 20 points when they responded too slowly, they lost only 10 points when they responded erroneously. An important question is how this pattern influenced the results. Particularly, does the beneficial effect of monetary rewards on performance depend on the reward scheme or not? Furthermore, are participants able to adjust their behavior to different reward schemes to the same degree? And if so, can they do so on the fly, as the reward scheme changes during an experimenent? These questions will be examined in Experiments 5 and 6.

## IV.2 Experiment 4

As already stated in the introduction to this section, for methodological reasons, both an ascending and a descending order of response deadlines were used in Experiment 3. However, these are likely to affect behavior differently. Considering the crucial role of individual skill level as a mediator for the effects of rewards on performance, it is clear that this must be so. Although the task (classifying numbers as odd or even) is highly overlearned, participants do have to learn how to deal with certain conditions of the task, for example, the response mapping on the mouse buttons, or – first and foremost – how to meet the response deadline. Clearly, then, a relatively long deadline will promote better learning than a short deadline, because it imposes less stress on the participants and thus leaves more working memory capacity for learning the task. Thus, one would predict that the overall accuracy will be higher if the participants begin with a relatively long deadline than if they begin with a short deadline. If monetary rewards are offered, accuracy will be better than when no rewards are offered, particularly for neutral stimuli. If participants receive monetary rewards but begin with a short deadline, the pattern of results will look different. Most probably, due to the rapid reward loss, participants in the reward group will try much harder to meet the deadline than participants in the payoff group. Consequently, they will respond faster. Once the deadline gets longer, the performance benefit will probably also be seen in terms of accuracy

So in summary, whether a participant begins with a short deadline and progresses towards longer deadline, or with a long deadline and progresses towards shorter deadlines will detrmine the pattern of benefits that monetary rewards will entail. However, a completely different issue arises when the deadline order is randomized. Most likely, such a deadline arrangement will benefit first and foremost the payoff group, as it renders the task more interesting and varied. In the reward group, however, this arrangement will interfere with learning.

To validate whether these hypotheses are correct, the data from Experiment 3 was split up according to deadline order, and new data was collected from a new group of participants that encountered the response deadlines in a randomized order. Within each response deadline arrangement (ascending, descending, or randomized) the performance of the reward and the payoff group was compared.

## IV.2.1 Method

### *IV.2.1.1 Participants*

For the new group, 60 students of the University of Konstanz participated in the experiment. They were randomly assigned either to the reward group (7 male, mean age 23.0) or to the payoff group (10 male, mean age 22.2). All had normal or corrected to normal vision. Participants in the reward group were paid a base payment of 6€ and, at the beginning of the experiment, were informed that they would have the chance to additionally gain up to 5€ depending on their performance. They were given a capital of 1000 points, which corresponds to 100 Euro cent. Participants in the payoff group were informed at the beginning of the experiment that they would receive a flatrate payment of 8€, independent of their performance in the experiment.

### *IV.2.1.2 Apparatus*

Stimuli were presented on a 18” color-monitor with a resolution of 1280x1024 pixels and a refresh rate of 60 *Hz*. Participants responded by pressing one of two buttons of a computer mouse. Stimulus presentation as well as response registration was controlled by the same personal computer (PC).

### *IV.2.1.3 Stimuli*

Target items were odd and even numerals (2, 4, 6, 8, and 3, 5, 7, 9). The characters $, &, ?, and # served as flankers. Target and flankers were arranged horizontally at the center of the screen. Each single character extended a visual angle of 1.27° horizontally and 0.89° vertically. The spacing between the items (center to center) was 1.27° of visual angle. Stimuli were presented in white against a black background.

### *IV.2.1.4 Procedure*

Participants were seated at a viewing distance of 45 *cm* in front of the screen. A trial started with the presentation of a fixation cross at the center of the screen for 400 *ms*. After a cue-stimulus interval of 600 *ms*, the stimulus array appeared for 165 *ms*. The screen remained blank until the participant responded. After the response, a feedback screen appeared for 1300 *ms*. After a blank screen of 1000 *ms* duration the next trial started. The task of the participants was to indicate whether the target numeral was odd or even by pressing a corresponding response button of the mouse with their index or middle finger of the right hand. Response errors were signaled by a short sound. The participants in both the payoff and the reward group performed 9 blocks of 64 trials each. Before the actual experiment began, both groups performed a practice block with a response deadline of 700 ms. Although points could be gained or lost during this block, the assets counter was reset after the practice block. The response deadline was altered after each block. All possible deadlines sequences were used. Participants were randomly assigned to one sequence at the beginning of the experiment. All in all, there were 6 possible sequences: long – medium – short (lms), long – short – medium (lsm), medium – long – short (mls), medium – short – long (msl), short – long – medium (slm), and short – medium – long (sml). The *long* deadline was 650 *ms* long, the *medium* deadline 525 *ms,* and the *short* deadline 450 *ms*.

The feedback procedure was similar to that used in Experiment 3.

### IV.2.2 Results

The results will be presented in two stages: first, I will present the results for the new group (randomized deadline) in isolation. Following this, I will report the results for the old data of Experiment 3, split up according to deadline order (descending and ascending).

#### *IV.2.2.1 Randomized deadline order*

Mean latencies of correct responses were entered into a three-factor ANOVA on the between-subjects factor *Group* (payoff vs. reward) and the within-subjects factors *Deadline* (long, medium, and short) and *Congruency* (neutral or incongruent). Accuracies were computed as in the previous experiments. A SATF for the results is displayed in Figure IV.1.

*Response times*

There was a significant main effect of *Deadline*, $F(2, 116) = 127.6$, $p < .001$. Response latencies decreased with decreasing deadlines (447 *ms* for the long deadline, 428 *ms* for the medium deadline, and 404 *ms* for the short deadline). The main effect of *Congruency* was also significant, $F(1, 58) = 224.4$, $p < .001$. Responses were faster for neutral than for incongruent stimuli (419 *ms* vs. 433 *ms*). Furthermore, there was an interaction between *Group* and *Deadline*, $F(2, 116) = 6.91$, $p < .01$. It indicated that, except for the long deadline, participants in the reward group responded faster than participants in the payoff group. Finally, there was a significant interaction between *Deadline* and *Congruency*, $F(2, 116) = 6.23$, $p < .01$, which indicated a smaller FCE under the short deadline than under either the medium or long deadlines (the FCE was 17 *ms* for the long deadline, 16 *ms* for the medium deadline, and 11 *ms* for the short deadline).

*Accuracy*

The ANOVAs for the accuracies revealed the same pattern of results as the ANOVAs for response times: Accuracy decreased as the length of the response deadlines decreased, as was reflected in a significant main effect of *Deadline*, $F(2, 116) = 105.4$, $p < .001$. Accuracies were 92% for the long deadline, 88.8% for the medium deadline, and 83.6% for the short deadline. Responses to neutral stimuli were more accurate than responses to incongruent stimuli (90.4% and 85.9%, respectively), the corresponding main effect of *Congruency* was highly significant, $F(1, 58) = 134.9$, $p < .001$. The interaction between *Group* and *Deadline* was significant, $F(2, 116) = 3.64$, $p < .05$, indicating that except for the long deadline, participants in the payoff group responded more accurate than participants in the reward group. Lastly, the interaction between *Deadline* and *Congruency* was significant too, $F(2, 116) = 3.71$, $p < .05$. It indicated a smaller FCE for the long deadline than for either the medium or the short deadline (3.3%, 5.1%, and 4.9%, respectively).

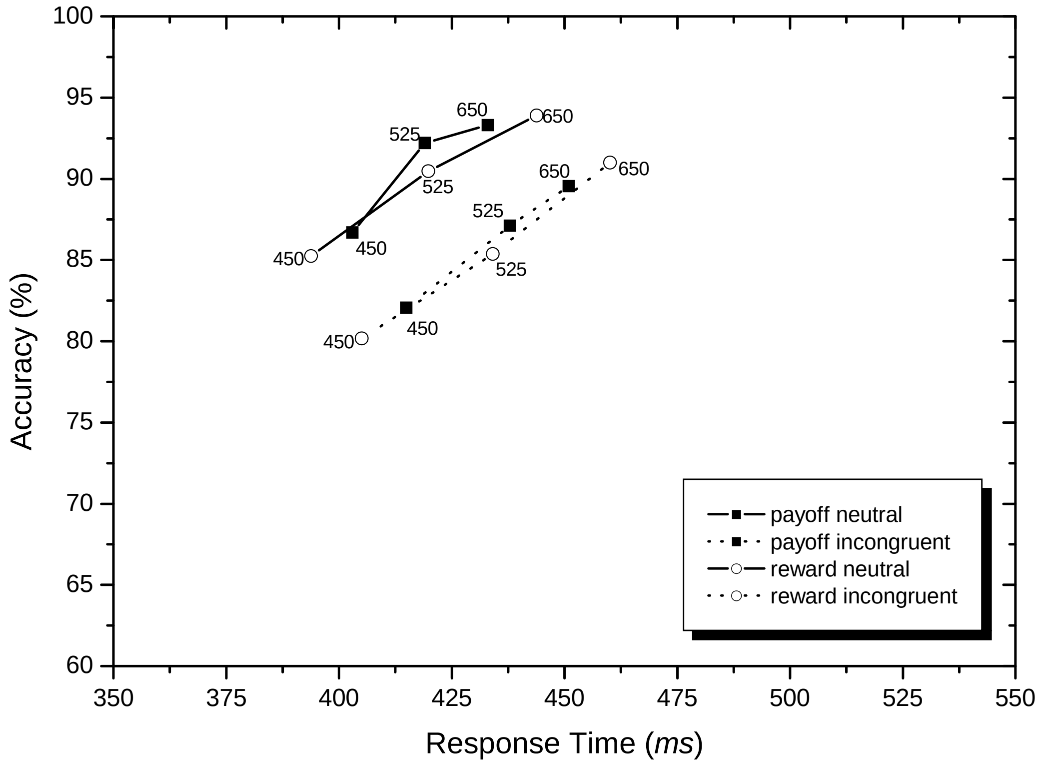


**Figure IV.1:** SATFs for the two groups of Experiment 4 that encountered the response deadlines in a randomized fashion. Numbers at the data points indicate the corresponding deadline.

*IV.2.2.2 Descending deadline order*

52 participants from Experiment 3 encountered the response deadlines in a descending order, beginning with the long deadline. For these participants, response times and accuracy data were entered into the same type of ANOVA as the data of the group that encountered the response deadlines in a randomized fashion. SATFs for this group are presented in figure IV.2.

*Response times*

There was again a significant main effect of *Deadline*, $F(2, 100) = 468.9$, $p < .001$, indicating that response latencies grew shorter with decreasing deadlines (485 *ms*, 438 *ms*, 401 *ms*). The main effect of *Congruency* was significant, too, $F(1, 50) = 212.0$, $p < .001$, with responses to neutral stiumuli being faster than responses to incongruent stimuli (431 *ms* vs. 451 *ms*). The only interaction that was significant was the one between *Deadline* and *Congruency*, $F(2, 100) = 13.36$, $p < .001$. This interaction indicated that the FCE was significantly larger under the long deadline than under either the medium or the short deadline (27 *ms* for the long deadline, 17 *ms* for the medium deadline, and 14 *ms* for the short deadline).

*Accuracy*

Most importantly, there was a significant main effect of *Group*, $F(1, 50) = 16.28$, $p < .001$, indicating higher accuracies in the reward group than in the payoff group (91.9% vs. 86.95%). The other two factors had significant main effects, too: the main effect of *Deadline*, $F(2, 100) = 75.62$, $p < .001$ indicated decreasing accuracies with decreasing deadlines. The main effect of *Congruency*, $F(1, 50) = 76.24$, $p < .001$ indicated that responses to neutral stimuli were more accurate than responses to incongruent stimuli. Two of the three two-way interactions were significant: The one between *Group* and *Deadline*, $F(2, 100) = 4.4$, $p < .05$ indicated better accuracies in the reward group under all three response deadlines. The interaction between *Deadline* and *Congruency*, $F(2, 100) = 4.92$, $p < .01$ indicated that the FCE grew the larger the shorter the response deadline became. Finally, the three-way interaction between *Group*, *Deadline*, and *Congruency* was also significant, $F(2, 100) = 4.12$, $p < .05$. It indicated that whereas the FCE remained largely constant in the reward group across the various response deadlines, it grew the larger the smaller the response deadline became in the payoff group.

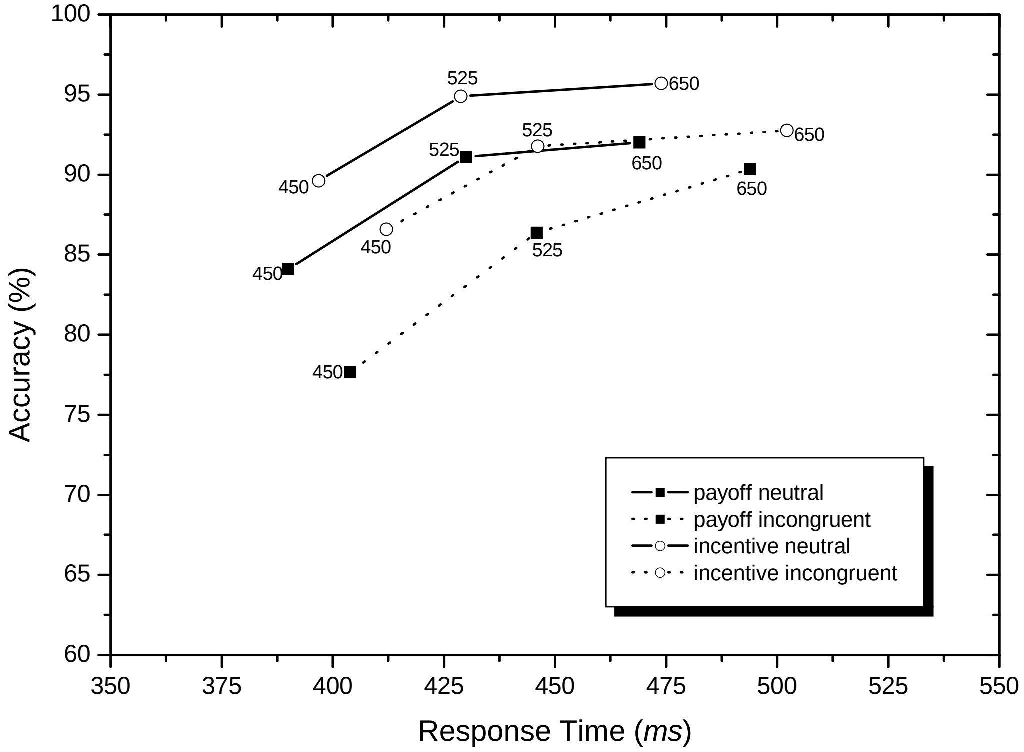


**Figure IV.2:** SATFs for the two groups of Experiment 3 that encountered the response deadlines in a descending fashion. Numbers at the data points indicate the corresponding deadline.

*IV.2.2.3 Ascending deadline order*

The data of the remaining 52 participants of Experiment 3 who encountered the response deadlines in an ascending order were entered into this analysis, and ANOVAs similar to the ones in the previous analysis were conducted. SATFs for this group are presented in figure IV.3.

*Response times*

The analysis revealed only two significant main effects: first, that of *Deadline*, $F(2, 100) = 11.47$, $p < .001$, indicating that response latencies were significantly slower under the long deadline than under either the medium or the short deadlines (451 *ms*, 429 *ms*, and 430 *ms*, respectively). Second, the main effect of *Congruency*, $F(1, 50) = 131.9$, $p < .001$, indicated faster responses to neutral than to incongruent stimuli (429 *ms* vs. 444 *ms*). There were no significant interactions.

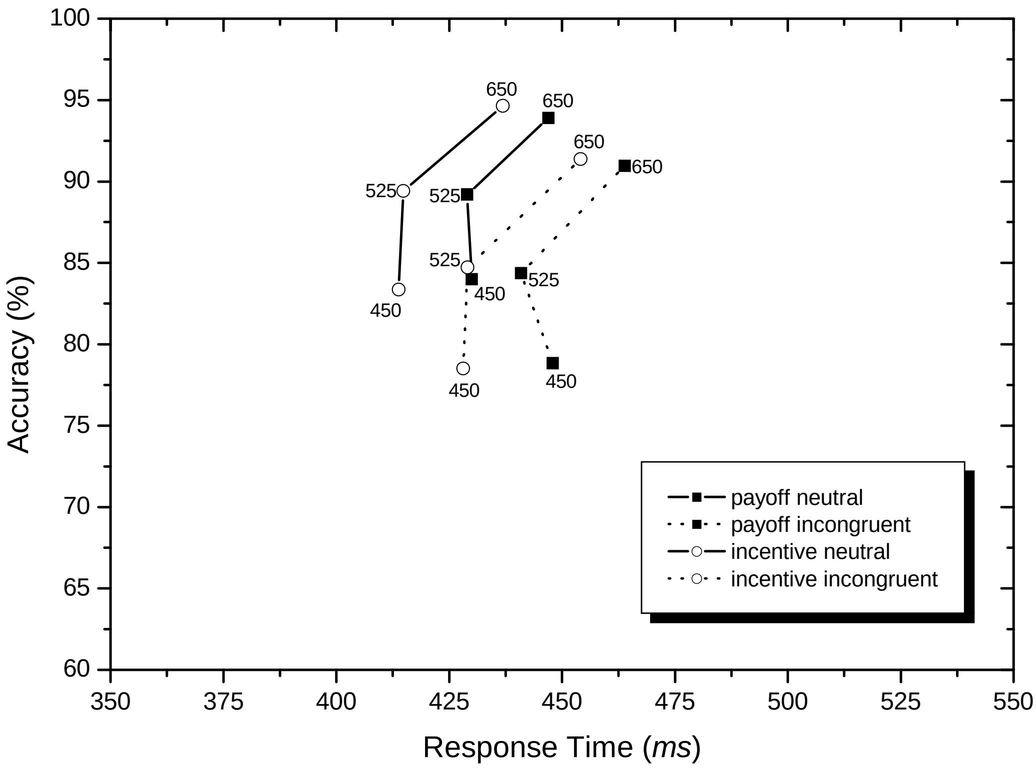


**Figure IV.3:** SATFs for the two groups of Experiment 3 that encountered the response deadlines in a ascending fashion. Numbers at the data points indicate the corresponding deadline.

*Accuracy*

There was a significant main effect of *Deadline*, $F(2, 100) = 85.96$, $p < .001$, indicating that responses became more accurate as the response deadlines became longer (81.2%, 86.95%, and 92.8%, for the short, medium, and long deadline, respectively). *Congruency* also had a significant main effect, $F(1, 50) = 82.63$, $p < .001$. Again, it indicated that responses to neutral stimuli were more accurate than responses to incongruent stimuli (89.14% vs. 84.81%). No interactions were significant.

### IV.2.3 Discussion

Inspecting the figures corresponding to the three different deadline orders, it is obvious that different orders influence behavior differently: under the randomized deadline order, there were barely any group differences. If anything, the payoff group was a little more accurate, but even this difference was far from significant. In contrast, when participants encountered a descending deadline order, rewarded participants responded more accurate than unrewarded participants. Furthermore, there were hints that they restricted their attentional zoom lens more to the target stimulus. Finally, when participants were confronted with an ascending deadline order, group differences showed up not in terms of accuracy, but in terms of response times: although these differences were not significant, there was a clear trend towards faster responses in the reward group.

What is the reason for these differences? The most plausible explanation seems to be that different deadline orders affect both learning and task motivation differently, because they differ naturally in difficulty. Consider this: As was already emphasized in the General Introduction, the effects of rewards hinge strongly on the fit between an individual's skill level and the complexity of the task (Bonner & Sprinkle, 2002). Now, remember that the task that the participants confront is an artificial one that was made up for a specific purpose. Thus, although the core skill necessary to perform the task (categorizing numbers) is common and highly overlearned, the specific calibration of the task is new. Hence, the initial skill level of the participants with regard to that task is low. Consequently, in order to promote learning, it would be best to make the task as easy as possible in the beginning. That is, start off with the most generous (longest) deadline. By doing so, rewards would have the maximal effect. This is exactly what is reflected in the results: The only condition in which rewards had a significant effect was the descending deadline order. In this condition, task motivation will be optimal as the learner is hardly ever overstrained by the task execution and is able to adapt gradually to the increasing task demands, as you start with the most generous deadline and gradually progress towards harder deadlines, while you're having enough time to solidify your task mastery over the course of three consecutive blocks that all have the same response deadline. As a consequence of learning, the difference between the reward group and the payoff group keeps getting larger as task demands increase, as can be seen for the incongruent stimuli in particular.

In contrast, if you start with the hardest task demands – namely, the short deadline – you are likely to become totally overwhelmed by these demands at first. Your motivation will drop as you struggle to avoid losing points but are initially unable to do so satisfyingly, and you will have a hard time adapting to the task demands. Furthermore, these task demands drag on and on for three blocks. Some participants might even give up completely and try to make their way through the task as effortlessly as possible by clicking only randomly. All this is not designed to promote learning. As you can see in Figure IV.3, there is still a superior performance in the reward group as compared to the payoff group, but in this case the difference is in terms of response times (although the difference is not significant). The nonsignificance of this trend points to the interpretation that the main effect of the rewards in this condition was not to promote task learning, but rather to prompt participants to avoid reward loss by trying to simply respond faster. Probably they were so caught up in trying to do so that there simply were no resources available for learning.

How might a randomized deadline order influence task motivation and performance? Given the results of the previous two groups, it is not too difficult to see how the reward goup's performance would suffer under this arrangement. Unless you happen to be assigned to the lms group, learning conditions are suboptimal (and even if you are lucky enough to be in the lms group, you are still required to learn the skill rather quickly, as there is only one block for each deadline). Consequently, the task becomes pretty challenging to participants in the reward group. The fact that their payment is contingent on their performance puts additional pressure on them. In contrast, participants in the payoff group could well benefit from this deadline arrangement. As they have nothing to win or lose, their default task motivation is expected to be rather low. However, the fact that the deadline changes after each block might work to render the task a little more interesting to them, thus increasing the intrinsic motivation to perform the task, and hence, performance.

In summary, the results of this experiment demonstrate that the arrangement of the deadlines has a massive effect on the performance of each group as well as the performance differences between the reward and the payoff group. An important corollary of these results is this: if the focus of an experiment is to demonstrate group differences with regard to rewards, it might not be the best idea to randomize the deadline order, as that would minimize the chances of seeing any group differences, and also give an advantage to the unpaid group. This finding again points to the fact that the effects of rewards are subject to a host of mediators, and that experimenters who seek to investigate these effects need to design their experiments very carefully.

## IV.3 Experiment 5

In the previous experiment, I investigated the effects that the order in which the response deadlines are presented have on the effect of rewards on performance. Generally, this manipulation affected, in the first instance, task difficulty. But there is another interesting mediator which I want to investigate in the following, namely, the reward scheme, or which aspects of performance are rewarded (response speed versus response accuracy). As I already said in the General Introduction, rewarding one versus another aspect of performance has been shown to have a solid effect on performance. The purpose of the present experiment is to probe how a reward scheme that punishes response errors harder than slowness would affect the results that we saw in Experiment 3.

In all of the previous experiments, a reward scheme was used that punished slow responding harsher than erroneous responding. It is easy to see that this scheme might coax participants to respond in a certain way: when in doubt, push any button as fast as possible. Even if you get it wrong and lose 10 points, that still is much better than losing the 20 points that are subtracted from your assets for responding too slowly. And in fact, you are very likely to get it right on many occasions. That is because the task of categorizing numbers into odd or even is highly overlearned and can presumably be performed with very little involvement of consciousnes attention. Once you have learned the particular response mapping in this task, you can perform it largely automatically, without any involvement of conscious monitoring. However, if that reward scheme is switched so that wrong responses are punished harder than slow responses, this will likely affect how you deal with the task demands. Now, responding as fast as possible is no longer the best strategy to avoid unnecessary loss of rewards. In contrast, the best way to do so is to monitor the stimuli and your responses as best as possible, and rather risk responding too slowly. However, this strategy is likely to interfere with the automatized nature of the task. Overinvolvement of conscious monitoring has been shown to be detrimental to the performance in well-learned tasks, a phenomenon known as *choking under pressure* (Baumeister, 1984; Jackson & Beilock, 2007). As the task here is so well-learned, performance is likely to be disrupted under a reward scheme that favors correct responding over fast responding as compared to performance under a reward scheme that works in the opposite direction. Thus, the hypothesis is that such a reward scheme affects the effects of rewards less positively than the reward scheme that was used in Experiment 3. Furthermore, performance is expected to be the about the same than that of the payoff group of Experiment 4. To see whether this is true, the present experiment was conducted.

## IV.3.1 Method

### *IV.3.1.1 Participants*

26 students of the University of Konstanz participated in this experiment (10 male, mean age 22.1). All had normal or corrected to normal vision. They were paid a base payment of 6€ and, at the beginning of the experiment, they were informed that they would have the chance to additionally gain up to 5€ depending on their performance. They were given a capital of 1000 points, which corresponds to 100 Euro cent.

### *IV.3.1.2 Apparatus*

The apparatus was the same as that used in Experiment 4.

*IV.3.1.3 Stimuli*

The stimuli were the same as those in Experiment 4.

*IV.3.1.4 Procedure*

The procedure was similar to that of Experiment 4, except for the feedback procedure where the reward scheme was different: the participants received 10 points when their response was faster than the deadline *and* correct. If their response was faster than the deadline but incorrect, they lost 20 points. If they missed the deadline, they lost 10 points, regardless of whether the response was correct or incorrect. Furthermore, the participants encountered the response deadlines in a descending order: 3 blocks with a response deadline of 650 *ms*, followed by 3 blocks with a response deadline of 525 *ms*, and finally, 3 blocks with a response deadline of 450 *ms*.

IV.3.2 Results

The new group was labeled as *punish error* (PE). The results will be presented in two steps: first, the results of the new group will be presented in isolation. Then, these results will be compared first to the subset of 26 participants in the reward group of Experiment 3 who encountered the response deadline in a descending order (renamed *punish slowness* (PS) here), and second to the subset of 26 participants in the payoff group of Experiment 3 that encountered the response deadline in a descending order.

*IV.3.2.1 PE group*

Mean latencies of correct responses were entered into a two-factor ANOVA on the within-subjects factors *Deadline* (long, medium, or short) and *Congruency* (neutral or incongruent). Accuracies were computed as in Experiment 4. SATFs for the results are displayed in Figure IV.4.

*Response times*

Both *Deadline,* $F(2, 50) = 149.2$, $p < .001$ and *Congruency,* $F(1, 25) = 85.05$, $p < .001$ had a significant effect. Response times decreased as the response deadlines became shorter, and responses to neutral stimuli were faster than responses to incongruent stimuli (438 *ms* vs. 456 *ms*). The interaction between *Deadline* and *Congruency* was not significant.

*Accuracy*

Again, *Deadline,* $F(2, 50) = 41.1$, $p < .001$ as well as *Congruency,* $F(1, 25) = 50.5$, $p < .001$ had a significant effect. Accuracies decreased as the response deadlines became shorter, and responses to neutral stimuli were more accurate than responses to incongruent stimuli (91.7% vs. 87.4%, respectively). The interaction between *Deadline* and *Congruency* approached significance, $F(2, 50) = 2.6$, $p = .085$. Thus, the FCE grew slightly larger as the response deadlines became shorter, indicating that the participants slightly relaxed the focus of visual attention.

*IV.3.2.2 PS group versus PE group*

Mean latencies of correct responses were entered into a two-factor ANOVA on the between-subjects factor *Group* (PE vs. PS) and the within-subjects factor *Deadline* (long, medium, or short) and *Congruency* (neutral or incongruent). Accuracies were computed as in Experiment 4. A SATF for the results is displayed in Figure IV.4.

*Response times*

There was a significant main effect of *Deadline*, $F(2, 124) = 491.95$, $p < .001$. Response latencies decreased with decreasing deadlines (490 *ms* for the long deadline, 441 *ms* for the medium deadline, and 406 *ms* for the short deadline). The main effect of *Congruency* was also significant, $F(1, 62) = 257.89$, $p < .001$. Responses were faster for neutral than for incongruent stimuli (436 *ms* vs. 455 *ms*). There was a significant interaction between the factors *Deadline* and *Congruency*, $F(2, 124) = 4.1$, $p < .05$, indicating that the FCE became smaller with decreasing deadlines (21 *ms* for the long deadline, 19 *ms* for the medium deadline, and 14 *ms* for the short deadline). Nor further interactions were significant or approached significance.

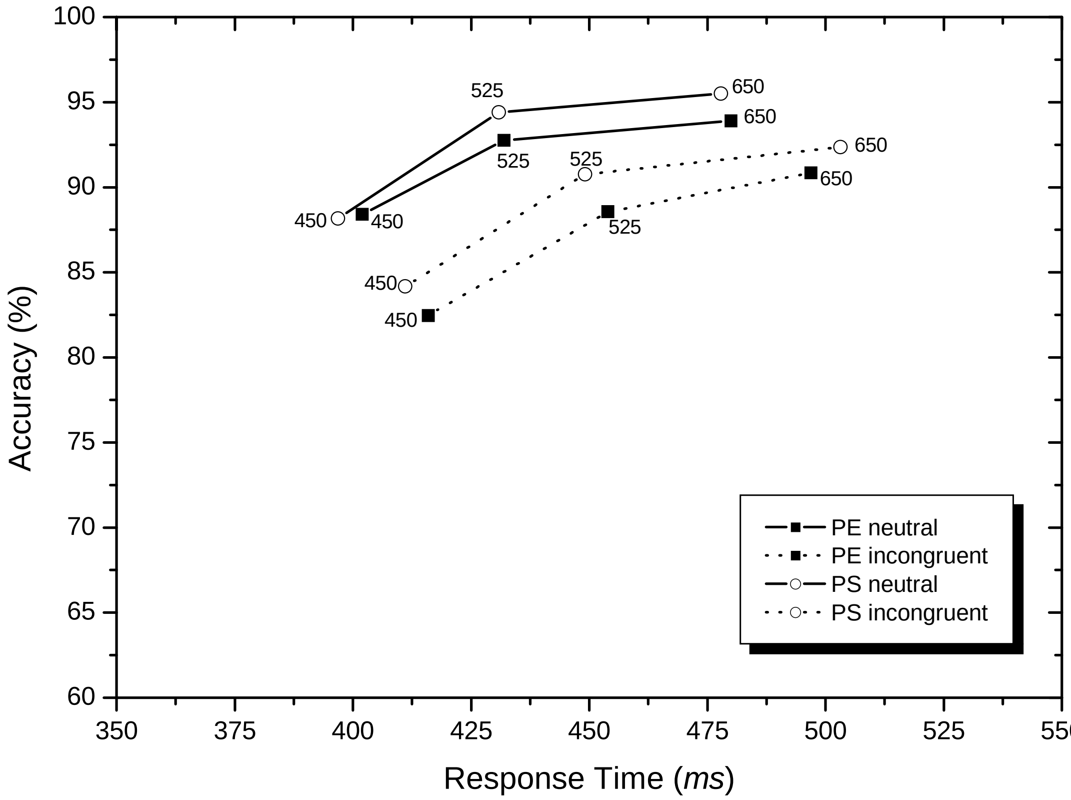


**Figure IV.4:** SATFs for the new group of Experiment 5 (PE) and the 26 participants of the reward group of Experiment 3 that encountered the response deadline in a descending fashion. Numbers at the data points indicate the corresponding deadline.

*Accuracy*

Only the two within-subjects factors had a significant effect: the main effect of *Deadline*, $F(2, 124) = 63.9$, $p < .001$, indicated decreasing accuracies with faster-growing response deadlines (93.35% for the long deadline, 91.85% for the medium deadline, and 85.91% for the short deadline). The analysis also revealed a significant main effect of the factor *Congruency*, $F(1, 62) = 120.9$, $p < .001$, indicating a higher accuracy for neutral stimuli than for incongruent stimuli (92.3% vs. 88.4%). There were no significant interactions.

*IV.3.2.3 PE group versus payoff group*

Mean latencies of correct responses and accuracies were entered into an analysis similar to that in the previous paragraph. A SATF for the results is displayed in Figure IV.5.

*Response times*

The analysis revealed a significant main effect of *Deadline*, $F(2, 124) = 400.5$, $p < .001$, indicating that response latencies became shorter with decreasing deadlines (482 *ms* for the long deadline, 440 *ms* for the medium deadline, and 404 *ms* for the short deadline). The main effect of *Congruency* was significant, too, $F(1, 62) = 215.84$, $p < .001$, with responses to neutral stiumuli being faster than responses to incongruent stimuli (433 *ms* vs. 451 *ms*). There was a significant interaction between *Deadline* and *Congruency*, $F(2, 124) = 4.75$, $p < .05$. This interaction indicates that, with decreasing deadlines, the FCE became smaller (22 *ms* for the long deadline, 19 *ms* for the medium deadline, and 15 *ms* for the short deadline). Finally, the three-way interaction between all factors was also significant, $F(2, 124) = 3.27$, $p < .05$. This indicates that the size of the FCE took a different course over the various deadlines in the payoff group than in the PE group (24 *ms* for the long deadline, 17 *ms* for the medium deadline, and 14 *ms* for the short deadline in the payoff group, and 17 *ms* for the long deadline, 12 *ms* for the medium deadline, and 14 *ms* for the short deadline in the PE group).

*Accuracy*

There were two significant main effects: *Deadline*, $F(2, 124) = 179.0$, $p < .001$, indicating decreasing accuracies with decreasing deadlines (92.2% for the long deadline, 90.0% for the medium deadline, and 83.5% for the short deadline), and *Congruency*, $F(1, 62) = 115.24$, $p < .001$, which indicated more accurate responses to neutral than to incongruent stimuli (90.8% vs. 86.4%). Furthermore, there was a significant interaction between *Group* and *Deadline*, $F(2, 124) = 5.1$, $p < .01$: thus, the accuracy was similar in the two groups for the long deadline only, wheras it was worse in the payoff group than in the PE group for the remaining two deadlines. Finally, there was a significant interaction between *Deadline* and *Congruency*, $F(2, 124) = 13.05$, $p < .001$. It indicated that the FCE grew larger as the deadline grew shorter (2.35% for the long deadline, 4.65% for the medium deadline, and 6.22% for the short deadline).

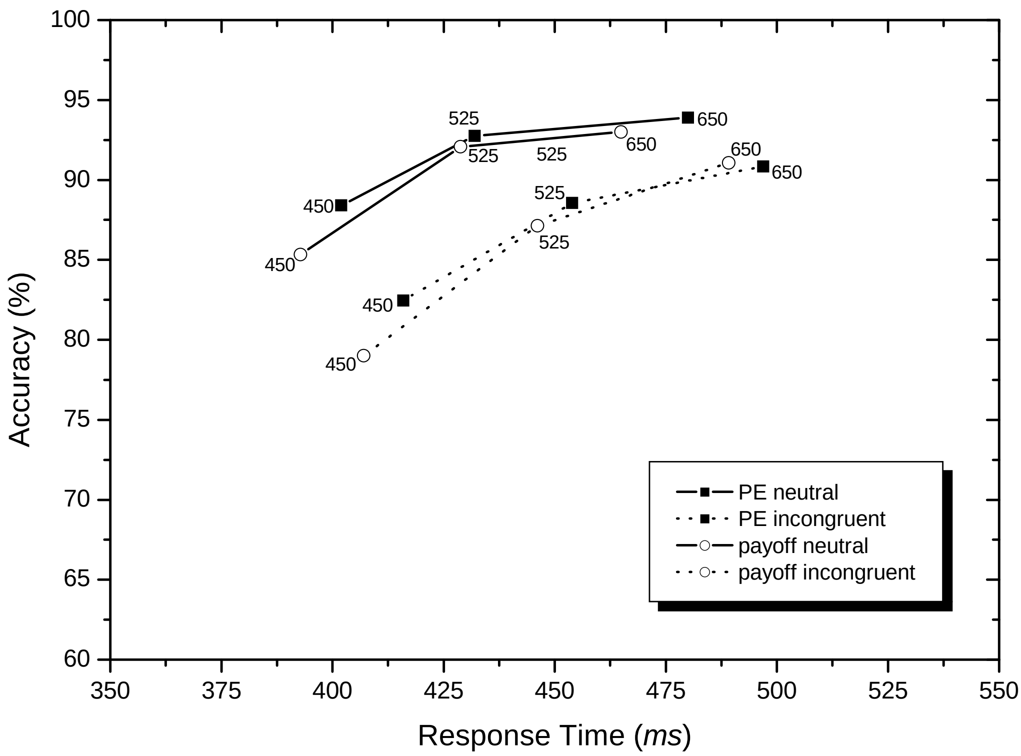


**Figure IV.5:** SATFs for the new group of Experiment 5 (PE) and the 26 participants of the payoff group of Experiment 3 that encountered the response deadline in a descending fashion. Numbers at the data points indicate the corresponding deadline.

IV.3.3 Discussion

The present experiment was designed to test the assumption that participants would respond differently to a reward scheme that punishes errors harder than slowness as compared to a reward scheme for which this contingency is reversed. Specifically, it was hypothesized that a) the former scheme would be less effective in increasing performance than the latter one, and b) that the performance of the participants who worked under the former scheme would be about the same than that of the payoff group of Experiment 3. Both predictions were generally confirmed. As you can see in Figure IV.4, the performance of the group working under the PE scheme was inferior to that of the group working under the PS scheme, although not significantly so. What is the reason for this finding? One possible explanation was suggested in the introduction to this experiment: it could be that the PE scheme led participants towards an overmonitoring of their responses, resulting in an increased error rate. Another possibility is that it is simply easier to control the speed at which a response is emitted than the accuracy of it. That would seem plausible from an evolutionary point of view, as speed is often more important than accuracy in real life (Gigerenzer & Goldstein, 1996). From an introspective point of view, this explanation makes sense, too: if you are required to respond faster, it is easy to do so by terminating the information-accumulation process earlier and responding faster. In contrast, it is hard to see how the accuracy of responses could be improved, except for the mechanisms that were described in Study II (Experiment 3). Obviously, these mechanisms could either not be mobilized at all under this reward scheme, or could not be used, for example, because these mechanisms too favor fast responses. Clearly, more researched is needed to come to a satisfying explanation. But in any case, the results of this experiment show that the nature of the reward scheme mediates the effects of rewards on performance quite remarkably.

The second finding that there were hardly any differences between the payoff group of Experiment 3 and the PE group again underlines this decisive role that is played by the reward scheme when it comes to increasing performance: not only do rewards have to be presented, but the reward scheme must support mobilization and usage of appropriate attentional resources, otherwise the performance of the participants will be virtually indistinguishable of that of participants who receive no performance-contingent monetary rewards. Of course, to be completely clear about these findings, there should be another payoff group that also works under the PE scheme. However, for economic reasons I relinquished this option.

All in all, this experiment highlights the role that the reward scheme plays as a mediator for the effects of rewards on performance. Nevertheless, as null results like the one found in this experiment have to be dealt with carefully, I aimed to extend the findings of the present experiment in Experiment 6.

## IV.4 Experiment 6

Experiment 5 demonstrated that the behavior of the participants depends not only on the presence or absence of monetary rewards, but also on the question of what aspect of performance is rewarded. So far, this was only demonstrated in a between-subjects design. However, it would be interesting to know whether this also holds in a within-subjects design. Specifically, are subjects capable of adapting their behavior to the reward scheme flexibly, or does the behavior towards one scheme simply carry over to the next? Or stated otherwise, do subjects behave optimally, or do they prefer to limit the effort they invest (and thus save energy) and settle for a non-optimal performance that yields a non-optimal but still acceptable payoff. Answering these questions would not only yield insight into the issue of how flexible these response strategies are, but also give hints as to whether it is rather hard or rather easy for participants to adapt their response strategy to the tak demands. Furthermore, finding that participants are indeed capable of adapting their behavior flexibly to the reward scheme would qualify the findings of Experiment 5: although it was clear from the results of this experiment that a reward scheme that punishes slowness rather than errors is superior to a reward scheme in which that contingency is reversed, this difference was not statistically significant.

To investigate these issues, I set up an experiment that was similar to previous experiments, except for the fact that the participants alternated between two different reward schemes over the course of the experiment. I expected performance in the condition in which slowness was punished harder than errors (PS condition) to be superior to that in the condition in which errors were punished harder than slowness (PE condition). In order to keep the duration of the session within reasonable limits, only neutral stimuli were used in the present experiment, in which a within-subjects design was used.

## IV.4.1 Method

### *IV.4.1.1 Participants*

16 students of the University of Konstanz participated in this experiment (4 male, mean age 23.1). All had normal or corrected to normal vision. They were paid a base payment of 6€ and, at the beginning of the experiment, they were informed that they would have the chance to additionally gain up to 5€ depending on their performance. They were given a capital of 1000 points, which as usual corresponds to 100 Euro cent.

### *IV.4.1.2 Apparatus*

The apparatus was the same as in Experiment 5.

### *IV.4.1.3 Stimuli*

Stimuli were the same as in Experiment 5, except for the fact that there were only neutral stimuli in the present experiment.

### *IV.4.1.4 Procedure*

Participants were seated at a viewing distance of 45 *cm* in front of the screen. A trial started with the presentation of a fixation cross at the center of the screen for 400 *ms*. After a cue-stimulus interval of 600 *ms*, the stimulus array appeared for 165 *ms*. The screen remained blank until the participant responded. After the response, a feedback screen appeared for 1000 *ms*. After a blank screen of 1000 *ms* duration the next trial started. The task of the participants was to indicate whether the target numeral was odd or even by pressing a corresponding response button of the mouse with their index or middle finger of the right hand. Response errors were signaled by a short sound. The participants in both groups performed 9 blocks of 64 trials each, under each of the two reward schemes (see below), thus totalling 18 blocks.

The response deadline was decreased in two steps: in both experimental groups, the participants began with 6 blocks in which there was a response deadline of 650 *ms* (long deadline), followed by 6 blocks with a response deadline of 525 *ms* (medium deadline) in the second block, and finally 6 blocks with a deadline of 450 *ms* (short deadline). The participants alternated blockwise between the two reward schemes. These two reward schemes were as follows: under the punish slowness reward scheme (PS condition), participants received 10 points for a correct response that was fast enough, they lost 10 points if their response was wrong but still fast enough, and they lost 20 points if their response was too slow. Under the punish error reward scheme (PE condition), the participants again received 10 points for a correct and fast enough response, they lost 20 points for an erroneous response that was still fast enough, and they lost 10 points if their response was too slow. Half of the participants started the experiment with the PS condition, while the other half started with the PE condition.

As in the previous experiments, an additional feedback screen was shown for maximally 60 seconds that displayed information about participants' overall performance.

## IV.4.2 Results

Mean latencies of correct responses were entered into a two-factor ANOVA on the within-subjects factors *Reward Scheme* (PS condition or PE condition) and *Deadline* (long, medium, or short). Accuracies were computed as in the previous experiments. A SATF for the results is displayed in Figure IV.6.

### *IV.4.2.1 Response Times*

The analysis revealed a significant main effect of *Reward Scheme*, $F(1, 15) = 7.67$, $p < .05$. Response times were slightly faster in the PS condition than in the PE condition (425 *ms* vs. 430 *ms*). There was also a significant main effect of *Deadline*, $F(2, 30) = 82.16$, $p < .001$. This indicates that response times were the faster the shorter the deadline was (465 *ms* for the long deadline, 422 *ms* for the medium deadline, and 395 *ms* for the short deadline).

*IV.4.2.2 Accuracy*

*Deadline* was the only factor that had significant main effect, $F(2, 30) = 39.9$, $p < .001$, which indicated decreasing accuracies with faster-growing response deadlines (93.9 for the long deadline, 89.6 for the medium deadline, and 81.4 for the short deadline).

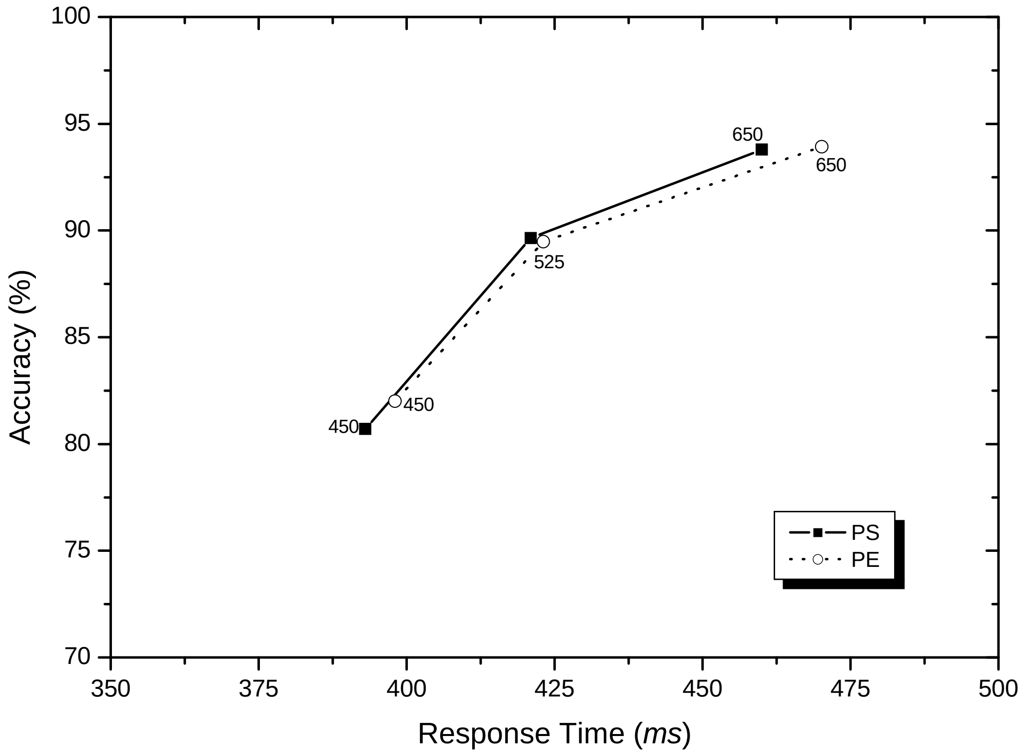


**Figure IV.6:** SATFs for Experiment 6. Numbers at the data points indicate the corresponding deadline.

IV.4.3 Discussion

The goal of the present experiment was to investigate whether participants would change their behavior from block to block to adapt to the different demands of two different reward schemes. Using one reward scheme that punishes slowness and one that punishes errors, the results indicated that the participants did behave slightly differently under the two schemes, but this difference was unlike the difference that was seen in earlier experiments. Specifically, the difference was seen in the response latencies rather than in the accuracies. What does this mean? Obviously, participants are able to adjust their response strategy to the task demands quite flexibly, on a block-to-block basis. However, this adjustment is suboptimal. Their might be several reasons responsible for this. First, it could be that the process of adjusting the response strategy is rather cumbersome in and of itself, and needs some time to be fully implemented. However, the task demands change from block to block, so there would be not enough time available for that adjustment to be fully implemented. Second, the motivation to adjust might be rather low, as the expected reward is also low. Therefore, the adjustment might be executed rather sluggishly.

In any case, this experiment provides evidence that the response startegies that are routinely employed under the PS and PE scheme are flexible enough to allow the participant to adjust to task demands. It remains open to further research whether this adjustment can be optimized, for example by offering higher rewards.

## IV.5 Intermediate conclusion

Over the course of three experiments, Study III demonstrated the importance of the ordering of the response deadlines and the reward scheme as mediators of the effects of monetary rewards on performance.

Experiment 4 demonstrated that an increase in performance is most likely to occur – at least in the context of the flanker task – if the response deadlines are arranged in a descending fashion. Presumably, this arrangement is optimal for learning to perform the task. An ascending deadline order also yields a (statistically non-significant) increase in performance, but this increase is seen rather in terms of response speed than in terms of accuracy. Most likely, this setup increases the stress put on the participants and induces an inclination to respond faster. Finally, if response deadlines are organized in a randomized fashion, no differences are seen between rewarded and unrewarded participants.

Experiment 5 made it clear that it is vital to reward speed rather than accuracy in order to observe an increase in performance. If accuracy rather than response speed was rewarded, the performance of the participants was virtually indistinguishable from that of participants who received only a flatrate payment.

Finally, Experiment 6 demonstrated that participants are able to flexibly adapt their behavior block-by-block, according to which aspect of performance is rewarded in a given block. However, these adaptions seem to be suboptimal.

All in all, Study III identified at least two important mediators that one should remember when designing flanker tasks that incorporate performance-contingent rewards. A lot of experiments will be necessary to learn more about these and other mediators of the relationship between rewards, effort, and performance in the future, and the experiments in the present study lay a good foundation to do so.

# V.

# General Discussion

## V.1 Summary of the results

In the present work, 6 experiments were conducted in order to investigate the influence of monetary rewards on performance in the flanker task. More specifically, it was hypothesized that monetary rewards would increase performance in a standard flanker task, either in terms of speed or accuracy, or both.

From the outset, it was clear that there are many factors that mediate the effects that monetary rewards have on performance (see General Introduction). Thus, a pilot study was necessary to determine the optimal conditions to investigate these effects in the context of a visual selective attention task. For example, it was not obvious how the various deadlines should be arranged. Therefore, in Study I, two pilot experiments were conducted in order to lay out a general experimental design.

Experiment 1 was designed to probe whether rewards lead to any observable effect at all. The results hinted at the possibility that the rewards did indeed improve performance. However, the methodology was suboptimal. Most importantly, Experiment 1 confounded the factor ‘learning’: learning was unequal between the deadline condition and the reward condition. Therefore, in Experiment 3, a between-subjects design was used in which one group received performance-contingent rewards and encountered a response deadline, whereas the other group encountered the same response deadline, but without performance-contingent rewards. Again, the effects of the rewards pointed in the direction of an increased performance in the rewarded group. All in all, the results of the pilot study suggested that there are at various important factors to keep in mind when setting up an experiment that is designed to examine the effects of rewards on performance. For example, it must be ensured that methodological factors like stimulus eccentricity or stimulus size are chosen in such a way that they result in a moderate task difficulty, so that the majority of participants have the necessary skill level to cope with the task demands.

To solidify the claim that monetary rewards increase performance and to extend this finding beyond this basic premise, Study II was conducted. In this study, the concern was not only to once more observe positive effects of rewards on performance, but also to probe the nature and the specifity of the mechanism that is responsible for the observed improvement. Furthermore, to exclude the possibility that the positive effects seen in Study I were due to differences in feedback rather than to the monetary rewards, symbolic rewards were introduced for the control group. The results indicated that rewards enhance the quality of sensory coding, thus leading to an improved stimulus representation. However, that enhancement was not so specific that it would lead to a differential modulation of the zoom lens of visual attention, although there were hints that pointed towards the possibility that such an effect could be observed under slightly different conditions. It also became clear that the rewards have to be real in order to have an effect. Mere symbolic rewards did not lead to an improved performance.

Study III extended the findings of Study II and investigated two main questions: first, how does the order in which the participants encounter the response deadlines modulate the effects of monetary rewards? Second, how does the rewarded dimension (response speed versus response accuracy) modulate these effects? Consequently, in Experiment 4, the performance of participants who encountered an ascending versus a descending versus a randomized deadline order was compared. The results made it clear that, whereas both the descending as well as (at least by tendency) the ascending order led to a performance improvement in the rewarded group, the randomized order did not do so. Thus, it was concluded that the order in which the deadlines are presented to the participants are highly important as a mediator of the effects of rewards on performance.

In order to investigate the effect that the rewarded dimension has, an experiment was conducted in which the reward scheme was adjusted to punish response errors harder than slowness, unlike in previous experiments. As a result, monetary rewards did not lead to an increase in performance under this reward scheme. Thus, it was concluded that the reward scheme clearly influences the effects of rewards on performance. One further experiment was carried out in order to examine the flexibility of participants' response strategies under the two different reward schemes. In a within-subject experiment, participants encountered both schemes, alternating after each single block. The results demonstrated that in this setup too, a payoff scheme that punishes slowness harsher than errors is still superior to a scheme that works in the opposite direction, although this time, the difference was seen in terms of response times rather than accuracy. Thus, the strategies used under these two reward schemes seem to be flexible, but only to a certain degree, as the adaptation was rather suboptimal. However, it is likely that flexibility could be increased under more optimal task conditions.

The most important results from Study III thus were the following two: 1. The order in which deadlines are administered (ascending, descending, or randomized) is crucial for observing positive effects of monetary rewards. Only when deadlines are arranged in a descending order do the rewards have a significantly positive effect on performance in terms of higher accuracy. If deadlines are arranged in ascending order, a non-significant trend towards faster response times is observed, whereas a randomized deadline order does not result in any beneficial effect of rewards on performance. 2. At least for the type of task investigated in this work, rewards have a positive effect only when high response speed is rewarded, but not when good accuracy is rewarded.

## V.2 Integration of the results with theories of the effects of rewards on effort and performance

The general picture that emerges from the results fits well into the existing literature on rewards and performance. They emphasize the critical role of mediating factors for the level of effectiveness of rewards. This result is in line with the general point made by Bonner and her colleagues (Bonner, et al., 2000; Bonner & Sprinkle, 2002) that there is a multitude of factors to be kept in mind when trying to influence behavior with monetary rewards. The present research confirmed the critical role of these factors, of which task difficulty, self-efficacy, and rewarded dimension of performance are only three examples.

The present results also add to the growing body of literature that is concerned with the intricate interactions between motivation and cognition. They address one previously under-investigated aspect within this field, namely, whether or not monetary rewards are actually capable of increasing performance, rather than merely modulating behavior in one way or another. It also sheds light on the questions of which mechanism is responsible for such an increase in performance, and what the conditions are under which an improvement can be observed. The results indicate that, at least for the task type and setups used in this work, even relatively small monetary rewards are capable of increasing performance, if the modulating factors are adjusted correctly. As for the mechanism responsible for this effect, the SATFs obtained in Experiment 3 hint towards an enhanced quality of sensory coding due to the rewards. However, as ususal when one is working with rewards in an experiment, one has to keep in mind a lot of other factors when judging a finding like this, for example, the magnitude of the reward. The findings demonstrate that rewards of the magnitude used in this work, in a task like that used in this work, lead to a recruitment of specific cognitive resources (namely, the enhanced quality of sensory coding). However, it is entirely possible that a variation of one of these or other factors could lead to a recruitment of even more (or more specific) resources. For example, it cannot be ruled out that offering higher rewards could affect the zoom lens of visual attention.

The present results fit nicely into the attentional effort network as proposed by Sarter (Sarter et al., 2006): as task demands increase, the need to engage attentional control mechanisms grows stronger. However, these adaptations are only executed if the motivation to do so is sufficient. In the case of the present work, the motivation was induced by the monetary rewards. In contrast, if mere symbolic rewards that had no real value were offered, the required motivation just was not given, and consequently, no control mechanisms to guard performance were engaged. Thus, the results demonstrate a close link between the motivation system and visual selective attention.

## V.3 Specifity of the mechanism engaged by the monetary rewards

A rather surprising result was that rewards did not significantly influence the zoom lens of visual selective attention. Generally, the FCE remained constant in the rewarded conditions, whereas it increased in the non-rewarded conditions (cf. Experiment 3). One interpretation of this result is that, in the unrewarded conditions, participants relaxed their spatial sensitivity, as a narrow focus presumably requires effort, and due to the lack of rewards, there was no motivation to invest this effort. Conversely, in the rewarded conditions, participants detected their declining performance, but they were motivated to invest the effort that is necessary to keep the focus narrow, and thus prevent a further performance decline.

This line of reasoning is perfectly in line with the concept of attentional effort as adopted by Sarter (Sarter, et al., 2006).

However, there is another line of research that is concerned with a related question: how do affective states influence the scope of visual selective attention (e.g., Derryberry, & Tucker, 1994; Gable & Harmon-Jones, 2008; Rowe, Hirsh, & Anderson, 2007; Schmitz, De Rosa, & Anderson, 2009)? As motivation and emotion are intricately linked (see General Introduction), these results are of interest for the present research. However, the results in that field are rather a mixed bag. Some researchers report that positive emotions lead to a broadening of the focus of visual attention (Rowe, et al., 2007), whereas others report just the opposite (Gable & Harmon-Jones, 2008). Derryberry and Tucker (1994) reported that failure (or rather negative feedback) narrows the scope of attention, thus impairing detection of peripheral targets and global (as opposed to local) forms. Similarly, anxious individuals show a preference for processing local as opposed to global targets (Derryberry & Reed, 1998). Both the emotions of failure and anxiety could in principle be present (in a mild fashion) in the reward groups of the experiments reported in this work: as the task demands increase with the shorter-growing deadlines, the probability for failure increases, as well as the anxiety associated with losing rewards. Ironically, negative emotions might thus actually lead to a better performance in the context of the flanker task, as a narrowed focus is beneficial here, whereas it may be not so beneficial in other domains (the well-known tunnel vision comes to mind here). Consequently, it seems possible to increase focusing even more by offering higher rewards. These should also induce higher anxiety and a more profound sense of failure. Clearly, these questions need further experimental evidence in order to be resolved.

## V.4 The modulating effects of the rewarded dimension

One aspect of our findings that needs to be discussed is that the improved performance we observed is confined to situations in which response speed rather than accuracy is rewarded. The question arises why this is so. The evolutionary perspective offers some hints: in the real world, it is often far more important for the survival and the reproduction of an organism to react in a quick and dirty manner rather than in a slow but one hundred percent accurate manner. In other words, organisms are generally better off when they rely on computational mechanisms that are correct most of the time (but far from one hundred percent) and extremely fast, because they just do not have infinite time available for making decisions. Gigerenzer and his colleagues coined the term *fast and frugal heuristics* for this kind of mechanisms (Gigerenzer & Goldstein, 1996; Gigerenzer & Todd, 1999). More generally, these mechanisms belong to the class of *satisficing* mechanisms, a term coined by Herbert Simon (Simon, 1956; Simon, 1982). The notion references the fact that in the real world, information-processing systems rarely need to optimize. All they need to be capable of is to produce satisfying/sufficient results. One famous example to illustrate this fact is mate choice (Gigerenzer & Todd, 1999): nobody has the time to evaluate all potential mates and then pick the best one. Rather, once a potential mate lives up to certain standards, he or she is likely to be chosen. It may not be the best of all choices, but given that picking a mate in this fashion saves a lot of the limited resource 'time', it is a satisfying and clearly environmentally rational choice.

So the key to understanding the effect that the rewarded dimension has lies in the fact that humans evolved in a threatening, hostile environment in which they were subject to all kinds of threat all the time. Therefore, in most cases, it is far more conducive to an organism's well-being and his chances of propagating his or her genes to set the speed-accuracy tradeoff in such a way that a relatively high false alarm rate is allowed, as an error would potentially result in the organism's death. Accordingly, humans presumably evolved to err on the side of reacting quickly to uncertain information of threat, rather than waiting for more information to be accumulated, as it could be too late for the right decision right then. The bottom-line is that individuals have to make decisions with limited amounts of time and knowledge, and as errors are potentially extremely costly, they evolved to accept a higher rate of false alarms for the sake of avoiding these costly errors. This is in line with the concept of bounded rationality (Simon, 1982). There are already some modern models of choice that acknowledge the idea that there might have been an evolutionary pressure towards speed of decisions (Bogacz, Usher, Zhang, & McClelland, 2007). The explanation is also consistent with the idea of the existence of two decision-making systems in the human brain that are responsible for making decisions in situations of threat (LeDoux, 1996; Morris, Öhman, & Dolan, 1999), one of them subcortical, and the other cortical. These two systems differ in terms of their speed-accuracy tradeoff: whereas the subcortical pathway allows for fast but inaccurate decisions, the cortical pathway delivers slower but more accurate decisions. As Trimmer and his colleagues (Trimmer et al., 2008) have shown, the operations of the subcortical pathway can be modeled by using simple signal detection theory, so the idea that organisms trade speed for accuracy to come to satisficing decisions may be pretty accurate.

However, there is another possible account: it could be that the response deadline might prompt participants to finish the information accumulation process too early. Generally, higher accuracy is achieved by trading off response speed for the sake of more time to accumulate information (Bogacz et al., 2009). However, with a response deadline impending, this is rather difficult to achieve adequately, as the time limit interferes with the need to take more time to accumulate more information, especially if you can never be sure when the time limit will be reached.

There is yet another alternative account for the result that it makes a difference whether speed or accuracy is punished harder. This account draws more on the phenomenon of ‘choking on the money’ (Mobbs, et al., 2009). It is reasonable to assume that the classification of numbers as either odd or even is highly overlearned in educated people like university students. A characteristic of such highly automatized behavior is that it is performed without the involvement of consciousness, or conscious attention (Norman & Shallice, 1986). In fact, conscious attention can be harmful to the performance of automated behavior. Two well-known examples that illsutrate this fact are trying to walk consciously, or tying one’s shoes in a conscious, step-by-step manner. However, when the stakes are high, for example, in a professional level soccer penalty shootout, people try to do particularly well, and therefore start monitoring their own actions more closely than they normally would. While it introspectively feels to be the right thing to do, in reality, for highly skilled players, it can actually result in a considerable performance decrement, a phenomenon well known as choking under pressure (cf. Baumeister, 1984; Jackson & Beilock, 2007). A similar phenomenon might arise in the case when errors are attached to a greater monetary loss than slowness. In such a scenario, people might try to adapt to these conditions by consciously trying to avoid errors by monitoring their decisions. However, as the task (categorizing oddness of numbers) is highly overlearned, such conscious monitoring might result not in less, but actually in more errors than would be the case if they would simply relax their control processes and let the automatic processes take care of themselves.

However, it is also reasonable to assume that the results would look different if the stakes were higher. For example, in our flanker task, if errors would be punished very harshly (say, 100 points per error) and/or reward correct reactions highly, chances are that the participants would invest far more effort in adapting their response strategy to these constraints.

## V.5 Implications for the design of experiments concerned with the effects of rewards on performance

In experiments involving response deadlines, a current common procedure is to randomize these deadlines across blocks. However, as the results of Experiment 4 suggest, this bears the danger of obscuring possible effects of rewards on performance. As it was demonstrated, it is more likely to observe positive effects of rewards if response deadlines are arranged in such a way that they promote learning and the build-up of self-efficacy with regard to the task at hand. In most cases, this would mean arranging the deadlines in a descending order, beginning with the longest. In contrast, if you arrange the deadlines randomly, you run the risk of compromising self-efficacy and learning, resulting in either a negative or no effect at all of rewards. The reason why this is so can easily be understood using the framework theory of Bonner and Sprinkle (Bonner & Sprinkle, 2002). In this framework, it is posited that the effect of rewards is moderated by a number of environmental, reward, task and person variables. One factor that these authors particularly emphasize is the fit between an individual’s skill level and task complexity. As is easy to see, within a task like the one used in the present work, the response deadline is a major determinant of task complexity. However, if they are arranged in descending order, this order gives a participant the chance to gradually develop his skill. Metaphorically speaking, you start by jumping over a bar that is reasonably low above the ground, and you are given sufficient time to train with this height. By the time it is finally raised, your skill level has already developed to the point were you are confident that you can beat the new height too. Conversely, it would be daunting to begin with the highest bar, because you would get discouraged quickly.

Thus, arranging deadlines in a descending order entails several effects that all contribute to increasing performance in the task. Self-efficacy is built, which is known to affect task performance positively (Stajkovic & Luthans, 1998). Simultaneously, skill learning is promoted by that ordering, which again also contributes to the development of self-efficacy. Finally, by gradually raising the difficulty level without discouraging the participant fosters intrinsic motivation. If you arrange the deadlines in any other way, you will compromise all these factors, and as these are all extremely important mediators, probably eliminate or at least considerably weaken any positive effect of rewards.

## V.6 Further implications for experimental designs: flatrate or performance-contingent payment?

The present results do also have implications for the debate between psychologists and economists as mentioned in the General Introduction: when conducting an experiment, is it necessary to reward participants according to their performance, or is it better not to use performance-contingent rewards, and instead use a flatrate payment? What the present results tell us is that the answer to this question depends on the purpose of the research project in question, as well as its procedure. If the purpose is to find ways in which to boost performance in a task, it certainly is advisable to consider the use of performance-contingent rewards. However, it is then also necessary to choose the reward scheme wisely. For example, as we have seen, punishing errors harder than punishing slowness results in a zero effect of rewards (at least in the context of the flanker task). Furthermore, adapting the difficulty of the task to an individual's skill level is advisable when using rewards. For other purposes, such as investigating information processing dynamics, monetary rewards may not necessarily be useful, as they complicate the experimental setup. For example, if the aim is to obtain speed-accuracy functions in order to investigate information-processing dynamics, it might be more suitable to use response deadlines or response signals alone, without any monetary rewards (see Wickelgren, 1977).

The bottom line is that monetary rewards are nothing more and nothing less than a further tool in the experimenter’s toolbox (cf. Read, 2005), which needs to be applied with the same care and thought as any other tool. Depending on what a researcher wants to do, it can be either a useful or a useless tool, or one that might as well be replaced by another (cheaper) one.

## V.7 Individual differences and the role of the individual skill level

In the present research, the focus was primarily on the modulatory effects that rewards have in the flanker task, how specific these effects are, and how they are affected by various methodological variations. Individual differences were explicitly not the focus of this research. However, future research will definitely have to address these issues, for they clearly have an important influence on the relationship between rewards, effort, and performance. Among the factors that supposedly exert a considerable influence on these relations are behavioral inhibition/behavioral activation or reward drive (e.g.,Beaver et al., 2006; Engelmann, et al., 2009; Scheres & Sanfey, 2006), the individual discounting rate (Ainslie, 1975; Shamosh, et al., 2008), the intrinsic motivation to perform well in the given task (Deci, 1971; Deci, et al., 1999), an individual’s cognitive style (Armstrong, 2000), sex (Ermer, et al., 2008), trait anxiety (Derryberry & Reed, 1998), and general sensitivity to monetary rewards.

Nevertheless, the present results in fact do allow some preliminary glimpses into this issue. Presented in figures V.1 and V.2 are the graphs for the individual data of two participants of an experiment that is not reported in the present work, but that was similar to Experiment 1. Furthermore, it is reported how much the respective participant gained, split up for congruent and incongruent stimuli.

The experiment had two parts: in the first part, the participants performed a standard flanker task. Neither a response deadline nor rewards were offered. Then, in the second part, rewards were introduced alongside a response deadline. As you can see from the graphs, the participants differed considerably in their individual skill level: participant A clearly had a lower skill level than participant B, as can be seen when you compare their performance in the first part of the experiment. Consequently, whereas participant B had no problems whatsoever dealing with the task demands facing him or her in the second part of the experiment, participant B suffered a severe loss in rewards. Thus, these graphs highlight the importance of the fit between the individual skill level of a participant and the task demands. The question arises of how the task demands could be adapted to an individual's skill level. Obviously, one way to do so would be to determine the response deadlines individually, on the basis of the performance in a baseline block that has a response deadline that is so generous that each and every participant is capable of handling it (or even no response deadline at all).

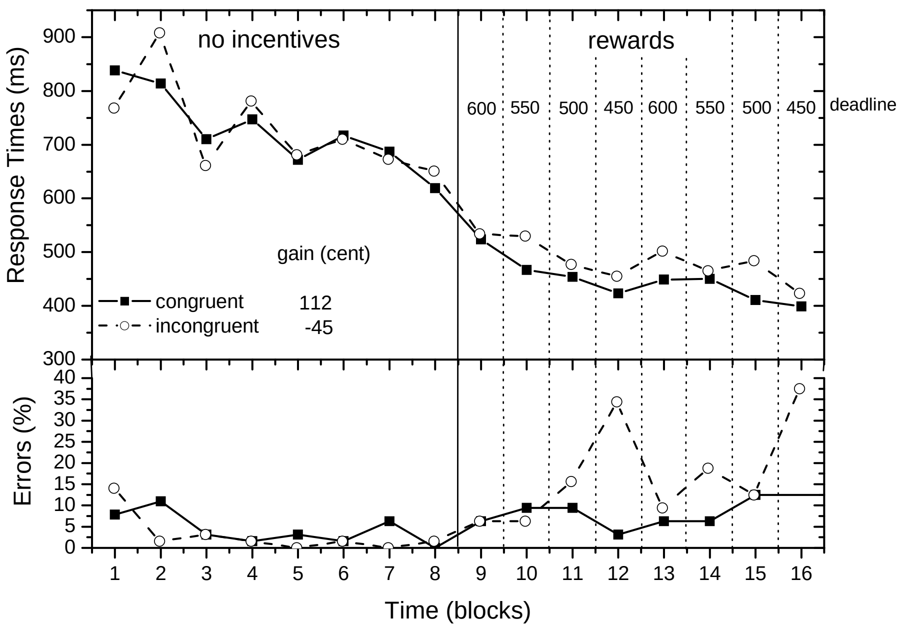


**Figure V.1:** Data of an individual participant from an experiment not reported in the present work

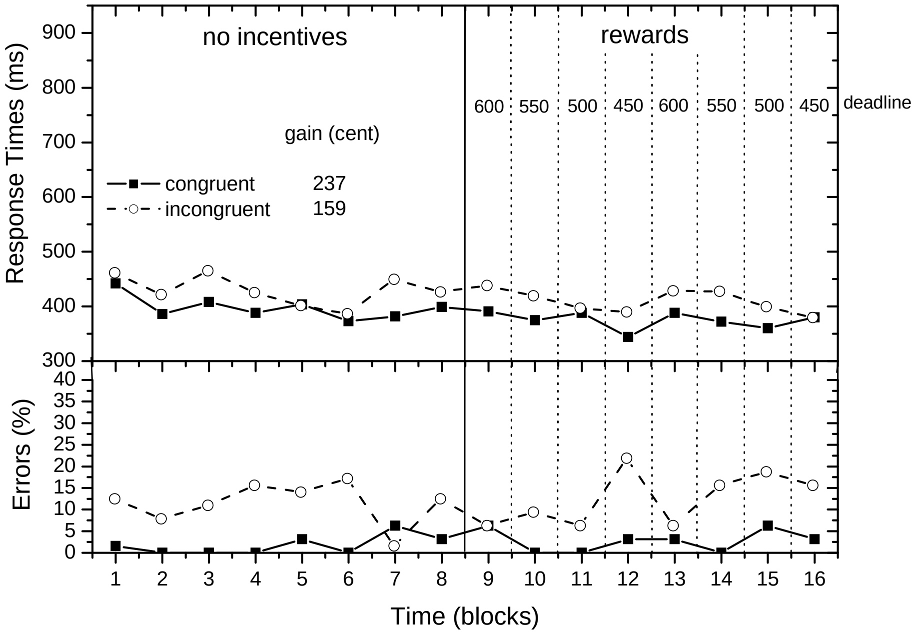


**Figure V.2:** Data of an individual participant from an experiment not reported in the present work

In fact, the results of preliminary experiments in which this methodology was applied suggest that this could strengthen the effects of rewards on performance. However, there is also a caveat to this methodology: naturally, when there is an individual deadline for each participant, the data suffers from a considerable between-subjects variance. Hence, the methodology needs to be refined before convincing evidence can be gathered. This, however, is up to future research.

## V.8 Limitations of the present work

Although a lot of convincing results were produced in the present work, it is clear that there are several shortcomings to it that should be addressed in future research concerned with the same topic.

For one thing, it is possible that the framing of the rewards might have obscured some effects, particularly an effect on visual selective attention. This is because in a given trial, the participants could win as well as lose money. However, it is well-known that people weigh losses more heavily than gains (losses are valued higher than gains by a factor of about 2, cf. Tversky & Kahneman, 1992), a phenomenon known as loss aversion (Kahneman & Tversky, 1984). Therefore, it is well possible that clearer results might have been observed if a reward scheme had been used that allows only for losses, not gains on a given trial (or vice versa).

Using gains alongside losses could be problematic in another way. It has been hypothesized that rewards (gains) and threat (losses) each trigger a separate motivational system (Cacioppo & Gardner, 1999; Carver, 2001). Depending on which of these two systems is engaged in a given moment, the influence of affect on cognition differs. If the appetitive motivational system is triggered, this presumably leads to a more controlled information processing mode (Ashby, Isen, & Turken, 1999), as it increases dopamine level in brain areas that are particularly involved in cognitive control, such as the PFC and the ACC. However, on the other hand, there are authors that suggest exactly the opposite result, namely, an inhibition of cognitive control by appetitive motivation (Bush, Luu, & Posner, 2000). It is difficult to decide between these two accounts, as there is evidence for both: an improvement of cognitive control with appetitive motivation (Gable & Harmon-Jones, 2008; Kuhl & Kazen, 1999), as well as an impairment of cognitive control by positive affect (Phillips, Bull, Adams, & Fraser, 2002; Rowe, et al., 2007). Altogether, this issue needs further clarification based on research that focuses more closely on exactly what mediators influence whether cognitive control is enhanced or impaired by appetitive or aversive motivation. Given the enormous range of mediators that were mentioned in the introduction, it is hardly surprising that the results vary so much.

What would definitely be worth investigating is how varying the magnitude of the rewards influences the results. Intuitively, one would assume that increasing the magnitude should also increase the effect of the rewards on performance. However, one cannot be sure about that. Given the phenomenon of choking on the money (Mobbs, et al., 2009), and given that it depends on the task and on so many other factors whether a reward is regarded as high or low, it would be interesting to know where the boundaries are in the context of the flanker task. The literature on this topic is inconclusive: on the one hand, there are studies indicating that higher rewards increase – for example – the firing rate in Brodmann area 46, indicating an enhancement of spatial working memory compared to lower rewards (Leon & Shadlen, 1999). On the other hand, a meta-analysis by Bonem and Crossman (Bonem & Crossman, 1988) indicates that increasing reward does not have any measurable effect on performance. Thus, investigating this question would help to elucidate this issue further and would certainly come in valuable.

## V.9 Implications for the wider field of psychoeconomics

The present work has also implications for the larger field of psychoeconomics (more often referred to as *neuroeconomics)* (Loewenstein, Rick, & Cohen, 2008; Sanfey, Loewenstein, McClure, & Cohen, 2006) as its results add to the knowledge about the interactions between emotions and cognition in the context of perceptual decision making. The results stress the fact that the speed and the quality of perceptual decisions depend, in part, on the rewards or punishment associated with the decision. If the participants are motivated to gain rewards or avoid losing rewards, they invest more effort (attentional effort in the present case) into the execution of perceptual decisions. That is, compared to the case where there are no rewards, additional cognitive resources are engaged. The results of Experiment 3 even delivered evidence regarding the nature of this engagement. In the context of a larger framework of perceptual decision making (e.g., Heekeren, Marrett, & Ungerleider, 2008), the results carry us a step further towards explaining where exactly in the course of perceptual decision making monetary rewards exert their influence (and how), and how humans trade speed and accuracy when forming a perceptual decision with associated rewards.

All in all, the present work delivers important contributions to the understanding of how humans form perceptual decisions, how these decisions are affected by monetary rewards, and – in a larger context – how emotion and motivation systems interact with cognition and visual attentional focusing. It also draws attention to the importance of mediating factors and the design features experiment investigating the effects of rewards on performance, such as the optimal arrangement of response deadlines and the decision about what aspect of performance should be rewarded.

# VI.

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# A) Erklärung

Ich erkläre hiermit, dass ich die vorliegende Arbeit ohne unzulässige Hilfe Dritter und ohne Benutzung anderer als der angegebenen Hilfsmittel angefertigt habe. Die aus anderen Quellen direkt oder indirekt übernommenen Daten und Konzepte sind unter Angabe der Quelle gekennzeichnet. Weitere Personen, insbesondere Promotionsberater, waren an der inhaltlich-materiellen Erstellung dieser Arbeit nicht beteiligt. Die Arbeit wurde bisher weder im In- noch im Ausland in gleicher oder ähnlicher Form einer anderen Prüfungsbehörde vorgelegt.

Konstanz, im Mai 2011, ________________________________

(Jan Schlösser)