Effects of caffeine on visual attention

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Caffeine and visual attention: general introduction
Introduction

In this thesis the effects of caffeine on human visual attention were studied. From previous research (Lorist, 1995), in which several visual attention tasks were used to study the influence of caffeine on different stages of information processing, it was concluded that the arousal increasing properties of caffeine mainly affect the perceptual and motor-response processes in humans. Lorist also found indications that certain types of attention might be more susceptible to the influence of caffeine than others. Together with the numerous remarks from people in daily life, stating that they feel more alert and better able to concentrate and focus their attention after caffeine intake, additional research into the influence of caffeine on different attentional mechanisms seems justified. The aim of this thesis was to gather more details about the effects of caffeine on several types of visual attention, with specific interest for the effects on the perceptual processes. The effects of 250 mg caffeine were studied on selective attention and sustained attention tasks, while the effects of 1, 3 and 7.5 mg/kg doses were studied on a divided attention task. The relevance of this type of studies for everyday life is easily recognisable; think for example about computer operators, staring at a computer screen for most of the day with too much information on it, while zipping coffee. Would it make any difference if important information would light up in a different colour, in a different location, or if short rest pauses were regularly intermixed, and how would caffeine intake interact with the processing of this information?

A more extensive background on both caffeine as a substance, and the concept of visual attention will be given in this chapter, in order to gain a better understanding of the possible influence that caffeine might have on different aspects of visual attention. Furthermore, the research methods that were used will be explained, and an outline of the subsequent chapters of this thesis with a description of the tasks that were used, will be given.

Caffeine

Caffeine can be described as a mild stimulant acting on the central nervous system that is used by many people in daily life. Found in tea, chocolate products, certain soft-drinks (cola for example) and some medicines, the largest intake of caffeine has always been through coffee. The legend goes that around the year AD 800, the goat herder Kaldi from Ethiopia was the first to discover the impact of the coffee bean. He noticed that his goats were a lot friskier after eating the red berries from a local shrub, and started to experiment with the berries himself (a berry contains two beans). He too felt a lot more energetic after eating the berries and he soon spread this knowledge to his friends. Around AD 1100, the first coffee trees were planted in Arabia and the Arabs started making a beverage from the plants that would be the forerunner of our cup of
Since then, the consumption of coffee beans and related products increased and spread from Arabia to other countries. Around AD 1600 coffee entered Europe and soon after, the United States. Presently, an estimated average of 2.25 billion cups of coffee is consumed in the world each day.

The largest coffee producing countries in the 1990s are Brazil (1271 million kilograms per year), Colombia (817 million kilograms per year), Indonesia (409 million kilograms per year), Mexico (363 million kilograms per year) and Ethiopia (216 million kilograms per year), followed by many equatorial countries that produce smaller quantities. The top coffee consuming countries are the Scandinavian countries (12 kilograms per capita per year), while Japan ranks third. This makes coffee the second largest export product world-wide after oil. From the seed to the cup coffee beans pass through 10 stages: harvesting-, processing-, and drying the beans, hulling, polishing, grading and sorting, exporting the beans, tasting, roasting and grinding. Millions of people around the world earn their living working on these different product stages. For more facts, figures and general information about the coffee industry the interested reader is referred to e.g. Dicum and Luttinger (1999).

Coffee contains several hundreds of chemicals. The main physiologically active ingredient is isolated as 1,3,7-trimethylxanthine, or caffeine. In pure form caffeine is a white crystalline powder that tastes very bitter. The amount of caffeine in a single serving of coffee ranges from about 60 to 160 mg and depends on a number of factors, such as the variety of the coffee bean, the level of grind, how the product is manufactured, the method of preparation and the size of the cup in which the coffee is served. Some of the reasons why coffee is so popular are most likely its exquisite smell and taste as well as the social aspects related to drinking coffee. Apart from that, coffee usually makes people feel more alert and energetic - it helps them “wake up”. In contrast, too much coffee can have unfavourable consequences on the body as well; for example, the trembling feeling and the deterioration of fine motor co-ordination. However, caffeine is a substance that is normally considered as “self-regulating”, meaning that most people can normally determine when they have had enough coffee and usually stop drinking any at that point.

Most research has focused on the effects of caffeine on health. Despite previous controversy on the subject, the current prevailing opinion is that a moderate amount of caffeine has no clinically significant effects on the human body. The globally determined moderate amount of caffeine is typically in the range of 300–400 mg per day. However, a dose that is moderate to one person may be too much for another person. Several factors contribute to the determination of the personal moderate caffeine dose (see the Methods section of this chapter). Little or no effects of moderate caffeine intake have been found on blood pressure, heartbeat irregularities, exercise tolerance and cholesterol levels. Interestingly, the effect on cholesterol levels mainly depends on the brewing method, since boiled unfiltered coffee does seem to have a cholesterol increasing effect. In addition, moderate consumption of coffee and caffeine does not seem to affect cardiovascular health or specific aspects of woman’s health,
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including bone health (osteoporosis), breast health and reproductive health (for reviews see Garattini, 1993; an excellent review can also be found on the internet: the Coffee Science Source (CSS), http://www.coffeescience.org/css.html). Although caffeine does not meet the criteria of an addictive drug, it is habit forming and some people may experience mild withdrawal effects (headache, fatigue or drowsiness) after an abstinence of 24 hours or more.

Another branch of research has focused more on the effects of caffeine on behaviour and (cognitive) performance. Most of these studies show a beneficial influence of moderate amounts of caffeine on reaction time (RT), that is, it speeds up the motor processes. In addition, accuracy levels and perceptual sensitivity seem to be higher under caffeine, and the EEG (electroencephalogram) generally shows a heightened cortical arousal level by caffeine conditions as shown from an increase in activity in the alpha frequency band. Although there is a lot of supporting evidence converging to these general statements about caffeine, firm conclusions and a coherent set of results have still to emerge. Results among studies vary due to factors such as the task that was used, the amount of caffeine administered and the possible interactions with other substances (these are just a few possible factors that may influence the effects, for a more thorough discussion see the Methods section of this chapter).

How caffeine works

After oral ingestion caffeine passes through the stomach and small intestine. From there it is rapidly absorbed into the bloodstream and can easily pass the blood-brain barrier. After only 15 minutes the first traces of caffeine can be found in the blood, while its peak plasma levels are reached about 30 to 60 minutes after ingestion. The half-live of caffeine is generally 4 to 6 hours but this is mediated by several endogenous and exogenous factors. For example, pregnancy prolongs the elimination of caffeine, as well as taking the birth-control pill, while nicotine intake speeds up the elimination. The elimination of caffeine occurs mainly by metabolism in the liver and its breakdown products are excreted through the kidneys. Only about 5% is excreted unchanged in the urine.

Currently, three mechanisms are accepted as underlying the pharmacological effects of caffeine on the central nervous system: (1) antagonism of adenosine receptors, (2) inhibition of phosphodiesterase, and (3) mobilisation of calcium. However, the concentrations of caffeine in the blood needed to activate mechanisms (2) and (3) are relatively high, and these mechanisms are therefore not responsible for the pharmacological effects of moderate caffeine consumption in daily life. Thus, the prevailing opinion is that the effects of moderate amounts of caffeine are explained by the fact that caffeine blocks inhibitory adenosine receptors in the brain. There are three main classes of adenosine receptors: A1, A2 and A3. Adenosine regulates a number of
physiological functions either by inhibition (A1 and A3 receptors) or by stimulation (A2 receptors) of adenylate cyclase. The A1 receptors are present in virtually every cell type, but mainly in the hippocampus, neocortex and striatum. A2 receptors are mainly found in the striatum, geniculate nuclei, olfactory tubercle and the amygdala (Phillis, 1991). Caffeine mainly seems to bind to A1 and A2a receptors, occupying about 50% of the adenosine receptors after intake of only a few cups of coffee (Fredholm, 1982). The A3 receptors seem to be largely insensitive to blockade by xanthines (of which caffeine is one), at least in rodents (Daly, Shi, Nikodijevic & Jacobson, 1994), but more research is needed to determine the role of this receptor type. Normally, adenosine builds up in the course of a day, and when levels are high enough, the adenosine binds to receptors that cause nerves to release inhibitory signals that lead to drowsiness and sleep. By caffeine intake, the modulatory effects of adenosine on ongoing neural activity are reduced and the levels of other neurotransmitters, such as acetylcholine, noradrenaline, dopamine and serotonin may be increased.

For reviews about the pharmacology of caffeine, see e.g. Daly, Shi, Nikodijevic and Jacobson, 1994; Garattini, 1993; James, 1991; Nehlig, Daval and Debry, 1992; Sawynok and Yaksh, 1993; Snel and Lorist, 1998. After this introduction to the world of coffee and caffeine, we now turn to an overview of visual attention in humans.

**Visual attention**

Numerous sounds, smells, images and tactile sensations surround us every moment of our life. Add to that the internally originated flow of stimulation and it seems amazing that we are not driven crazy by this bulk of information imposing on us. Humans usually solve this by paying attention selectively, that is, only to the information of interest. Selective attention seems to be the ability to shift attention voluntarily (for example when studying a coral reef) or involuntarily (when your attention is captured because of a shark swimming by) towards a particular event.

The concept of attention is very old, dating from the 18th century when philosophers discussed the observed limitations of human attention. Scientific interest in attention was almost put to an end in the behaviourist period (1920s-1950s), only to be picked up again in the 1950s. However, the topic whether or not attentional capacity is limited was not resolved and discussions went on. Most theories of attention now agree that there is a limited capacity to the amount of information that can be processed at any particular time point, caused by the limitations of the human sensory systems. It is, for example, impossible to look at a bookshelf filled with books admiring the shelf, while at the same time perceiving all the individual titles of the books. In addition, there also seems to be a limitation in information processing capacity beyond initial perception: for higher level processing such as cognitive operations and the planning and control of action. This can become apparent, for example, in prolonged cognitive tasks.
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and dual task performance. Two tasks that are supposedly unrelated and should not interfere with each other can sometimes compete for the same capacity. Our sensory system may be able to handle driving a car talking while talking to somebody at the same time, but the talking may be interrupted for a difficult and busy roundabout, indicating a limitation of higher level processing.

Several theories tried to explain how limited capacity was applied on the basis of the observed task performance results, such as the specific interference that was observed when performing similar tasks in contrast to dissimilar ones. Multiple resource theories (e.g. Damos, 1991; Navon & Gopher, 1979; Wickens, 1980) proposed a specific set of resources (a conceptualisation of energy, related to mental effort) based on the assumption that there were separate resources for perceptual and higher level processing, which were all limited in their capacity. For example, Wickens (1984, 1991) postulated a multiple resource model consisting of three dichotomous dimensions (stages: perceptual-cognitive processes versus response processes; codes: spatial versus verbal and input modalities: visual versus auditory) each representing a separate resource. However, the main objection to resource theories and their variations is that they are descriptive rather than explanatory of the observed data (Neumann, 1996).

Another attempt to explain limited capacity is Broadbent's filter theory or early selection theory (1958). According to this theory all information from the different senses are analysed at a physical level whether or not they are attended. However, because higher level processing is limited in its transmission capacity, Broadbent proposed a filter to protect it from overload. Only the attended information would be processed to full identification, while unattended information was disregarded. Thus, Broadbent introduced an early concept of selective attention. Later, versions of the filter theory generally used a series of filters to explain selective attention. On each different level some information is passed through while other information is attenuated. Although Broadbent "located" his filter early in the information-processing stream, some theorists opposed this and assumed a later selection (Duncan, 1980; Norman, 1968; Deutsch & Deutsch, 1963). Such theories suggested that all information, attended or not, is analysed to a point after initial stimulus identification, and it is therefore referred to as late selection. Presently, research tends to favour early selection, although some late selection is not entirely ruled out. An additional feature that is proposed for filter type theories is the aspect of whether the filter has a fixed location in the information processing stream, or possibly a variable location. In the latter ones, the filter location would be adjusted according to the input the information processing system receives, for example, the amount and type of stimulation.

Besides explaining selective attention with filter-type theories, other theories used the spotlight metaphor (e.g. Eriksen & Hoffman, 1973; Eriksen & St James, 1986; Posner, 1980). The spotlight would be a bundle of attention that can be directed at any particular spot in space, thus favouring the processing of information of this particular spot above all surrounding information. In the centre of the spotlight, attention would be maximal whereas the amount of attention declines near the edges of the spotlight.
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This theory has in the past been said to provide a useful description to explain a change in the amount of energetical resources. More available energy (for example as a result of intake of a stimulant or by quitting performing a secondary task) is said to narrow the spotlight (Easterbrook, 1959), thereby improving selectivity.

In general, selective attention is said to work according to the principle of differential activation. However, up till now it is unclear whether this is achieved by facilitation of the processing of preferred information, while other information remains neutral; or by inhibition of the non-preferred information, while the preferred information remains neutral. Similarly, associated theories propose a continuum along these lines, enabling different gradients of activation. One of the main questions is to what extent unattended information is processed, and where in the information processing stream this processing comes to a halt.

Thus far, several aspects of attention have been described. In sum, the main statements are: attention is limited in its capacity, both in a perceptual and a higher level processing stage; and regardless of the type of theory that is followed, selective attention seems to be the main tool to discriminate between all available information. In an early model of attention, Posner and Boies (1971) identified a third component of attention: alertness or maintenance of attention, in addition to selectivity and limited capacity.

Of further interest, to be able to predict and interpret the possible effects of caffeine on visual attention is some of the detailed knowledge, originating from neurophysiological research, about the brain structures involved in visual (selective) attention. For instance, it is known that there is a distinction between the processing of spatial and nonspatial information in the brain. Nonspatial information, such as colour and form, seems to activate a lower pathway continuing into the ventral portion of the temporal lobes, the so called “what” system, while spatial information seems to activate the upper pathway continuing into the posterior parietal lobes, the so called “where” system (Ungerleider & Mishkin, 1982). Neurocognitive models that have been proposed for visual input selection (for an overview see Heslenfeld, Kenemans, Kok & Molenaar, 1997) share a modular structure, feedback and feedforward connections between functionally compatible representations, and separate and parallel pathways for spatial and nonspatial information. In addition, in all models attention is implemented as an energetical resource, which can be directed to representations and pathways in the system. Or as Heslenfeld (1999, p. 10) put it “... selective attention is implemented as a form of extra energy (or a heightened activation level) which is directed towards certain nodes or pathways in the system”. Although several theories have come forward with the possible brain structures involved in selective attention, little is known about the neurotransmitters that might be involved herein. Pribram and McGuinness (1975) proposed a model based on three separate but interacting neural systems: an arousal system (based in the amygdala), an activation system (based in the basal ganglia) and a third, co-ordinating system (based in the hippocampus). Based on this model, Tucker
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and Williamson (1984) proposed different neurotransmitters that might be involved in the functioning of these systems: norepinephrine and serotonin are supposed to be mainly responsible for the functioning of the arousal system, whereas dopamine and the cholinergic pathways would be responsible for the functioning of the activation system.

Although as an introduction to this thesis, the above overview about theories and concepts of visual attention cannot be anything but limited, it suffices to understand the rationale of the present line of studies. For more extensive overviews of visual attention, the interested reader is referred to e.g. LaBerge (1995), Neumann and Sanders (1996), Pashler (1998), or Van der Heijden (1992).

Caffeine, information processing and visual attention

The majority of research up till now, found that caffeine intake leads to faster reactions. Using only RTs as the dependant variable, however, this result could imply faster perceptual processes, faster cognitive processes or faster motor responses, to name only a few possibilities. Lorist et al. (Kenemans & Lorist, 1995; Lorist, Snel & Kok, 1994; Lorist, Snel, Kok & Mulder, 1994, 1996; Lorist, Snel, Mulder & Kok, 1995) studied the influence of caffeine on different stages of human information processing, using both RTs and event-related potentials (ERPs) in different types of visual attention tasks. A major advantage of using ERPs is that they reveal insight into the ongoing neural processes that represent information processing in the brain. The parametric experimental design that was used is a sophisticated method, and is based on the assumption that incoming information runs through three successive processing stages: perception related processes, central processing and motor response related processes. In addition, the efficiency of these processes relies on the available energy in the brain and the amount of effort invested. Using different types of tasks, such as spatial and non-spatial selective attention tasks, a stimulus-degradation task, and a memory search task, Lorist (1995) reached the conclusion that especially the input- and output stages of information processing were susceptible to influences of caffeine, leaving the central stages unaffected. Furthermore, it was concluded that caffeine might have an effect in spatial attention conditions, but not in nonspatial attention conditions. In addition, Lorist, Snel, Kok and Mulder (1996) found that the effects of caffeine are not restricted to focused or divided attention conditions, but seem to depend more on the memory loads that were used in this task to manipulate task difficulty.

The effects of caffeine on the output processes seem mainly to consist of the speed up of motor-responses, brought about by moderate amounts of caffeine. Kenemans and Lorist (1995) found no differences in the onset of the lateralized readiness potential (LRP) to targets between a caffeine and a placebo condition. Since they did find shorter reaction times in the caffeine condition, it was suggested that this resulted from an improvement in processes that have taken place after response preparation had begun,
thus, at the central or peripheral motor execution stages. Ruijter, Daselaar and Snel (unpublished data), however, found no evidence of an influence of caffeine on the peripheral motor execution stage, in a task where the actual movement time was measured from pressing one button to another. In this study, faster reaction times due to caffeine were only found on button presses on the first button, which might indicate that caffeine mainly influences the central motor execution stages.

Lorist (1995) also studied the influence of caffeine on the input processes with ERPs, using tasks that required different types and levels of attention for task performance. By manipulating stimulus processing with different selection criteria, she found that caffeine influenced the processing of stimulus quality and diagonal selection (spatial selective attention), but did not influence processing of stimulus features such as spatial frequency and orientation (nonspatial selective attention). The cautious conclusion was drawn that a specific influence of caffeine might exist for the processing of spatial information as opposed to nonspatial information. Taking into account the different neuronal pathways along which spatial and nonspatial information are processed, this differentiation in the effects of caffeine seems theoretically plausible. However, Kenemans and Verbaten (1998) who used RTs to study the influence of caffeine on visuo-spatial attention at the input stages, found faster responses in the caffeine condition but did not contribute this improvement to an effect on the input stages, but rather as an effect related to the preparation and execution of the motor response. Using a Stroop-interference task, which is said to represent early processing, Kenemans (1998) found that caffeine reduced Stroop interference when neutral and incongruent conditions were presented in separate blocks but not when they were mixed. One should keep in mind that with results and conclusions based on reaction time experiments it cannot be ruled out entirely that the speeding of the final observed response was generated at another stage of information processing than the output stage. The contrasting evidence prevents firm conclusions about the effects of caffeine on input processes at this moment.

The primary objective of the studies described in this thesis was to gather more information about the influence of caffeine on different aspects of visual attention and the possible interaction with the perception and processing of information. Considering the suggestion of Lorist (1995) that caffeine could have a more pronounced effect on the processing of spatial information as opposed to nonspatial information, two selective attention tasks were used representing spatial and nonspatial information processing. Apart from addressing the spatial-nonspatial issue, at the same time the results on these tasks will reveal more information about the effects of caffeine on the attentional processes in visual selective attention tasks. This, in turn, generated interest about the effects of caffeine on other types of visual attention. Integrating the properties of caffeine and the general concept of attention, a probable hypothesis might be that caffeine influences the available processing capacity or energy, thereby influencing all kinds of attentional processes. As mentioned before, three components of attention can be identified: selectivity, alertness or maintenance, and limited central capacity. In this
thesis, the effects of caffeine on all three components will be studied: on limited
capacity by using a dual-task (divided attention), on selective attention as described
above, and on the maintenance of attention with a concentration task (sustained
attention). So, without pretending to elucidate on the dilemmas in attention research,
several different approaches were used to enlighten the role of caffeine on different
aspects of visual attention and perceptual processing.

Measuring attention

To measure the effects of caffeine on selective attention, the following dependent
variables will be used in this thesis: behavioural responses, event-related potentials
(ERPs) and spline- and current source density (CSD) maps.

Behavioural responses such as reaction times, number of hits, misses and false
alarms may provide valuable insight into the effects of caffeine on the quality of task
performance. However, these measurements seem less effective to reveal information
about the effects of attention, since behavioural responses usually only have to be given
to the particular class of stimuli which the participant had to attend to. Consequently,
there is no comparison possible to reveal the effects of attention, since there is no
comparable response for the classes of stimuli the participant did not attend to.

An informative way to study the information processing stream and the attentional
processes is by using ERPs. The ERP is derived from the EEG signal and is therefore a
cheap and non-invasive method to obtain information. The EEG signal is recorded
together with a signal that registers stimulus presentation during a selective attention
task. Later, all brainwaves that follow a particular stimulus category (for example target
stimuli) will be averaged together, thereby discarding the random ongoing EEG signal
and revealing the ERP waveform. An advantage of ERPs is that they can be recorded in
response to every stimulus category. For example, ERPs can be recorded to physically
identical stimuli in both an "attend" and an "ignore" condition, the differences thereby
demonstrating the effect of attention. Moreover, ERPs allow a more precise analysis of
the timing and organisation of cognitive processes in the brain during task performance.
From stimulus presentation onwards the ERP consists of a number of consecutive
positive and negative voltage deflections. The peaks (or components) of the wave are
named according to their polarity (P for positive and N for negative) and their time-
position in the sequence (for example P1 is the first positive peak of the ERP
waveform). Sometimes peaks are named according to their exact time-position; for
example P112 is a positive deflection with its maximum peak at 112 ms after stimulus
presentation. Each component reflects activity from a different set of brain areas and
with enough electrodes topographical differences within and between components can
be observed. Because the time course of a component indicates the period during which
the corresponding brain area is active, the early components reflect sensory processing
and the later components reflect higher cognitive processes and motor-related activity. Differences in components of the ERP, for example due to different conditions, may be observed as differences in peak latencies and/or mean component amplitude. Latencies reveal information about the time-course of a specific process in the information-processing stream, while amplitudes are said to reflect changes in the amount of energy mobilised for task performance. Thus, ERPs may provide evidence on the question which stages (input, central, output) of information processing are influenced by caffeine. This way important insight about the influence of caffeine on visual attention could be uncovered, either showing a general change in information processing or a stage-specific change.

When enough electrodes are used to measure the EEG, the Brain Electric Source Analysis (BESA) programme can be used to calculate spline- and current source density maps, thereby indicating which brain structures might be involved. Spline maps display the observed activity as represented by the different electrodes that are used to measure ERPs. Data from the spline maps are then re-referenced to an average reference and interpolated for mapping, using a spherical surface spline method, to form the CSD maps. Thus, both maps display the distribution of voltage over the surface of the head, indicating the cortex areas with most activity. Based on these maps and a physiologically plausible model, hypotheses can be made about the probable generator areas in the brain that are responsible for the observed activation pattern.

**Methods**

Some remarks should be made concerning the methods used in this thesis. All studies used a within-subjects design, meaning that participants served as their own control. In other words, each participant was tested once under a placebo condition and once (or in chapter 2, trice) under a caffeine condition. This way, all observed differences in dependent measures between the sessions of the same participant can presumably be subscribed to the effects of caffeine, since is the only factor that was intentionally manipulated between sessions. To be able to monitor possible contaminating influences such as a difference in the participant’s mood between the sessions, subjective feelings, such as anxiety, vigour and fatigue, were measured with questionnaires, as well as the quality of the participant’s sleep on the night before the experimental sessions. In addition, to monitor the physical well-being of the participant, blood pressure (BP) and heart rate (HR) were measured as well. Although not explicitly predicted, these measures were also used to assess the effects of caffeine intake.

Caffeine is a substance that may evoke a range of responses depending on personal differences; for example, individual differences in pharmacological responses to caffeine such as the amount of caffeine somebody is used to, the state of mind, whether somebody smokes or not, the amount of caffeine that is administered, etc.
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Therefore, it seems rational to use participants that form a group that is as homogenous as possible to start with. For the studies described, the following criteria were used to select participants: participants had to be habitual coffee consumers, accustomed to three to five cups of coffee a day, be nonsmokers, have a right hand domination, a good physical health and no history of brain damage. In addition to that, participants were asked to refrain from all caffeine containing foods and beverages for 12 hours prior to the experimental sessions, not to consume alcohol on the night before the experimental session and have a normal night rest. All experimental sessions were held in the morning to prevent time-of-day effects and the possible occurrence of withdrawal symptoms. While these criteria might narrow the range of possible responses, interindividual differences will still be observed, which is why the within-subjects design was used, as well as the statistical repeated-measurements method.

The amounts of caffeine studied in caffeine research vary substantially. Although most research aims to investigate the effects of moderate, normal daily doses of caffeine, others want to find out the effects of caffeine when taken in extreme doses or on the opposite, in very small quantities. As stated above, this topic is also related to the amount of caffeine people are used to, and effects may vary according to the values of these two variables. The present research aims to reveal more about the effects of caffeine in daily life. Therefore, the moderate to high amount of caffeine of 250 mg was used (chapters 3, 4 and 5), that is, moderate to the pre-selected participants. This amount would be equivalent to the caffeine found in about three cups of coffee. In chapter 2 increasing amounts of caffeine were used of 1 mg per kg bodyweight (BW), 3 mg/kg BW and 7.5 mg/kg BW.

Outline of the thesis

After this introduction to the topics of caffeine, visual attention and the general objectives of this thesis, a brief description will be given below about the specific hypotheses and the tasks that were used in the separate experiments to study the possible effects of caffeine on visual attention.

Using the theoretical model of Wickens (1980, 1984) as a basis, the effects of caffeine on divided attention were studied in chapter 2, using a visual dual-task. Following the reasoning of several separate resources, each with limited capacity, the hypothesis was that caffeine would be able to enlarge the available capacity of (one of) the resources. With a depletion of the available capacity of one of the resources by the task demands, resulting in a non-optimal performance in the placebo condition, the hypothesised energy-increasing effects of caffeine should become clear. In addition, several doses of caffeine were used in this experiment to study the possibility of gradual energy-increasing effects, or a possible deterioration in performance with the highest caffeine dose. RTs and ERP were used as dependent measures, and especially the P3
component of the ERP was of interest here since the amplitude of this component is said to reflect the amount of energy that is used.

In chapter 3 and 4 the specific effects of 250 mg caffeine on selective attention were studied. Chapter 3 studied the effects of caffeine on selection of a nonspatial stimulus feature, namely colour, which follows the “what”-pathway of information processing. In the task that was used, participants were presented with target and nontarget stimuli in both a relevant and an irrelevant colour. Consequently, ERPs can reveal important information about the processing of relevant as well as irrelevant information. The same task was used before by Van der Stelt, Kok, Smulders, Snel and Gunning (1998), and Van der Stelt, Gunning, Snel and Kok (1998), and is known to yield three clear selection components in the ERP: a frontal selection positivity (FSP), a central N2b and an occipital selection negativity (OSN), which were the ERP components of interest, together with the target P3 component. The main objectives of this experiment were to find out if caffeine influenced the processing of this non-spatial feature (colour), and if caffeine facilitated or inhibited the processing of relevant or irrelevant information. In addition, the same task was used in a slow and a fast version to examine the influence of this factor on the modulating effects of caffeine on the selection processes. Besides RTs and ERPs, CSD maps were also calculated in this study to examine the topography of the caffeine effects and shed some light on the cortical areas that might be involved.

In Chapter 4, the effects of caffeine on the processing of spatial information that follows the “where” pathway of information processing, was studied. An often used spatial selective attention task was presented to the participants, in which they attended selectively to stimuli with a specified location in order to react to the occurrence of a target stimulus. Spatial selective attention effects are normally reflected in the occipital ERPs as a more positive going P1 and a more negative going N1 component. Based on previous research the hypothesis was studied that caffeine would affect spatial information processing by influencing these ERP components. RTs, signal detection parameters and ERPs were used as dependent variables.

In chapter 5, a self-paced reaction time task of approximately 10 minutes was used. In this sustained attention task a long period of continuous concentration was used to assess the durability of the cognitive functions, requiring attentional capacity over time. This study did not focus on the amount of information the system can process at one particular time (addressing the issue of limited or unlimited central processing capacity) but rather investigated the durability of the central processing capacity under placebo and caffeine conditions. The effects of caffeine were studied using RTs and ERPs to assess so called “lapses of attention”, as well as several other measures of concentration and time-on-task effects.

Finally, in Chapter 6, a summary of the results and the general conclusions based on these results will be discussed. Then, some remarks on the current level of knowledge about the effects of caffeine on visual attention and the implications for future research will be stated.