Do we need to be aware of words to process their meaning?

An overview of studies researching unconscious semantic processing

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Abstract

This paper aims to find out what evidence exists at this moment in time for us processing the meaning of words unconsciously. There has been done much research previously on unconscious processing. This paper focuses on experiments which investigate the possibility of unconscious semantic processing. I aim to give an overview of what evidence has been found so far, and analyse this evidence to give a recommendation for future research. This paper finds that there is evidence that the meaning of words is processed unconsciously, but that evidence is influenced by a great many factors and thus easily gives different kinds of results, whether that is in favour of or against unconscious semantic processing. The findings of this thesis are in line with a theory by Dehaene et al. (2006), who say that different types of unconsciousness seem to exist, which find themselves in different streams of processing.

Keywords: conscious processing, unconscious processing, semantic processing, visual masking, binocular rivalry, continuous flash suppression

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1. General Introduction

1. Introduction

Consciousness has always been an interesting topic. A lot of actions we take in our daily life we do consciously, while being aware about what we are doing. But at the same time, even more actions don't require consciousness at all. Blinking, breathing, balancing while walking, so many processes are automatic and thus unconscious. This begs the question though, how much actually happens in our heads without us being aware of it? There have been many experiments done previously on this kind of unconscious processing; what does get processed unconsciously, and what does not? Different means of researching these kinds of questions have been used as well, mostly focusing on specific parts of unconscious processing. For example, when looking around, you don't process each and every detail you see. This kind of visual information processing has been investigated by using binocular rivalry (e.g. Zimba & Blake, 1983), while subjects like the processing of language and the meaning of words (semantic information processing) have been investigated with paradigms such as continuous flash suppression (e.g. Sklar et al.,2012).

This paper, however, will focus only on experiments which investigate the possibility of unconscious semantic processing. Semantic processing is what happens when we hear or read a word, and encode the meaning, relating the word to others with a similar meaning. Do we process the meaning of words, without being aware of having heard or read those words? A lot of research has been done on this specific topic, often by means of showing a masked visual stimulus so briefly it cannot be consciously seen and read. Many papers can be found whose results show that these stimuli can be processed at various sub-semantic levels (Kouider & Dehaene, 2007). But in recent years more ways of investigating consciousness have appeared. This is why it will be interesting to reevaluate what kind of evidence can really be gathered. Therefore, the research question that this thesis aims to answer is "*What evidence exists at this point in time that the meaning of words is processed unconsciously?*"

2. Theoretical Background

Even when this paper focuses only on the word meaning aspect of information processing, understanding whether the meaning of words can or cannot be processed unconsciously will get us one step closer to understanding consciousness as a whole. Reading is generally seen as a complex cognitive process, with multiple stages and brain areas needed to process the information (Jobard et al., 2003). If there is enough proof that high level processes such as reading can happen unconsciously, it could change such views of conscious and unconscious processes significantly.

In this paper I have focused on three specific paradigms that measure unconscious processing: visual masking, binocular rivalry and continuous flash suppression (CFS). These are three well-known paradigms that have been used often in research about unconscious processing and which will be explained throughout this thesis. Visual masking is a paradigm that has been used for a long time, introduced near the end of the 19th century, while binocular rivalry and CFS are more often used in more recent research. This is why it seemed interesting to try and compare the results given by these paradigms that have originated in very different time periods.

3. Relevance to Artificial Intelligence

Artificial intelligence (AI) is a field that studies and improves the intelligence of artificial entities. The term is often used to describe machines that replicate cognitive processes that we associate with the human mind. Since it is hard to define what intelligence exactly entails, it makes it difficult to define artificial intelligence as well. To be able to study artificial intelligence, it is necessary to first investigate what this intelligence means. Why do we find certain cognitive processes 'intelligent' and how do these so-called intelligent and uniquely human processes occur? We differ from other organisms in that way. Consciousness - and with that, the unconscious - is associated with capabilities which are assumed to be uniquely human (Shanon, 1998). This is why it is necessary to understand the conscious and unconscious processes, to even begin to understand human intelligence. The findings reported in this thesis can be used as a stepping stone for further research into the workings of conscious or unconscious processing. It is believed that consciousness is necessary for high-level computations, such as semantic processing (Baumeister, & Masicampo, 2010) and thus the study of the human consciousness and unconsciousness is central to understanding the workings of the human mind. It is fruitful to combine the field of AI together with the field of consciousness as they are both so strongly linked to understanding human intelligence. Only by understanding these processes that are so uniquely human will it be possible to create successful artificial intelligence.

4. Methodology

The method that I have used to answer the research question is an analysis of papers done on the topic of unconscious semantic processing. I started with two papers recommended to me by my thesis supervisor dr. Chris Paffen. These papers are Sklar et al. (2012) and Gayet et al. (2014). Supplementary sources I have found either by using the search engine on Google Scholar, or through sources of the paper provided and the sources of papers I found at a later moment. Through Google Scholar I searched for papers by searching for related keywords such as 'unconscious processing' and 'semantic processing'. After initial research, I decided on reading papers using three different techniques to measure unconsciousness. I specified my search terms by including keywords such as 'masking', 'binocular rivalry' and 'continuous flash suppression'.
I have read a little over 20 papers on different sorts of experiments done on the conscious and/or unconscious processing of the meaning of words. The timeline of these papers is widespread, some are quite a few years old (i.e. Allport, 1977) while other papers are more recent(Stein et al., 2020). This is a conscious choice, as to hope to find a more complete view on what evidence there is that the meaning of words gets processed unconsciously. The focus is on how the experiments have been conducted and what their results were.
By summarising the findings of many past experiments and analysing what methods found which results, I will argue whether there is enough evidence to say that the meaning of words does or does not get processed unconsciously.

2. Visual Masking

Visual Masking
Visual masking occurs when the presence of one image, the mask, reduces the visibility of another image, the target (Ogmen & Breitmeyer, 2007). To research unconscious influences, masking often makes use of lexical decision tasks. In these tasks participants view a screen on which two words will be displayed, first a prime word, then a target word. Participants need to undertake a certain action once they see the target word. The prime is a word which is often related to the target word in meaning, which would activate semantic networks and cause people to respond faster to the target word. This effect is called priming (Weingarten et al., 2016). In visual masking, the prime word will be hidden behind a visual mask. This can be done with different techniques. In forward masking, the mask will appear before the target appears, and in backward masking the mask appears after the target. In simultaneous masking, the mask and the target are shown together.
In the following papers, the mask would usually consist of a string of random letters presented before and after the prime word, combining forward and backward masking. This masking of the prime word makes it so that the visibility is reduced: if the prime is processed, it can only have happened unconsciously.

Research
In the late 1950s and early 1960s, interest in the unconsciousness rose, which resulted in a lot of reports of supposed unconscious perception. Nowadays, a lot of these reports are not seen as very trustworthy (Dixon, 1971) and warrant a closer look. Nolan & Caramazza (1982) were two people who thought to test one of the experiments from that time. They tried to replicate the results of Allport (1977), who claimed to have demonstrated unconscious semantic processing of visual information. In Allport's design of the experiment, a word was presented to the participants on half of the trials, and on the other half there was a blank field shown. After either of these options a mask would follow at the same place as the target. The time between the first and the second stimulus is called the stimulus onset asynchrony (SOA). In this case, that is the time between the prime and the target. Afterwards, participants had to answer a yes or no question of whether a word had been presented. When 'yes' was answered, a follow-up question was asked. Participants had to choose, out of two words, which was more similar in meaning to the prime word. When replicating this experiment, Nolan & Caramazza found no significant difference when it came to the similarity judgements. They failed to replicate Allport's results, who had claimed to have found evidence for unconscious semantic processing.

Of course, with just one failed replication, more research was needed. Greenwald et al. (1996) also found unconscious priming controversial. According to them, it had been difficult to prove that masked primes truly are perceived unconsciously. So they did their own research. Greenwald et al. had 10 subjects perform a categorisation task. Participants had to categorise presented words as either pleasant or unpleasant, and common first names as either male or female. Their mask to target SOA varied from 67ms to 400ms. They did find a priming effect, and thus concluded that the meaning of words can be processed unconsciously. Another noteworthy thing is that they found that unconscious priming was strongly influenced by the SOA. The longer the SOA, the smaller the priming effect. In other words, if the target was presented much later than the prime, the priming effect would grow gradually smaller. They found the limit of the priming effect to be around 150ms. When they used SOAs bigger than that, Greenwald et al. found only a very small priming effect.

Dehaene et al. (1998) also found results in support of unconscious semantic processing, and wanted to locate where in the brain this processing takes place. They set up an experiment in which participants were first shown a masked prime (a number between 1 and 9) for a short duration. Afterwards they were shown a number either smaller or larger than 5, and had to reply as quickly as they could with a

button press whether that number was smaller or larger than 5. The button they had to press depended on their answer, either left or right. The numbers were presented as either an Arabic digit or as a written word. The results showed that subjects responded quicker in the trials where the prime and target were on the same side of 5 (congruent trials) than in the trials were they were not on the same side of 5 (incongruent trials). Even when asked to focus on the prime after their task, participants could not report it and only reported seeing the mask. This makes it probable that the prime is not consciously accessible.
An interesting find was that the amount of priming stayed the same, whether the number was presented as an Arabic digit or as a written word. This would imply that priming occurred at a level independent of the notation. And even when trials in which the prime number and target number were the same were excluded, the same amount of priming remained. Dehaene et al. made use of ERPs to measure what was happening in the brain during priming. ERP recordings in masked semantic priming experiments are used to track the time course of changing electrical brain activity to words perceived unconsciously. They found that in incongruent trials the prime-induced motor activation would mismatch with the response required for the target, which caused response competition. Response competition is a condition where a stimulus activates multiple responses, which then compete for dominance. This simultaneous activation then results in mutual inhibition (Eriksen et al., 1985). This slowed down the response, resulting in larger response times for incongruent trials (prime-target congruency effect). These results show that masked primes are accompanied by measurable brain activity, and that that brain activity is not confined to just one brain area, as the motor regions were activated as well.

The next study we will be taking a look at was conducted by Naccache & Dehaene (2000). They wanted to test the semantic hypothesis which states that the effects of priming stem from an unconscious categorisation of the primes at a semantic level. The setup of the experiment was very similar to the one of Dehaene et al. (1998) mentioned above and included masked primes again. Once again, participants had to press a button when a number was shown. Depending on the shown number being higher or lower than 5, a corresponding button had to be pressed. The subjects were not told about the masked primes. The results here support the semantic hypothesis mentioned before. Reliable response priming was found for new sets of primes, which shows the existence of the semantic processing of those numbers. Responses were found to be faster when the prime and target were numerically closer. Another thing Naccache & Dehaene found was that unconscious response priming was shown to be already present within the first block of trials, and that its intensity did not increase with time. This would imply there was no learning effect present. All three of these results point towards unconscious semantic processing.

Kiever & Spitzer (2000) argued that the discussion about unconscious semantic processing was due to not having used the right measures to assess participants' awareness of stimuli. This is why they made use of ERP recordings in their experiment. Kiever & Spitzer found two important things. First, both conscious and unconscious semantic priming bring forth the N400 ERP component, a component that appears 400ms after the start of a semantically deviant word; it is very much ingrained in semantics. Second, conscious and unconscious priming show up at different time courses. Unconscious priming decays rapidly, whereas conscious priming increases with longer SOAs. This is in line with what Greenwald et al. (1996) had found, as mentioned above.

Kouider & Dehaene (2007) have given a good overview of the findings of visual masking and non-conscious perception through the years. By summarising these experiments and their results on the topic, they concluded that priming from genuinely unconscious stimuli does really exist, and is something that can be studied. They concluded that in masked priming, evidence for semantic processing is real, but restricted. Unconscious priming effects are present here, but can be very small, much smaller than with awareness.

3. Binocular Rivalry

Binocular Rivalry
Binocular rivalry is a phenomenon in which perception alternates between different images presented to each eye; two eyes view dissimilar patterns at corresponding areas. The two patterns presented to each eye compete for dominance, and while one pattern is visible to the viewer, the other one is not. This 'losing pattern' is suppressed from conscious awareness (Blake & Logothetis, 2002). Due to this suppression from conscious awareness, binocular rivalry is also one of the paradigms used to measure unconscious processes.

Research
It is debated whether the information that is suppressed from conscious awareness still remains available for some degree of processing. If it is possible to process that information, the next question would be: can that information be used for high-level processes? Different theories exist. Some people follow the idea of Walker (1978), and his so-called cognitive hypothesis. This hypothesis states that abstract, high-level features of the suppressed stimulus are registered, such as its semantic content. Other hypotheses generally claim that only certain physical, low-level characteristics of a stimulus can be analysed, such as its contrast (Abadi, 1976).

Ever since binocular rivalry was discovered, multiple experiments have been conducted, but this paradigm does not come without questionable results. An example of this is the experiment by Somekh & Wilding (1973). They presented a drawing of a neutral face to one eye, while an emotional word (e.g. happy) was shown to the other eye. Subjects reported to have only seen the face, but even then their judgements of the face's expression was influenced by the 'unconscious' word. Because of this, Somekh & Wilding claimed that semantic information can be extracted from a suppressed stimulus, which would support the cognitive hypothesis. They relied on introspection as a measure for consciousness. This method of research is kind of questionable by today's standard, but we will come to that in the discussion.

Zimba & Blake (1983) also conducted an experiment on binocular rivalry and unconscious processing. They wanted to test whether a word presented to the suppressed eye could influence performance on a lexical-decision task. First a prime word was shown, followed by the target which was either an existing word or a string of letters forming a nonword. The subject had to make the decision on whether the target was an existing word or not as quickly as they could. Zimba & Blake only found effects of semantic priming if the prime was present strongly enough to break the suppression caused by the binocular rivalry. This would imply that suppression interferes with visual processing at a level prior to the extraction of semantic information. These results contradict with the cognitive models of rivalry which says that semantic priming can be obtained from a masked word.

Research continued after this, and Blake (1988) made participants observe two different continuous streams of letters, one presented to each eye. The semantic content of the two streams was varied, to determine whether it was possible for text that had meaning to dominate nonsense strings. Participants were asked to read the text they viewed aloud. Results showed that most of the participants could not read either of the two texts for an extended period of time. The most probable reason for this is that this comes from a unique limitation within binocular vision. In the following experiment, targets were inserted into the strings, which were used to measure the ability to read the texts. Only about half of the targets were detected. The undetected targets were most likely to be in the letter string of the eye that was suppressed at the moment. When asked, the participants described that it seemed as if they viewed one single stream of letters, not two interfering ones. When the target was detected, it was as visible as it was when seen under the monocular control condition. This means that the targets

were not being masked or partially obscured by the binocular vision, as you could only see one stimulus completely at a time, not a mix of the two stimuli. These results indicate that the presence of targets has no influence on rivalry dominance. This implies that the underlying neural events transpire early in visual processing. Blake reported no semantic influence on rivalry dominance, and that rivalry events occur before the stage where semantic information could be extracted.

Finally, Costello et al. (2008) made participants view a prime word for 2 seconds, then one eye was presented with a dynamic noise pattern while the other eye was presented with a target word. They compared how long it took for semantically related words and semantically unrelated words to break suppression. Results from all participants indicated a significant effect of word relatedness on suppression time. If the words were related, suppression was broken faster. However, a subset of the word pairs had subword components in common. This would make it unclear if the priming came from semantic meaning, or from subwords. This meant that a second experiment was needed. The setup was the same, but the experiment was split into two groups. One group would be shown the semantically related word pairs, and the other group would be shown the word-parts related words. Here as well, a significant effect of the suppression times of the semantically related word pairs was found. This suggests that words primed with a semantically related word take less time to gain dominance against the suppression noise. These results imply that suppressed target words are able to reach regions involved in the semantic information of words.

4. Continuous Flash Suppression

Continuous Flash Suppression

Continuous Flash Suppression (CFS) is a very recent masking technique (Tsuchiya & Koch, 2004). The first eye is presented with a static stimulus (the target), while the second eye is presented with a series of rapidly changing stimuli. This setup results in the rapidly changing stimuli suppressing the static stimulus for the eye that was stimulated first. The rapidly changing masks dominate awareness until the target breaks into consciousness. CFS is a very important technique when it comes to studying the unconscious. This is because it gives unconscious processes time to engage with an unconscious stimulus, as the suppression of the target may last seconds. This was not possible with earlier methods, as for visual masking and binocular rivalry, there was only a limited amount of time the unconscious stimulus could be shown before it would reach awareness (Sklar et al., 2012). By keeping the stimulus in CFS dynamic, it is possible to suppress the unconscious stimulus for a longer period of time.

Research

Since CFS is only such a recently developed method, the papers reviewed here are not as spread-out through time the way the papers for the other paradigms are. But even in such a short time, there has been much interesting research done concerning CFS, which makes it very worthwhile to discuss these papers. For example, Sklar et al. (2012) had the goal to understand how consciousness and unconsciousness are implemented in the brain. In their experiment, they presented verbal expressions to one eye, while a series of Mondrian-like colourful shapes was presented to the other eye. They asked participants to press a key as soon as the verbal stimuli broke suppression. In the first experiment, participants were presented with either semantically incoherent or coherent expressions. Results showed that the expressions which were incoherent would break suppression faster than the coherent expressions. Since the coherence in a sentence is a property of the multiple words together, this result would imply that the difference in suppression time could only mean that the sentences get processed semantically. In another experiment they managed to show that the more negative a verbal expression was, the sooner it would break into consciousness. All these results indicate that the participants process multiple-word expressions unconsciously. In a follow-up experiment in the same paper they tested whether participants can solve arithmetic equations unconsciously, once again using breaking suppression as the way of measuring unconsciousness. In the experiment, they had participants solve simple single-digit equations (e.g. 9 – 4 – 2 = …), which were masked with CFS. After this prime, a visible number (e.g. the number 3) was presented which the participants had to pronounce. A significant priming effect was found. This implies that those equations can be performed unconsciously, which is in favour of unconscious semantic processing.

Zabelina et al. (2012) still were not convinced whether semantic processing can occur under CFS and decided to do some more research. They used the compound remote associate word problem to investigate semantic processing. In this problem, three common stimulus words appear, and they seem to be unrelated (e.g. pine, crab, sauce). The person being tested had to think of a fourth word that is somehow related to each of the first three words (e.g. apple). During the experiment, the word triplet was presented to one eye, while the other eye was presented with a dynamic mask. After three seconds, the word triplet was presented to both eyes. This could be either the same or a different word-triplet than during the suppression phase. Participants had to press a key when they knew an answer, and then verbalised their solution. Participants had to indicate whether they reached their solution by insight or by analysis. Insight solving was explained to mean that the answer ‘suddenly’ appeared, like an aha-moment. This is more dependent on semantic integration. Analysing, on the other hand, is deliberate and conscious solving, which would imply that there is not much semantic integration across the word-triplet (Jung-Beeman et al., 2004). After that, participants were asked whether they had seen a word-triplet during the suppression phase. The results showed that

participants solved the compound remote associate word problems more quickly following the same word-triplet than they solved problems following irrelevant words. When people viewed a word-triplet under CFS, the words were suppressed and thus unable to reach consciousness, yet participants still processed them enough to speed up the solution times. But, more importantly, participants only seemed to solve the problems faster when they reported having solved it analytically. Insight solutions would have meant that participants wouldn't be able to report how they reached the solution they presented, while analytic solutions would have been conscious and deliberate. The latter would imply that CFS does not allow for unconscious semantic processing. Thus, their conclusion was that only limited semantic processing can occur without awareness.

Just those two papers already made way for contradictory results. To make sense of such results, and give a more concise overview, Gayet et al. (2014) reviewed 30 different studies that provided breaking-CFS (b-CFS) results. In b-CFS researchers measure the time it takes for a suppressed stimulus to break that suppression. They found that many of those studies, just like the studies above, showed inconsistent results, and even the ones that claimed to have found unconscious high-level processing were doubted by Gayet et al. The only study that in their mind convincingly demonstrated high-level processes in a b-CFS experiment, is the one by Yang & Yeh (2011). They showed that words which describe negative emotions get detected later than words with positive or neutral emotions. Gayet et al. concluded that to be certain that what is demonstrated is truly unconscious semantic processing one or more conditions should be included that are known to interfere with high-level image properties, while keeping low-level image properties unaffected. An example of such a condition would be to invert the image or inverting the image polarity, as such a manipulation would constrain the extraction of meaning from an image. But even with such added conditions, they are inclined to agree with the idea that there is no semantic analysis under interocular suppression, since they found that interocular competition at a visual level is an adequate explanation for most b-CFS studies.

Continuing with the trend of doubting semantic unconscious processing, Heyman & Moors (2014) found no evidence either that word stimuli are processed up to the semantic level when suppressed through CFS. To participants either word or pseudo-word stimuli was presented and they had to, upon breakthrough, detect as fast as they could where the stimulus was presented (either above or below the fixation point). Contrary to their predictions, they found no effect of word type nor word frequency on suppression time.

More research did not seem in favour of unconscious semantic processing either. Kido & Makioka (2014) did three experiments to see whether unconscious semantic processing could be measured during CFS. Their first experiment aimed to examine the effect of repetition priming, which they could observe under CFS, even when participants could not observe the prime. In their second experiment they explained the effect of cross-script priming. The Japanese language uses different alphabets, and they wanted to see whether the reaction times of participants would be faster even when the prime and the target are transcribed in different scripts (Katakana and Kanji). Cross-script priming effects were observed even when the participants could not perceive the prime words. In their third experiment, Kido and Makioka examined the effect of semantic priming by using words as primes and pictures as targets. They found that the main effect of consciousness was significant, but relatedness was not. A priming effect was not observed when participants were unaware of the prime word, even when that prime word denoted the target. In short, when the participants could not perceive the prime, only repetition priming and cross-script priming were observed. It is difficult to accept cross-script priming as semantic priming. The words written in the different scripts are pronounced the same, which makes it is possible that only the phonological components were processed, and not the semantic components. This explanation seems likely, as semantic priming was not found in the third experiment.

Yang et al. (2017) decided to take a bit of a different approach. They researched unconscious semantic processing with a lexical decision task, making use of electroencephalography (EEG). EEG is a noninvasive, electrophysiological method to monitor electrical brain activity. In the experiment, a prime word or non-word was presented under CFS, followed by a visible word or non-word target. The main effect of prime-target congruency was significant, but post-hoc tests revealed that priming effects only occurred when the prime was visible to the participant. This means that no priming effect was found under CFS. In their second experiment, the primes only existed out of existing words. Word targets were either semantically related or unrelated to the prime, and here they found some differences from the first experiment. Target words following invisible, incongruous primes, triggered different ERP responses than invisible, congruous (related) primes. This was observed principally during the N400, but also during P200 (the P200 also being a component related to the expectancy of a given word). In other words, they only found neuronal evidence of unconscious semantic processing, and no behavioural evidence. In other words, participants did not respond differently after having witnessed the prime, but the ERP did show different brain activity there. This would imply that unconscious processing does occur, and that it relies on a different mechanism than conscious processing does.

Even with the above-mentioned positive results, Stein et al. (2020) were not yet convinced that higher-level processing such as semantic processing can occur without awareness. They replicated a backward masking experiment done by Van den Bussche et al. (2009), and wanted to compare the results to a CFS version of this experiment. Stein et al. used line drawings as the prime, and the targets were Dutch names of the prime image. These were the exact same set of images and words as the ones used in Van den Bussche et al.'s experiment. Participants had to categorise the target words as either objects or animals. Pictures were used as the prime, to see if the meaning would carry over. For the backward masking experiment, they found no significant difference in reaction time to congruently primed targets and incongruently primed targets. This was the same for CFS. But a concern with this experiment is that the prime-target SOA was quite long. In previous research, priming results were often found with shorter SOAs (Greenwald et al.,1996, Kiever & Spitzer, 2000). Thus a second experiment was performed in which they shortened the SOA from 290ms to 90ms. But in this experiment, Stein et al. did not find any significant results either. They found priming results only when the prime was unmasked. This means they failed to obtain evidence for unconscious semantic priming from pictures under continuous flash suppression.

5. Comparing results using different methods

What do the results of experiments applying different methods have in common? Almost all papers that used visual masking found evidence in favour of unconscious semantic processing, and only one failed to find evidence. Papers that research binocular rivalry were more evenly distributed. Two claimed to have found evidence, while the other did not find any. Finally, we have also taken a look at the continuous flash suppression paradigm. Only two papers found evidence, whereas the other five claimed to have found no evidence in favour of unconscious semantic processing. A quick overview can be found in the table below.

Paper	Method Used	Measure for unconsciousness	Evidence for unconscious semantic processing?
Allport (1977)	Visual Masking	introspection	Yes
Nolan & Caramazza (1982)	Visual Masking	introspection	No
Greenwald et al. (1996)	Visual Masking	Forced-choice task	Yes
Dehaene et al. (1998)	Visual Masking	Forced-choice task	Yes
Naccache & Dehaene (2000)	Visual Masking	Introspection & forced-choice task	Yes
Kiever & Spitzer (2000)	Visual Masking	Forced-choice task	Yes
Kouider & Dehaene (2007)	Visual Masking	N/A	Yes
Somekh & Wilding (1973)	Binocular Rivalry	Introspection	Yes
Zimba & Blake (1983)	Binocular Rivalry	Forced-choice task	No
Blake (1988)	Binocular Rivalry	Forced-choice task	No
Costello et al. (2008)	Binocular Rivalry	Forced-choice task	Yes
Sklar et al. (2012)	Continuous Flash Suppression	Forced-choice task	Yes
Zabelina et al. (2012)	Continuous Flash Suppression	Introspection	No
Gayet et al. (2014)	Continuous Flash Suppression	N/A	No
Heyman & Moors (2014)	Continuous Flash Suppression	Forced-choice task	No
Kido & Makioka (2014)	Continuous Flash Suppression	Forced-choice task	No
Yang et al. (2017)	Continuous Flash Suppression	Introspection	Yes
Stein et al. (2020)	Continuous Flash Suppression	Forced-choice task	No

6. Discussion

In a quick glance, it's easy to see the difference in results between methods that have been used. Using visual masking, a lot of papers claimed they found evidence for unconscious semantic processing. Only Nolan & Caramazza (1982) found no evidence for unconscious semantic processing with visual masking. How can that be? A couple of possibilities exist. The first possibility is due to how Nolan & Caramazza tested for unconsciousness, as they asked the participants whether they had seen the masked prime. There was no objective test. Another possibility is that it could be due to a flaw in the original experiment design with the experiment being a replication of an older study by Allport (1977). According to Nolan & Caramazza, a flaw in this experiment was that half of the stimulus words were presented at least two times to the participant, which could result in a learning effect instead of a semantic priming effect. Words can get recognised unconsciously, resulting in faster reaction times. This recognition can be due to processing on the shape level, and does not have to be processing on the semantic level. This flaw could be a reason as to why Allport claimed to have found evidence for unconscious semantic in his experiment while Nolan & Caramazza did not when recreating it.
A somewhat different, but nonetheless very interesting thing to note is the common occurrence in the visual masking paradigm, which was found by Greenwald et al. (1996) and Kiever & Spitzer (2000). They both found that SOA influences responses to unconscious semantic priming, claiming that the longer the SOA, the weaker the priming effect. Since they were the first to note this, it is a possibility that some of the inconsistencies found in results of past research (Dixon, 1971) can be caused by irregular SOAs.

Research done with binocular rivalry, on the other hand, has more mixed results. Somekh & Wilding (1973) claimed to have found evidence for unconscious semantic processing, but their method was rather questionable. They presented images in the suppressed eye very briefly to the participants. Such a short duration would not cause binocular rivalry to occur, more time is needed for that according to Zimba & Blake (1983). Their results for their evidence may actually be due to masking, and not due to binocular rivalry. Blake (1988) found no evidence for unconscious semantic processing. This was probably not due to cognitive overload, as he did a control experiment to test this. According to him, it is more likely that it came from a unique limitation within binocular vision. Costello et al. (2008) claimed to have found evidence in favour of unconscious semantic processing, but still found some uncertainties in their own research. They questioned how the target word interacts with the neural networks activated by the prime word. Another issue is describing how a suppressed word is able to overcome suppression faster with a related prime word than an unrelated word. Is there a possibility that unconscious processing only takes place with certain specific tasks? Maybe that was because this experiment was much more similar to a visual masking experiment than the other binocular rivalry papers we discussed. We saw that visual masking research generally more evidence in favour of unconscious semantic processing yielded, so perhaps the type of task has an influence on the effect.

Most research that used the CFS paradigm, did not find evidence for unconscious semantic processing. This is interesting, because visual masking is the oldest existing paradigm to test unconscious processing, and CFS is the most recent. Sklar et al. (2012) claimed to have found evidence for unconscious semantic processing. They used the time it took for a stimulus to break suppression as the dependent measure. They concluded that weaker semantic associations break suppression faster, such as word combinations that are unexpected and surprise you. But that is a rather quick conclusion to make, as there could be other reasons as to why words and images could break suppression faster. For example, word familiarity is known to have an effect on breaking suppression (Gayet et al, 2014). A novel stimuli should be less familiar, and thus it is unexpected that this suppression time gets shortened. To make sure what is happening is truly a high-level process such as semantic processing, it is necessary to have a control condition that would disrupt such high-level processing. If you, for example, invert the image, it would limit the extraction of a meaning from that image. Sklar et al. did

not have such a control condition. Yang et al. (2017) found different ERP responses when it came to unconscious semantic processing. These results support that words can be processed without awareness, but use a distinct mechanism from processing with awareness. While they did not find any behavioural evidence, they did find neuronal evidence that the words were being processed. Something that should also be mentioned, is that this experiment was done using the Chinese language. It is possible that close shape-meaning relations could activate the semantic system more easily under CFS. While visual processing also is a high-level function, it is something different from semantic processing. To be sure that their experiment indicates unconscious semantic processing, it would be necessary to have a control condition in English. Not to mention the same problem with the results of Sklar et al. (2012) arises. To make sure what is being seen is a result of high-level processing, it is necessary that a control condition is applied that disrupts those processes.

Something that can possibly shed some light on these contradictory results, is the method that was used to measure consciousness. In the table on page 12, we see what paper used either introspection or a forced-choice task. Introspection means to ask the participant whether they saw a prime. The use of introspection is not a very reliable way to test unconsciousness, as it is very subjective. Even when participants respond with a *'no'*, you cannot be entirely sure they did not see anything prior to the mask. It is possible they just were not sure enough they saw something. Introspection is a post-hoc manner of measuring, and usually not a reliable method. A forced-choice task, on the other hand, makes the participant either act as soon as they see the prime, or make a decision, and thus makes for a more reliable way of measuring prime visibility. For visual masking research, evidence in favour of unconscious semantic processing has been found using either introspection or a forced-choice task as a measure for unawareness. There does not seem to be a correlation between the method and results for this paradigm based on the papers we have covered in this thesis. For binocular rivalry research, there are some more remarkable results. Somekh & Wilding (1973) used introspection as a measure and claimed to have found evidence in favour of unconscious semantic processing. With them being one of the few to argue for unconscious semantic processing using binocular rivalry, it becomes a bit more questionable. To be certain the prime truly was unconscious, it would be necessary to test this using a more reliable method such as a forced-choice task. The same can be said for the research done by Yang et al. (2017). They were one of the few that had claimed to have found evidence in favour of unconscious semantic processing using CFS, but they are also one of the two who used introspection. This makes way for a possibility that there is a link between the results and the measure of awareness used, and it might be better to take the results of research that used introspection with a grain of salt.

A second remarkable thing to note is that the differences in results per paradigm used are actually in line with the findings of Kouider & Dehaene (2007), who reviewed papers on the visual masking. It is possible that these findings are due to the type of unconsciousness that is being measured. According to a theory by Dehaene et al. (2006), there are three types of processing; conscious, subliminal and preconscious. Subliminal processing is a process where bottom-up activation is not enough to trigger a large-scale reverberation. So even with focused attention, subliminal information cannot be brought to consciousness. Visual masking interrupts bottom-up processing (Long & Kuhl, 2018), which would imply that visual masking measures subliminal processes. Preconscious processing is the other side of the same coin, it occurs when top-down activation is not strong enough. As shown by the binocular rivalry and CFS paradigms, even when a stimulus is strong and constantly present, it can still stay temporarily unconscious. With enough focus and attention, this stimulus is able to break the suppression. This breaking of suppression has often been the measure for binocular rivalry and CFS. This would imply that only subliminal processing allows for processing of meaning, which is in accordance to Dehaene et al. (2006), who says that only (attended) subliminal processing can reach the semantic level. In their paper, Dehaene et al. (2006) go into great detail about the neuroimaging data that complies with this theory, and the testability of this tripartite distinction. If this theory is true, it would explain the central difference in processing and why the different methods find such contradictory results.

7. Conclusion

A lot of factors contribute to unconscious processing, and it is interesting to see that the depth of the processing may be dependent on the paradigm used. Noteworthy to mention, is that the newer paradigms, such as binocular rivalry and continuous flash suppression, find less evidence for unconscious semantic processing than visual masking. Experiments done with visual masking that claim to have found evidence in favour are abundant, but with newer methods those results grow more and more rare. So we can conclude there certainly is evidence that says that the meaning of words is processed unconsciously, but this evidence is influenced by a great many factors and thus easily gives different results. The method used to measure awareness seems to have an influence, and different types of unconsciousness seem to exist according to Dehaene et al. (2006). These different types of consciousness find themselves in different streams of processing, and are able to process different types of information.

Since there are many different ways of measuring unconscious processing, and different methods deliver different results, it is important to find out what those results could mean. Experiments that made use of visual masking mostly provide evidence in favour of unconscious semantic processing, while binocular rivalry and continuous flash suppression have a harder time proving such a thing. An idea for future research would be to test the theory of these different types of unconsciousness. That could be done by interfering with either top-down processes for methods that find preconscious processing (binocular rivalry and CFS), or interfere with bottom-up processes that find subliminal processing (visual masking). If these interferences would stop the unconscious processing, we can be more certain of the inner workings of unconscious semantic processing. The findings reported in this thesis can be used as a stepping stone for further research into the workings of conscious or unconscious processing. High-level computations are such a uniquely human thing, and if they truly happen unconsciously, it is necessary to understand how these processes work exactly to create successful artificial intelligence.

8. Bibliography

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