Ups & downs: Individual Differences in the Temporal Dynamics of Attention
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Chapter 1

General Introduction
1 The attentional blink and its theories
Attention is needed everywhere in our daily life and forms the basis for other cognitive processes and behavioral performance. Every moment we receive a huge amount of sensory input through different modalities including vision, audition and touch. How the brain selects and tracks useful information over time is one of the most fundamental and important questions in the field of attention.

Our attention, however, is known to be intrinsically variable over time, especially when divided over multiple sources of information. For example, when a car driver is deeply engaged in a conversation with one of the passengers, even an important traffic sign that is in plain view can easily be missed. Also, individuals differ in their ability to divide and focus attention on relevant information. It is thus important to know which factors play a role in this ability, whether it can be trained or instead reflects fundamental limitations that cannot be overcome. In this thesis, we confirmed the trainability of the AB and investigated a number of such factors, including the ability to time attention and to control it. We firstly delve into attentional oscillations as a potential cause of behavioral variability, and furthermore determine what happens when self-relevant information is encountered. Finally, we investigated whether or not the processing of relevant information is modulated by depression.

1.1 The attentional blink
Within the lab, a remarkable demonstration of our limited ability to process sequentially presented information is provided by the paradigm of the attentional blink (AB). In this task, participants are typically instructed to identify two targets (e.g., letters), embedded in a rapid serial visual presentation (RSVP) stream of irrelevant distractors (e.g., digits). The second target (T2) is often missed when it is presented within 200-500 milliseconds following the first target (T1) (Broadbent & Broadbent, 1987; Raymond, Shapiro, & Arnell, 1992). The AB effect itself has been observed within different modalities (Arnell & Jolicoeur, 1999; Chun & Potter, 2001; Duncan, Martens, & Ward, 1997; Hein, Parr, & Duncan, 2006; S. Martens, Kandula, & Duncan, 2010) underlining the fundamental nature of the phenomenon.
1.2 Capacity Limitation Theories

Previous studies suggested the AB effect to be resilient to training (Bowman & Wyble, 2007; Chun & Potter, 1995; Dale, Dux, & Arnell, 2013; Jolicœur & Dell'Acqua, 1998; Taatgen, Juvina, Schipper, Borst, & Martens, 2009). For example, one study, in which both participants who practiced thousands of trials prior to the experiment as well as experts who had much experience in processing rapidly presented stimuli in their daily work, showed no better performance compared to participants who performed the AB task for the very first time (Braun, 1998).

Early theories regarded the AB as a structural limitation when processing rapidly presented stimuli, resulting from insufficient attentional resources for T2 after processing T1 (Bowman & Wyble, 2007; Braun, 1998; Chun & Potter, 1995; Dale et al., 2013; Jolicœur & Dell'Acqua, 1998; Maki & Padmanabhan, 1994; Raymond, Shapiro, & Arnell, 1995; Wyble, Bowman, & Nieuwenstein, 2009). For example, the inhibition model raised by Raymond et al. (1992) considered the AB as the result of inhibiting distracting stimuli to reduce confusion between the targets’ and distractors’ features. This theory suggested that the stimuli following T1 are suppressed at an early perceptual stage due to an inhibition effect induced by T1 (Isaak, Shapiro, & Martin, 1999; Shapiro, Raymond, & Arnell, 1994). Namely, in an RSVP task, an attentional episode is triggered when physical features of T1, such as color or shape, are detected. The features of subsequent items including T2 would cause confusion after detecting the features of T1, which would lead to an AB. Shapiro and his colleagues thus considered the AB as a result of interference between initial perceptual representations. From the instructions, participants would generate a selection template about the targets, and each stimulus would have a weighting based on the overlap with the original target template. This theory thus tried to explain the Lag-1 effect: among all the stimuli, the first target (T1) and the target immediately following it (T1 + 1) are always transferred to working memory, leading to good performance for T1 and the item immediately following it. When the second target (T2) is not immediately following T1, T2’s representation loses the competition with T1’s representation to be consolidated.
Chun & Potter (1995) subsequently proposed their influential two-stage theory, indicating that the processing of targets presented in an AB task can be divided into two stages. At stage 1, the presented stimuli can be processed up to the level of semantics. The processing capacity at this stage can be regarded as unlimited, in contrast to the next consolidation stage. In this so-called stage 2, target stimuli need to be consolidated into working memory before they can be reported, but the capability to concurrently store the information to a more durable form is severely limited. That is, T2 will often not be consolidated until consolidation of T1 is completed, rendering the representation of T2 vulnerable to decay and interference. As a result, the AB is likely to occur.

1.3 Control models
Later research, however, a study by Choi and his colleagues (2012) found that the AB could be reduced or even be eliminated simply by setting T2 as a salient color in a special training task prior to the standard AB task without colored T2, which could even be maintained for several months (Choi, Chang, Shibata, Sasaki, & Watanabe, 2012). In their study, the training procedure enhanced participants’ temporal resolution such that it allowed them to consistently overcome the AB. A subsequent study acknowledged that the elimination of AB effect was obtained by the use of the salient target, which may have helped to build up temporal expectations about when the targets appear (Tang, Badcock, & Visser, 2014).

Subsequent studies have turned to a more macroscopic training, attempting to adjust the level of engagement in the AB task by altering its distribution across time. For example, when attention got rest in a prolonged and systematic way, like sleep (Cellini et al., 2015) and meditation (Van Vugt & Slagter, 2014), the magnitude of the AB can be reduced. In the past years, many studies have presented evidence that AB can be eliminated by training or changing the strategies (Arend, Johnston, & Shapiro, 2006; Nieuwenstein & Potter, 2006; Oei & Patterson, 2013; Olivers & Nieuwenhuis, 2006; Reedijk, Bolders, Colzato, & Hommel, 2015; Tang et al., 2014; Willems, Damsma, Wierda, Taatgen, & Martens, 2015). These studies pointed to the AB as a product of the interaction between temporal
attention and cognitive control. As a result, the blame of AB turned from the structural limitation to cognitive control, which suggested that an AB occurs from a lack of control, resulting in a suboptimal distribution of cognitive resources.

For example, the loss of control theory (Di Lollo, Kawahara, Shahab, & Enns, 2005) postulated that in the RSVP task, both the detection of targets and the rejection of distractors are achieved by controlling an input filter. When T1 is detected, control of the input filter is diminished, thus leaving more cognitive resources to process T1. If T1+1 is also a target, the configuration of the input filter will remain the same, allowing T1+1 to be processed. If T1+1 is also a distractor, control on the input filter is temporarily disrupted, which has a negative impact on the processing of the subsequent stimulus (including T2), and probability leads to a blink. Similarly, the Boost and Bounce model (Olivers & Meeter, 2008) suggests that the AB is caused by insufficient cognitive control. This theory assumes that detection of the first stimulus facilitates the next item. If T1+1 is still a target, then it will be facilitated. In contrast, detection of the distracter produces an opposite force (suppression, i.e. a ‘bounce’) that controls the processing of the next item, resulting in an AB.

A few years later, the episodic simultaneous type serial token (eSTST) model was presented (Wyble, Bowman, & Nieuwenstein, 2009), which is composed of neurobiological plausible neural elements and simulates the attentional blink with a competitive attentional mechanism. It proposed that the AB originates from the mechanism that provides episodic features between WM representations and target input. In this model, attention keeps controlled by the competition between inhibitory and excitatory forces from WM and target input. More specifically, each target in the RSVP stream induced a recurrent excitation of attention. If no target is presented for 200 ms (or more) after the presentation of the preceding target, the consolidation of the preceding target (T1) would succeed in suppressing the input of a second target (T2) presented between 200-500 ms. This would lead to an AB because the T2 would be less able to reach attention due to the suppression. That is, items following T1 (except the T1 + 1 item) in the stimulus sequence are suppressed to avoid interference.
between WM representations. The eSTST model stressed though that the AB effect is a cognitive strategy rather than a resource limitation.

The later Threaded Cognition model merged the strengths of control models like the TLC model (Di Lollo et al., 2005), eSTST (Wyble et al., 2009), and the Boost and Bounce model (Olivers & Meeter, 2008) together with the two-stage model and interference model, attributing the AB to a conflict between fast target detection and slow memory consolidation. In this model, the AB task can be regarded as a combination of two pre-existing skills: detection of a target and integration of the target into memory. As indicated by the nature of the RSVP task, target detection and memory integration are simultaneous and can be regarded as two tasks competing for resources. In the threaded cognition model, an AB is generated when target detection and memory consolidation are performed simultaneously, additional control is added to the model to suppress stimulus detection and thus ensure that memory consolidation is completed. This model explained individual differences in the AB effect as the imposition of too much cognitive control by large blinkers (Martens, Munneke, Smid, & Johnson, 2006; Willems & Martens, 2016; Willems, Wierda, Viegen, & Martens, 2013).

Previous theories of the AB assumed that the functional use of the AB phenomenon is to distinguish and separate items in memory (Akyürek, Abedian-Amiri, & Ostermeier, 2011). Against this assumption, a study reported that the AB could disappear when the two targets are reported as one syllable rather than two separate letters (Ferlazzo, Lucido, Di Nocera, Fagioli, & Sdoia, 2007). On the basis of this result, the Threaded Cognition model proposed the disappearance of the AB to result from an adjustment in processing strategy prompted by the instruction to consolidate targets as chunked objects.

This model not only regarded non-blinkers as those who have a correct consolidation strategy, but also suggested that the training effects of the AB can be regarded as the result of learning to adopt a better strategy. In conclusion, these control models challenged the traditional theories and went a step further in explaining individual differences in the AB effect to
be due to processing strategy rather than processing capacity.

1.4 Individual differences
As we know from the Limited Capacity Theories, the AB has thus long been regarded as a fundamental limitation when processing rapidly presented information and has long been thought to be resilient to training. Intriguingly though, large individual differences in the magnitude of the effect have been observed, with about 5% of the people, referred to as non-blinkers, showing no AB whatsoever (Martens, Munneke, et al., 2006; Willems & Martens, 2016). While this could be due to individual differences in for instance working memory ability or general intelligence (Arnell, Howe, Joanisse, & Klein, 2006; Arnell, Stokes, MacLean, & Gigante, 2010; Arnell & Stubitz, 2010; S. Martens & Johnson, 2009), it also raised the possibility that the AB reflected a cognitive strategic rather than structural bottleneck (Martens & Wyble, 2010; Taatgen et al., 2009). As described above, later studies indeed found that the AB can be attenuated and sometimes even eliminated using laboratory training tasks (Choi et al., 2012; Wang, Luo, Aleman, & Martens, 2021). Consequently, the theoretical landscape shifted towards explaining the phenomenon as a limitation to time attention rather than a structural processing bottleneck.

2 Potential factors that influence temporal attention

In the current thesis, to investigate individual differences in temporal attention in more detail, we explored a number of factors that could influence temporal attention including timing ability, learning ability, and oscillations in attention, as well as emotional disposition.

2.1 The ability to time attention
Converging evidence from behavioral, EEG, and pupil dilation studies have indeed suggested that non-blinkers are better able to control the timing of attention than most people do. For instance, non-blinkers tended to respond quicker to the first target than ‘blinkers’ did (Martens, Munneke, et al., 2006; Willems, Damsma, et al., 2015; Willems, Herdzin, & Martens, 2015; Willems et al., 2013). The P3, an Event-related potential (ERP) component that is assumed to reflect the updating of working memory, was
found to occur earlier in time. Moreover, the P3 was found to be decreased when processing irrelevant distractors, reflecting more efficient target selection (Martens, Munneke, et al., 2006). Moreover, a previous study suggested that in an AB task, temporal cues about when T2 would be presented can significantly enhance its accuracy, helping to overcome the AB (Martens, Elmallah, London, & Johnson, 2006). A later study measuring pupil dilation reported that earlier attentional allocation to the second target led to better performance in the AB task as reflected in a small AB (Willems, Damsma, et al., 2015). A subsequent pupil dilation study confirmed this earlier attentional allocation and showed that small blinkers were better than large blinkers in preserving temporal order information (Willems, Herdzin, et al., 2015).

Time plays an essential role in our daily life. Our daily behavior and decisions are largely dependent on the correct representation of time. There is a great deal of research on how humans perceive time (Wittmann, 2013), and two of the most prominent ones are the dedicated and intrinsic models (Ivry & Schlerf, 2008). The dedicated view suggests that there is a mechanism specifically designed to represent duration, such as the pace maker-accumulator model (Simen, Rivest, Ludvig, Balci, & Killeen, 2013), which is regarded as a leading model in the field of time perception for almost 60 years. This model assumes a pace-maker in the brain dedicated to creating a series of pulses, like ticks in a clock, and these recorded pulses represent time. In contrast, the intrinsic model (Ivry & Schlerf, 2008) denied the existence of an additional mechanism for the recording of time, and it is argued that memory decays by the passage of time. In this way, time can be perceived intrinsically by the degree of decay.

In addition to dividing time processing into intrinsic and extrinsic models, time processing is also often linked to either long- or short-term mechanisms. For example, one study revealed that a specific experimental manipulation could only change the brain's perception of time up to 300 ms (Buonomano, Bramen, & Khodadadifar, 2009; Spencer, Karmarkar, & Ivry, 2009), indicating that the duration of time at the millisecond level might rely on sensory processing, and that longer temporal processing may involve more cognitive abilities.
Moreover, as a very complex and precise process, the perception of time can also be influenced by the allocation of attention. An fMRI study found that behavioral performance in temporal attentional tasks increased when more cognitive resources were allocated to temporal features. At the same time, the pre-subjective motor area in the brain was associated with the behavioral performance on temporal attention (Coull, Vidal, Nazarian, & Macar, 2004). Moreover, plenty of neuroimaging studies have demonstrated the important role of the cerebellum in temporal perception, and a TMS study indeed showed that performance on AB was worse when the cerebellar region was stimulated (Kraus, Robinson, White, Eichenbaum, & Hasselmo, 2013; MacDonald, Carrow, Place, & Eichenbaum, 2013; Mangels, Ivry, & Shimizu, 1998).

In chapter 2, we proposed that timing ability is an important factor in explaining individual differences in the AB effect. More specifically, we hypothesized that small blinkers are better than large blinkers at timing attention. We used the interval of 300 ms to train the timing ability of the participants to test whether timing ability can indeed influence temporal attention.

### 2.2 The ability to train attention

As has been shown in a number of studies (Cellini et al., 2015; Choi et al., 2012; Tang et al., 2014; Van Vugt & Slagter, 2014) and as found in chapter 2, the AB can be diminished through training. Learning effects are known to be largely reliant on reinforcement learning processes, which involves learners to adopt their performance according to the current outcome. For example, in a time estimation task, the outcome is whether the estimation is longer or shorter compared to the actual duration; participants would adjust their estimated time in the next trial according to the current outcome. A broadly connected brain network, including the basal ganglia and the anterior cingulate cortex (ACC), is involved in reinforcement learning procedure (Schultz, 2002) and individual differences in time estimation learning ability have been associated with striatal dopamine function (Frank, Moustafa, Haughey, Curran, & Hutchison, 2007).
Many studies have focused on electrophysiological components during reinforcement learning, including reward positivity (RewP), frontal midline theta (FMT), and beta-gamma oscillation (Holroyd & Coles, 2002; Li, Peng, Li, & Holroyd, 2018; Marco-Pallares et al., 2008). Specifically, as an electrophysiological index of individual differences in reinforcement learning, the RewP has been commonly studied in learning tasks (Holroyd & Umemoto, 2016; Marco-Pallares et al., 2008; Santesso et al., 2008). In addition, a large number of studies have linked frontal midline theta activity (FMT) to the processing of negative reward prediction errors, thus explaining behavioral adaptation in reinforcement learning. In contrast to RewP and FMT thought, the beta-gamma activity (25–35 Hz), observed in a 250–400 ms time window over the left-central and the mid-frontal scalp (HajiHosseini, Rodríguez-Fornells, & Marco-Pallarés, 2012), has not often been investigated in reinforcement learning tasks.

In summary, it would be interesting to investigate the electrophysiological activity that can reflect the individual differences in the process of time learning. We examined the individual differences in electrophysiological activity during the time learning process in Chapter 3.

2.3 Oscillation as an intrinsic feature of attention

Our brain does not mechanically process incoming sensory input but depends on certain brain states, which can predict whether an input stimulus will be perceived or not. Many studies have shown that the magnitude or phase in neuronal oscillation is correlated with the perception of the visual input (Busch, Dubois, & VanRullen, 2009; Busch & VanRullen, 2010; Ergenoglu et al., 2004; Hanslmayr et al., 2007; Mathewson, Gratton, Fabiani, Beck, & Ro, 2009; Van Dijk, Schoffelen, Oostenveld, & Jensen, 2008). For an example, an EEG study suggested that different parameters of ongoing alpha oscillatory activity in the brain (~10 Hz) can predict whether a visual stimulus will be perceived or not (Hanslmayr, Gross, Klimesch, & Shapiro, 2011). Moreover, one study revealed the oscillatory influence on the AB magnitude on a trial-by-trial basis (MacLean & Arnell, 2011). The alpha event-related desynchronization elicited by a starting cue predicted the T1 and T2 performance on all lags, demonstrating that more investment of attentional
resources for T1 led to a larger AB magnitude (frequent misidentification of T2 at short lags). The important role of alpha oscillation in the AB task was also found in resting state EEG studies, which illustrated that the oscillation in the frontoparietal area is associated with AB magnitude (MacLean, Arnell, & Cote, 2012; Shapiro, Hanslmayr, Enns, & Lleras, 2017). Other studies have linked the AB phenomenon with alpha entrainment, pointing out the possible relationship between the stimulation frequency and the triggered brain oscillation (Kranczioch, Debener, Maye, & Engel, 2007; Zauner et al., 2012). In summary, brain oscillation, especially alpha band oscillation, is tightly linked with visual-spatial attention, suggesting that attention is not continuous and invariant, but processes stimuli in a rhythmic fashion.

A remarkable finding in the field of attention in the last decade is the discovery of behavioral oscillation. In traditional attention tasks, researchers only record the behavioral performance at a single point in time, where the resolution is too low to capture dynamic changes in behavior. However, using a high temporal resolution behavioral paradigm, it was possible to obtain densely sampled behavioral performance by sampling at a fine level (e.g. 20 ms) and then performing time-frequency analysis to obtain spectral information on behavioral performance. For example, as illustrated in figure 1, a previous study using this paradigm revealed that attention is fluctuating all the time, both within (8 Hz) and between objects (4 Hz) as reflected in behavioral performance (Fiebelkorn, Saalmann, & Kastner, 2013).
Figure 1. Rhythmic attentional sampling within and between objects (Fiebelkorn, Saalmann, & Kastner, 2013. Reproduced with permission (Elsevier/Copyright Clearance Center; license number: 5323981148218)). Rhythmic sampling within and between objects despite sustained attention at a cued location. (A) Participants were asked to detect the target which is most likely to occur at the spatial cued position (illustrated by the square frame). The time interval between cue and target was 300 ms to 1100 ms changed by steps of 50 ms in each trial. The researchers tracked target detection (the star symbol) at a cued location, an uncued location within the same object and an uncued location in a different object. Performance at the cued location and same object location oscillated at 7~ 8 Hz, but with a slight phase delay, as if attention was sweeping across the object. Performance at the different object location was also found to oscillate, but at a lower frequency of ~4Hz, showing an opposite phase with the cued location. (B) Power spectra of detection performance for each of the three tested locations. Within-object oscillation: Both the cued location and the other location of the same object showed a 7-8 Hz fluctuation within-object sampling. Between-object sampling: All three locations displayed 4 Hz oscillation in between-object sampling.
However, to date, previous studies have only confirmed that spatial attention is sampled in the form of oscillations over time at multiple locations, but it is unclear whether attention is similarly sampled over time when only a single location needs to be attended. In this thesis we addressed this question in Chapter 4. In addition, we examined whether the same oscillatory patterns can be observed in the paradigm of the attentional blink and if so, whether they can explain individual differences in AB magnitude.

2.4 The allocation of attentional resources
It is known that a more demanding T1 leads to a larger AB. That is, when T1 difficulty was manipulated, AB magnitude would be modulated too (Taatgen et al., 2009; Visser & Ohan, 2007). It is commonly assumed that when T1 and T2 are temporally close. As a result, T1 recruits attention in a way that hinders T2 consolidation by either consuming all available resources or by employing the attentional resources to bias the competition in its favor, and then to cause a delay or conflict in processing subsequent information (Martens & Wyble, 2010). Consequently, an easily processed T1 leaves more attentional resources for T2, making it more likely to be successfully reported. Thus, the AB paradigm can be useful in determining which stimuli require more attentional resources.

It remains an open question though whether processing a self-relevant stimulus will have a cost or benefit for the processing of subsequent stimuli. Specifically, previous research has pointed to a paradoxical relationship between the allocation of attentional resources and the processing of self-relevant stimuli. Some studies have argued that self-relevant information attracts more attention than other information, as illustrated by the well-known the cocktail-party effect (Alexopoulos, Muller, Ric, & Marendaz, 2012; Martens & Wyble, 2010; Sui, Liu, Mevorach, & Humphreys, 2015; G. Wang, Liu, & Fang, 2021). However, other studies suggest that self-relevant information requires fewer rather than more attentional resources (Bargh, 1982; Tacikowski, Freiburghaus, & Ehrsson, 2017). In Chapter 5, we adopted the AB paradigm to address this controversy regarding self-relevance and temporal attention.
2.5 Emotional disorders: depression

One final factor that we focused on in this thesis is depression. It is well known that depression can affect cognitive processes such as attention (Ellis, 1990; Farrin, Hull, Unwin, Wykes, & David, 2003), working memory (Ellis, Thomas, & Rodriguez, 1984; Hartlage, Alloy, Vázquez, & Dykman, 1993; Hertel & Hardin, 1990; Hertel & Rude, 1991), executive function (Fossati, Amar, Raoux, Ergis, & Allilaire, 1999; Stordal et al., 2004), and learning ability (Austin et al., 1992; Maag & Reid, 2006). Moreover, depression is one of the most frequent mental disorders that can cause a persistent influence on feeling, thinking, and action (Cuijpers & Smit, 2004; Davidson, Pizzagalli, Nitschke, & Putnam, 2002; Slavich & Irwin, 2014).

Previous studies have shown that current affective states have an impact on the AB effect (Vermeulen, 2010) and evidence from a number of studies has shown that participants with an emotional disorder such as depression, anxiety or dysphoria show impaired performance in the AB task compared to healthy participants (Arend & Botella, 2002; de Jong, Koster, van Wees, & Martens, 2009; Koster, Raedt, Verschuere, Tibboel, & De Jong, 2009; Rokke, Arnell, Koch, & Andrews, 2002). germane to the current project though is that depression showed an interaction with the other factors that influenced the individual difference (e.g., temporal attention, learning ability and self-relevant processing).

3 The interaction between depression, attention, learning and emotion

Depression is one of the most frequent mental disorders with an impact on cognitive processes. In the current thesis, we studied the interaction between depression and other factors that could have an influence on the AB effect in chapter 2 and chapter 5.

3.1 The influence of depression on general attention

According to the fifth edition of the Diagnostic and Statistical Manual of Mental Disorders (DSM-5), a diminished ability to think or concentrate is one of the diagnostic criteria of depression. In practice, depression has a general effect on attentional processes, such as selective attention, sustained attention, and divided attention.
3.2 The influence of depression on the ability to time attention
Numerous studies have shown that depressed people report perceiving time more slowly compared to healthy people (Bech, 1975; Blewett, 1992; Hoffer & Osmond, 1962; Kitamura & Kumar, 1982; Lehmann, 1967; Mezey & Cohen, 1961; Wyrick & Wyrick, 1977). Earlier studies have shown that depressed people are preoccupied with what has happened in the past and pay less attention to the present and future. In terms of time estimation and time interval production, some results are not entirely consistent, for example, an early study found that depressed people overestimate time from 160s to 30 minutes, suggesting that they perceive time as longer (Wyrick & Wyrick, 1977). However, some studies have found that the higher the level of depression, the shorter the time estimate of 400-1600ms, suggesting that the internal clock of depressed people goes slower than that of healthy people (Bschor et al., 2004; Fayolle, Gil, & Droit-Volet, 2015). A meta-analysis of previous results revealed that depressed people indeed perceive time to pass more slowly than healthy populations. However, no differences were found in time estimation tasks. When producing time intervals, they tend to overestimate the interval for shorter time intervals and underestimate the interval for longer time intervals (Thönes & Oberfeld, 2015).

3.3 The influence of depression on learning ability
Depression has long been associated with learning difficulties, and it has been proposed as an important factor of learning disabilities in schooling (Austin et al., 1992; Brumback & Staton, 1983; Clouston, 1884; Maag & Reid, 2006; Weinberg et al., 1989). Early research has shown that moderate depression affects a person's cognitive abilities. For example, using an auditory verb learning test, it has been shown that the ability to learn new knowledge, recall, and recollection were poorer in the depressed group (Austin et al., 1992). Depression in children is also becoming a rising problem. It has been shown that depressed children are less able to use their imagination than healthy children (Weingartner, Cohen, Murphy, Martello, & Gerdt, 1981), and that they lack problem-solving skills, which can prevent them from dealing effectively with problems in their lives.
3.4 A negative (self-) attentional bias due to depression

As illustrated in the fifth edition of the Diagnostic and Statistical Manual of Mental Disorders (DSM-5), one of the most central symptoms of major depression disorder is the tendency to have a negative view of oneself, including feelings of worthlessness and hopelessness (Association, 2013), and there is a general consensus that depression is accompanied with self-referential bias (Gronau, Cohen, & Ben-Shakhar, 2003; Kaiser et al., 2018; McIvor, Sui, Malhotra, Drury, & Kumar, 2021; Nolen-Hoeksema, Wisco, & Lyubomirsky, 2008). For instance, previous studies have shown that depressed people tend to allocate more attentional resources on a target when it is more self-relevant (Figueroa et al., 2015; Nejad et al., 2019).

In summary, depression seems to be a mediator for processing self-relevant information, temporal attention, and learning ability.

4. Overview of the present thesis

In the present thesis, we investigated individual differences in temporal attention and mainly focused on three aspects: the mechanism of the AB phenomenon, the role of learning in temporal attention, and the interaction between temporal attention, self-relevance emotion, and depression.

In Chapter 2, we focus on the sensitivity for temporal information on the ability to control attention. We hypothesized that the AB can be attenuated by a time training task compared to training on a control task (a frequency estimation training task). In addition, we looked at the learning effect for different levels of depression.

In Chapter 3, we revealed that beta-gamma activity manifests individual differences in reinforcement learning processing. We selected good learners and non-learners based on their behavioral performance in adapting to the Friedlander learning task. Subsequently, we tested the group differences in EEG signals in a time estimation task. We examined the individual differences in the RewP component, theta oscillation, and beta-gamma oscillation associated with unexpected reward feedback in the learner and non-learner groups.
In Chapter 4, we created a dense temporal profile in the time window during which the AB task was performed, and have two main results: a) behavioral oscillations could still be observed when attention was focused on a single location in an RSVP stream; and b) the power of these oscillations was related to individual differences in AB magnitude, indicating an important role of attentional oscillation on AB performance.

In Chapter 5, we explored whether processing a self-relevant stimulus comes at cost or benefit for subsequent stimuli. In addition, we investigated whether the effect of self-relevancy on temporal attention depends on one’s depression level. Our findings revealed that a processing advantage for highly self-relevant stimuli comes at either a subsequent cost or benefit in temporal attention depending on one’s mental disposition.
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