Positive Effects in Working Memory: Influences of Emotional Valence and Task Relevance

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Abstract

The positivity effect refers to the tendency of older adults, compared with young adults, to prioritize the processing of positive emotional stimuli over negative emotional stimuli. Recent working memory research has found that the positivity effect is influenced by emotional valence and task relevance: studies where emotional valence serves as a task-relevant attribute support the existence of a positivity effect in working memory, manifested specifically as enhanced memory for positive emotional stimuli and impaired memory for negative emotional stimuli in older adults; research where emotional valence serves as a task-irrelevant attribute in working memory tasks is relatively scarce, and has not found consistent positivity effects, suggesting that both emotional valence and task relevance are key factors influencing the positivity effect in working memory. Brain imaging studies have preliminarily indicated that age-related effects in emotional processing within working memory are associated with age-related functional changes in the dorsal executive system and ventral emotional system. Socioemotional selectivity theory and the dual competition model possess substantial explanatory power for the positivity effect in working memory, whereas the dynamic integration theory lacks support from empirical research. Future research could further investigate the characteristics of emotional processing at different stages of working memory in older adults, clarify the potential influence of differences in the intrinsic encoding processes of different emotional materials on the mechanisms underlying the positivity effect, explore the key neural circuits through which emotional valence and task relevance influence the positivity effect in working memory, and reveal the intrinsic mechanisms and potential application value of emotional working memory training in enhancing cognitive function and emotional experience in older adults.

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Positivity Effects in Working Memory: The Effects of Emotional Valence and Task Relevance

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Abstract: Age-related positivity effect refers to the phenomenon that older adults display a preference for positive rather than negative information in cognitive processing. Recent researches in working memory (WM) have found the effect of the interaction between emotional valance and task-relevance on positivity effect. Positivity effect has been observed in WM studies with emotional valence acting as a kind of task-relevant information. For instance, older people have enhanced performance in WM tasks with positive emotional stimuli, and decreased performance on negative emotional stimuli. In contrast, less attention has focused on the area of emotional valence as task-irrelevant information in WM and conflicting findings also have been reported. These remind that both emotional valence and task relevance are critical components in the processing of positivity effect in WM. Preliminary neuroimaging studies have revealed that the associations between age-related functional changes in the dorsal executive system and ventral affective system and the age effect in emotional process of WM. The socioemotional selectivity theory and the dual-competition model have been found to mainly account for age-related positivity effect in WM. But there is a lack of empirical evidence to support the dynamic integration theory. Overall, future studies are warranted in exploring the characteristics of emotional processing in different stages of WM in older adults, clarifying the potential influences of internal encoding processes of emotional materials on the mechanism of positivity effect, uncovering the important neural circuits related to the impact of task-relevance of emotion on positivity effect, as well as revealing the underlying mechanisms and potential benefits of emotional WM training on the improvement of cognitive functions and emotional experience in the elderly.

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Research on the interaction between emotion and cognition has found that older individuals tend to acquire and process stimuli with positive emotional characteristics more readily. This phenomenon is known as the positivity effect (Carstensen & Mikels, 2005). Numerous empirical studies have investigated the positivity effect and its mechanisms in the domains of attention and memory (English & Carstensen, 2015; Gronchi et al., 2018; Mammarella et al., 2016; Gong & Wang, 2012; Liu et al., 2019). In recent years, research on the positivity effect has expanded to working memory, a core cognitive function. Although studies using neutral materials have consistently found that working memory performance declines with age (Brockmole & Logie, 2013; Lugtmeijer et al., 2019), research employing emotional stimuli has found that emotional stimuli, particularly positive emotional stimuli, can improve older adults' memory performance. This suggests that the positivity effect also manifests in the domain of working memory, a phenomenon that has attracted considerable attention and discussion among researchers.

2 Discovery of Positivity Effects in Working Memory

Working memory is responsible for the simultaneous storage and processing of information and is closely related to other higher-order cognitive functions such as executive function, inhibitory function, and fluid intelligence. Moreover, it positively correlates with individuals' performance in daily activities such as problem-solving and reading (Peng et al., 2018; Swanson & Fung, 2016). Mikels et al. (2005) first discovered emotional effects in working memory. Their study required participants to complete an affective maintenance task and a brightness maintenance task. In the affective maintenance task, participants judged whether the emotional intensity of two sequentially presented emotional pictures was the same, whereas in the brightness maintenance task, they compared whether the brightness of two sequentially presented neutral pictures was identical. The results showed that older adults' accuracy in the brightness maintenance task was significantly lower than that of younger adults, while no significant difference was found between the two groups in the affective maintenance task. This suggests that compared with the age-related decline in working memory under neutral task conditions, older adults' working memory function does not show significant deterioration when memory materials are emotional stimuli. Additionally, studies using delayed matching-to-sample tasks have found that when participants were required to remember and judge facial identity, older adults' accuracy was significantly lower than that of younger adults. However, when they were asked to remember and judge facial emotions, the accuracy difference between the two groups was not significant, indicating that emotional materials can mitigate the decline in older adults' working memory performance (Hartley et al., 2015).

As research on the impact of emotional valence on older adults' working memory function has deepened, inconsistent results have been reported. Some studies have found evidence for positivity effects in older adults' working memory, showing that compared with neutral or negative emotional stimuli, the performance gap between older and younger adults narrows when task materials are positive emotional stimuli, and in some cases older adults even outperform younger adults (Mammarella et al., 2013; Sava et al., 2017). However, other studies have not found a facilitative effect of positive emotional stimuli on older adults' working memory (Truong & Yang, 2014), and some have even found that older adults' working memory performance is worse under positive emotional stimulus conditions (Ziaei et al., 2018). Notably, in some studies emotional valence served as task-relevant information, such as when participants were required to remember and judge whether the valence or intensity of emotional faces had changed (Mok et al., 2019). In other studies, emotional valence served as task-irrelevant information, such as when participants were instructed to ignore emotional information and remember and judge the spatial location of emotional stimuli (Borg et al., 2011), or when emotional stimuli were used as background information (Oren et al., 2017). These observations suggest that the experimental manipulation of emotional valence and task relevance may be a critical factor influencing whether positivity effects emerge. This paper reviews existing research on positivity effects in working memory by focusing on the core feature of task relevance of emotional valence. It also discusses the mechanisms through which the interaction between emotional valence and task relevance influences emotional processing in older adults' working memory, and outlines future research directions.

3 Impact of Emotional Valence and Task Relevance on Positivity Effects in Working Memory

Regarding the examination of positivity effects, researchers currently consider age effects under the same emotional valence as direct evidence for positivity effects. For example, when older adults outperform younger adults under positive emotional stimulus conditions, and/or when older adults perform worse than younger adults under negative emotional stimulus conditions. In contrast, differences among participants within the same age group across different emotional valence conditions are considered indirect evidence for positivity effects, such as when older adults' memory for positive emotional stimuli is better than for negative (or neutral) stimuli (Bi & Han, 2014; Liu et al., 2019).

3.1 Emotional Valence as a Task-Relevant Attribute

Most studies have treated emotional valence as a relevant attribute of target stimuli to investigate its impact on older adults' working memory capacity, requiring participants to store and manipulate memory representations of emotional valence. Relevant studies are summarized in Table 1 . Sava et al. (2017) employed a delayed matching-to-sample task with emotional faces. During the encoding phase, an emotional face was presented, and after a 0.5-second interval, participants were asked to select the memorized item from four options. The results showed that when target stimuli were sad or angry faces, older adults' accuracy was significantly lower than that of younger adults. When target stimuli were happy faces, no significant difference was found between the two groups.

Regarding reaction time, no significant difference was observed between older and younger adults when memorizing faces of different emotional valences. To further measure the fidelity of emotional stimulus memory representations, some studies have required participants to adjust the emotional intensity of a face presented during the probe phase to match that of the face presented during the encoding phase. The results revealed an interaction between age and emotional valence. Specifically, compared with the age difference in happy face conditions, the difference in accuracy between older and younger adults was larger in angry face conditions, indicating that older adults' accuracy was lower (Svärd et al., 2014). Another study measuring the precision of emotional information memory found that older adults' representation intensity of fearful faces in working memory was significantly lower than that of younger adults, while no significant age difference was observed in happy face conditions. Moreover, compared with younger adults, older adults were more likely to judge low- and medium-intensity fearful faces as happy faces (Mok et al., 2019). These findings suggest that with increasing age, older adults' ability to process negative information within working memory declines compared with younger adults. Analyses of age differences within the same emotional valence provide direct evidence for the existence of positivity effects in working memory.

Other studies have indirectly verified the existence of positivity effects in working memory by comparing differences among participants within the same age group across different emotional valence conditions (Bermudez & Souza, 2017; Majerus & D'Argembeau, 2011; Mammarella et al., 2013). Bermudez and Souza (2017) used a delayed matching-to-sample task, requiring participants to memorize emotional scene pictures presented sequentially during the encoding phase. The results showed that older adults' accuracy for positive and neutral scene pictures was significantly higher than for negative scene pictures, whereas younger adults showed no significant differences in accuracy across the three emotional valence conditions. Another study found that when memory items consisted of words with the same emotional valence, both younger and older adults showed significantly higher accuracy for positive words than for neutral and negative words. When memory items consisted of words with different emotional valences, younger adults showed significantly higher accuracy for both negative and positive words compared with neutral words, whereas older adults only showed significantly higher accuracy for positive words compared with neutral words, with no significant difference between negative and neutral word conditions (Majerus & D' Argembeau, 2011). A study using an operation span task found that older adults' working memory span was greater under positive word conditions compared with neutral words, whereas younger adults showed no significant difference in working memory span between positive and neutral word conditions (Mammarella et al., 2013).

In summary, studies treating emotional valence as a task-relevant attribute in working memory have provided both direct and indirect verification of positivity effects, offering supportive evidence for positivity effects in working memory. These findings align with research on positivity effects in attention and memory

(Ford et al., 2018; Meng et al., 2015). Working memory receives information input from attention and simultaneously retrieves memory representations from long-term memory for current task processing (Oberauer, 2019). This suggests that older adults exhibit processing advantages for positive information across general cognitive processes. To explain the mechanisms underlying positivity effects, Carstensen and colleagues proposed the Socioemotional Selectivity Theory (SST). This theory posits that as people age, their perceived time becomes limited, leading older adults to focus more on emotional goals. To enhance positive emotional experiences, older adults' processing bias for emotional information shifts from focusing more on negative information during youth to focusing more on positive information in middle and late adulthood. They also allocate more cognitive resources to process positive information to achieve emotional goals (Carstensen et al., 1999). The discovery of positivity effects in working memory expands and deepens the Socioemotional Selectivity Theory model. Notably, studies using emotional scene pictures and emotional words have found that older adults have better ability to process positive emotional stimuli (Bermudez & Souza, 2017; Majerus & D' Argembeau, 2011; Mammarella et al., 2013), whereas studies using emotional faces have found that older adults' ability to process negative emotional stimuli declines (Mok et al., 2019; Sava et al., 2017; Svärd et al., 2014). This suggests that positivity effects in working memory manifest not only as older adults' advantage in encoding and processing positive emotional stimuli but also as a decline in their ability to process negative emotional stimuli. However, differences in emotional stimulus materials may also contribute to these findings. Therefore, future research should examine and clarify the influence of emotional materials to further elucidate the mechanisms underlying positivity effects in older adults' working memory.

3.2 Emotional Valence as a Task-Irrelevant Attribute

Due to the limited capacity of working memory, older adults' ability to inhibit irrelevant stimuli within working memory shows age-related decline (Gazzaley et al., 2005). Recent researchers have also proposed that interference control for distracting stimuli is a core feature of working memory (Oberauer et al., 2016). Previous studies using neutral stimulus materials have consistently found that older adults have difficulty inhibiting interference from distracting stimuli (Clapp & Gazzaley, 2012; Samrani et al., 2017). Currently, only a few behavioral studies have investigated the mechanisms through which task-irrelevant emotional stimuli affect older adults' working memory performance (Table 2).

Truong and Yang (2014) employed a delayed matching-to-sample task paradigm. During the encoding phase, four emotional words were presented sequentially and marked with red or blue to distinguish task-relevant from irrelevant stimuli. Participants were required to remember the emotional words marked as task-relevant and ignore those marked as irrelevant. During the subsequent retrieval phase, participants judged whether a probe word had been presented previously as a task-relevant stimulus. The results showed that in terms of reaction time, no significant age differences were found across different emotional valence conditions. In terms of accuracy, when the probe stimulus was a negative irrelevant stimulus, older adults correctly identified it as irrelevant significantly less often than younger adults. However, when probe stimuli were neutral or positive irrelevant stimuli, no significant age differences were observed. This indicates that only negative irrelevant stimuli reduced older adults' ability to store task-relevant information in working memory. In another study, participants were required to remember the location of emotional scene pictures. The results showed that both healthy older adults and Alzheimer' s disease patients had significantly lower accuracy than younger adults. Additionally, the study found that healthy older adults' accuracy for remembering the location of negative emotional pictures was significantly lower than for neutral pictures. In contrast, within-group analyses of younger adults and Alzheimer' s disease patients showed no significant differences in accuracy between negative emotional and neutral picture conditions, suggesting that healthy older adults have greater difficulty inhibiting interference from negative irrelevant information (Borg et al., 2011). Furthermore, a study used an emotional face 2-back task to investigate the impact of task-irrelevant emotional stimuli on older adults' working memory function. This task required participants to judge whether the emotional valence of a currently presented face matched that of the face presented two trials earlier. Target stimuli were faces presented in the current trial (n), while distracting stimuli were faces presented in the previous trial (n-1) and three trials earlier (n-3). The results showed that compared with neutral face distractors, when angry faces served as distractors, no significant difference in accuracy was found between older and younger adults. However, compared with younger adults, older adults' reaction times increased. No main effect of emotional valence was found within the younger adult group, suggesting that older adults are more susceptible to interference from negative distractors (Berger et al., 2018).

In summary, studies treating emotional valence as a task-irrelevant attribute support the interference effect of negative irrelevant stimuli, showing that the presence of negative irrelevant stimuli reduces older adults' working memory performance. Compared with storing a certain number of task-relevant stimuli within the working memory processing space, individuals' ability to inhibit interference from irrelevant stimuli is more susceptible to aging (Gazzaley et al., 2005; Hasher et al., 2008). The automatic salience of negative information is closely related to survival adaptation during evolution (Mather & Knight, 2006). When negative stimuli serve as task-irrelevant materials, older adults appear to have greater difficulty inhibiting interference from negative irrelevant stimuli. Notably, among the aforementioned studies, only Truong and Yang (2014) examined the interference effect of positive emotional materials as task-irrelevant stimuli on older adults' working memory. The mechanisms through which task-irrelevant emotional stimuli of different valences affect older adults' working memory remain to be further explored.

4 Neural Processing Mechanisms of Positivity Effects in Working Memory

Behavioral studies have found differences in working memory performance between older and younger adults when processing information of different emotional valences. Whether these behavioral age effects are accompanied by differences in brain functional activation patterns is key to exploring the underlying neural mechanisms of positivity effects in working memory. Research on positivity effects in working memory has primarily focused on the behavioral level. To date, only three retrieved studies have used functional magnetic resonance imaging (fMRI) technology to investigate the neural mechanisms of positivity effects in older adults' working memory.

4.1 Empirical Research Evidence

Researchers at the University of Queensland, including Ziaei, adapted a visual delay recognition task. During the encoding phase, three pairs of pictures were presented sequentially. Participants were required to remember only one picture from each pair while ignoring the other. After a 4-second interval, a picture was presented as a probe stimulus, and participants judged whether the picture had appeared during the encoding phase. This paradigm was used to reveal the neural mechanisms underlying the processing of emotional targets and distractors briefly stored in working memory (Ziaei et al., 2017; Ziaei et al., 2018). At the behavioral level, researchers found that when distractor stimuli were emotional pictures, older adults' working memory performance was worse than that of younger adults, indicating that older adults are more susceptible to interference from irrelevant emotional stimuli. Whole-brain activation analysis also showed that when emotional pictures served as distractors, activation levels in older adults' frontoparietal network, including the ventrolateral prefrontal cortex, bilateral parietal cortex, and anterior cingulate cortex, were lower than those in younger adults. Further analysis of emotional valence indicated that when target stimuli were negative pictures and distractor stimuli were positive pictures, older adults' accuracy was significantly lower than that of younger adults, and activation levels in older adults' left inferior frontal gyrus and dorsal anterior cingulate cortex were also lower than those in younger adults (Ziaei et al., 2018). The left inferior frontal gyrus is responsible for inhibiting interference from emotional distractors in working memory (Dolcos et al., 2006), and reduced activation in this region reflects older adults' difficulty in effectively inhibiting interference from positive distractors. The dorsal anterior cingulate cortex is responsible for monitoring conflicts in emotional information, evaluating the degree of conflict and the cognitive effort required (Barch et al., 2000; Kanske & Kotz, 2011). Reduced activation in this region reflects that older adults invest fewer cognitive resources to suppress conflicts from positive distractors, resulting in greater interference from positive distractors.

Oren et al. (2017) investigated the impact of negative distractors on older adults' working memory processing. Participants were required to judge whether numbers on negative or neutral scene pictures were identical while ignoring the emotional scene pictures as background. At the behavioral level, older adults' accuracy in both 1-back and 2-back conditions was lower than that of younger adults, but the main effect of emotional valence and its interaction with cognitive load and age were not significant. In terms of brain imaging, age difference analysis showed that under negative distractor conditions, younger adults' activation in the right amygdala was significantly higher than that of older adults. Further analysis revealed that the amygdala showed deactivation in older adults, suggesting that older adults have insufficient encoding of negative irrelevant stimuli. Within-group comparisons of brain activation levels across different emotional valence conditions in older adults found that activation levels in the middle frontal gyrus and parietal cortex were lower under negative distractor conditions than under neutral distractor conditions. Moreover, a significant positive correlation was found between reaction time and middle frontal gyrus activation under negative distractor conditions, with shorter reaction times associated with lower middle frontal gyrus activation. This suggests that reduced interference from negative distractors on older adults' working memory is related to lower activation levels in the middle frontal gyrus. The amygdala belongs to the ventral emotional system, responsible for monitoring the appearance of emotional stimuli and regulating other brain regions to enhance attention and memory for emotional stimuli (Mather, 2016). The middle frontal gyrus and parietal cortex belong to the dorsal executive system, participating in the executive control of emotion and responsible for encoding task requirements related to target processing (Feredoes et al., 2011; Niendam et al., 2012). Notably, the brain imaging results from this study indicated that negative distractors had less interference on older adults' working memory, whereas behavioral results found no interaction between emotional valence and age. This inconsistency between brain imaging and behavioral results suggests that changes in neural functional activity levels may more sensitively capture and reflect the internal mechanisms of emotional processing in older adults' working memory compared with explicit behavioral measures.

4.2 Summary

In summary, brain imaging studies have found age differences in activation levels of the dorsal anterior cingulate cortex, left inferior frontal gyrus, and amygdala when inhibiting irrelevant emotional information in working memory. Notably, Ziaei et al. (2018) found that positive irrelevant stimuli caused greater interference in older adults' working memory, with older adults showing lower activation in the inferior frontal gyrus than younger adults. In contrast, Oren et al. (2017) found that negative irrelevant stimuli caused less interference in older adults' working memory, with decreased activation in the middle frontal gyrus. These results partially support the existence of positivity effects in working memory and suggest that the inferior frontal gyrus and middle frontal gyrus may play key roles in processing task-irrelevant emotional information. A study using a Go/Nogo task requiring participants to respond to all letters except "X" found that patients with inferior frontal gyrus damage showed significantly higher false alarm rates when Nogo stimuli appeared compared with control groups, suggesting that the inferior frontal gyrus may be related to inhibitory processes (Swick et al., 2008). When completing inhibitory control tasks, older adults showed significantly lower activation in the inferior frontal gyrus than younger adults (Coxon et al., 2016; Tsvetanov et al., 2018). Additionally, an intervention study using a stop-signal task paradigm provided further evidence for the involvement of the inferior frontal gyrus in inhibitory control processes. In this training, participants were required to judge the gender of emotional faces and stop responding to the current face when an auditory inhibition cue appeared. In the post-training test phase, no auditory inhibition cue was presented. The results showed that when faces from the stop trials in the training phase were presented in the test phase, participants' activation in the inferior frontal gyrus increased significantly (Lenartowicz et al., 2011). Furthermore, compared with conditions presenting only task-relevant stimuli, activation in the middle frontal gyrus increased significantly when both task-relevant and irrelevant stimuli were presented simultaneously. Activation in the middle frontal gyrus was significantly positively correlated with individual working memory capacity, suggesting that the middle frontal gyrus participates in the process of screening task-relevant information (McNab & Klingberg, 2008). Therefore, both the inferior frontal gyrus and middle frontal gyrus are involved in inhibiting irrelevant information in working memory, and their roles in inhibiting emotionally irrelevant stimuli warrant further investigation.

5.1 Socioemotional Selectivity Theory

Socioemotional Selectivity Theory explains age effects in the interaction between emotion and cognition from the perspective of time perception. Specifically, older adults allocate their limited cognitive resources to process emotional information, particularly positive information, to enhance and maintain their positive emotional experiences (Giasson et al., 2019; Reed & Carstensen, 2012; Sims et al., 2015). Therefore, the positivity effect is a "by-product" of older adults' pursuit of emotional goals (Carstensen & DeLiema, 2018). Socioemotional Selectivity Theory can explain positivity effects in attention and memory and aligns with research findings where emotional valence serves as a task-relevant attribute in working memory. That is, positive emotional information facilitates older adults' working memory performance, and older adults show processing advantages for positive information (Bermudez & Souza, 2017; Mikels et al., 2005; Sava et al., 2017).

5.2 Dynamic Integration Theory

Unlike the "active" perspective of Socioemotional Selectivity Theory, Dynamic Integration Theory attempts to explain the positivity effect from a "passive" perspective of functional decline (Labouvie-Vief et al., 2010). This theory suggests that older adults' automatic processing of positive information is a strategy to compensate for cognitive resource decline. Older adults with more cognitive resources, similar to younger adults, show a processing bias toward negative stimuli—that is, they pay more attention to and process negative information —whereas older adults with cognitive resource decline exhibit positivity effects. However, Sava et al. (2017) found that compared with age differences in sad face conditions, there were no significant differences in working memory performance between healthy older adults and younger adults in happy face conditions. In contrast, Alzheimer' s disease patients showed significantly lower accuracy than younger adults in both sad and happy face conditions, suggesting that older adults with more cognitive resources are more likely to exhibit positivity effects. Furthermore, according to Dynamic Integration Theory, older adults should be more susceptible to interference from positive irrelevant stimuli in tasks requiring inhibition of irrelevant emotional information. However, empirical research has shown that negative irrelevant stimuli cause greater interference with older adults' working memory performance (Berger et al., 2018; Truong & Yang, 2014). In summary, Dynamic Integration Theory acknowledges the reality of older adults' limited cognitive resources, but its predictions are inconsistent with existing research findings and lack empirical support.

5.3 Dual Competition Model

The Dual Competition Model explains the interaction between emotion and working memory from the perspective of the relationship between emotional information and task relevance (Pessoa, 2008; 2009). Specifically, this theory posits that whether emotion affects cognitive control depends on whether the processing of emotional stimuli occupies cognitive resources. In cases where emotional information serves as task-relevant or task-irrelevant stimuli, different patterns of cognitive resource allocation produce different effects on target tasks: task-relevant emotional information promotes target task performance by occupying more cognitive resources, whereas task-irrelevant emotional information impairs task performance by diverting cognitive resources needed for the target task (Pessoa, 2017). Existing research has found that when positive emotional materials serve as task-relevant stimuli in working memory, they facilitate older adults' working memory performance (Bermudez & Souza, 2017), but when they serve as irrelevant stimuli, they interfere with older adults' working memory performance (Ziaei et al., 2018). Therefore, researchers have introduced the Dual Competition Model to explain how task relevance influences positivity effects in older adults' working memory. However, current research findings are not entirely consistent with the Dual Competition Model. For instance, if only task relevance is considered, one might predict that positive and negative stimuli would have similar effects on older adults' working memory performance. However, research results show that older adults' memory for task-relevant positive stimuli is better than that of younger adults (Mikels et al., 2005), whereas their memory for task-relevant negative stimuli is worse than that of younger adults (Sava et al., 2017). This suggests that emotional valence and task relevance interact and must be considered simultaneously.

5.4 Summary

In summary, attention to and discussion of positivity effects in working memory have enriched the connotation of Socioemotional Selectivity Theory. The finding that the task relevance of emotional materials produces different effects on positivity effects in working memory supports the Dual Competition Model, suggesting that both emotional valence and task relevance are key factors influencing positivity effects in working memory. Notably, current research on positivity effects in working memory has not thoroughly examined the mechanisms through which emotional valence as a task-irrelevant attribute influences older adults' working memory performance. Research investigating how positive distractors affect older adults' working memory processing mechanisms is particularly lacking. When positive emotional valence serves as a target stimulus attribute, it preferentially captures older adults' attention. Based on this, researchers have speculated that when emotional valence serves as a task-irrelevant attribute, older adults may be more easily distracted by positive irrelevant stimuli rather than negative irrelevant stimuli (Reed & Carstensen, 2012), which aligns with Ziaei et al.' s (2018) findings. However, multiple studies have found that compared with neutral stimuli, older adults are more susceptible to interference from negative irrelevant stimuli (Berger et al., 2018; Oren et al., 2017; Truong & Yang, 2014), suggesting that besides the relevance of emotional valence, other moderating variables may influence whether and to what extent positivity effects emerge in working memory. Ziaei et al. (2018) found that when emotional irrelevant stimuli were presented during the working memory encoding phase, older adults experienced greater interference from positive distractors. In contrast, Truong and Yang (2014) found that when emotional irrelevant stimuli were presented during the maintenance phase, older adults experienced greater interference from negative distractors. This suggests that the time window in which emotional stimuli appear may be another important factor influencing older adults' working memory performance.

6 Summary and Future Directions

This paper reviewed research examining positivity effects in working memory from the perspective of the interaction between emotional valence and task relevance. The review found that when emotional valence serves as a task-relevant attribute, both comparisons of age differences across different age groups under the same emotional valence and comparisons of differences among participants within the same age group across different emotional valence conditions support the existence of positivity effects in working memory. Specifically, these effects manifest as enhanced memory for positive emotional stimuli and reduced memory for negative emotional stimuli in older adults' working memory. Research examining emotional valence as a task-irrelevant attribute is relatively scarce, with inconsistent findings. Most studies have found that older adults are more susceptible to interference from negative irrelevant stimuli, while individual studies have found that positive irrelevant stimuli cause greater interference in older adults' working memory. Investigating the interaction between emotional valence and task relevance in research on positivity effects in working memory has advanced our understanding of the mechanisms underlying emotional information processing in working memory and enriched and expanded the research topic of positivity effects. Notably, research on positivity effects in working memory is still in its infancy, and the internal processing mechanisms of positivity effects in older adults' working memory require further exploration.

First, do emotional processing characteristics differ across various processing stages of older adults' working memory? In experiments where emotional valence serves as a task-relevant attribute, researchers have not yet thoroughly examined the specific manifestations of positivity effects during the encoding, maintenance, or retrieval stages of working memory. In studies where emotional valence serves as a task-irrelevant attribute, two studies have examined emotional processing characteristics during the encoding and maintenance stages of older adults' working memory, revealing contrasting patterns. Specifically, when emotional irrelevant stimuli were presented during the encoding phase, older adults experienced greater interference from positive distractors (Ziaei et al., 2018), whereas when emotional irrelevant stimuli were presented during the maintenance phase, older adults experienced greater interference from negative distractors (Truong & Yang, 2014). This suggests that besides emotional valence and task relevance, the specific characteristics of internal processing during different stages of working memory may also be important factors influencing positivity effects. Studies using neutral materials have found that regardless of whether irrelevant stimuli were presented during the encoding or maintenance phase, older adults' working memory performance was significantly lower than that of younger adults. However, the age difference in working memory performance was greater when irrelevant stimuli were presented during the maintenance phase than during the encoding phase, indicating that with increasing age, individuals are more susceptible to interference from irrelevant stimuli presented during the working memory maintenance phase (McNab et al., 2015). Notably, a study using event-related potentials (ERPs) technology examined the time course characteristics of positivity effects in attention and found that positivity effects in attention only occurred during late processing windows. Compared with the negativity bias shown by younger adults, the main effect of emotional valence was not significant within the older adult group (Yu et al., 2015), suggesting that time course is a key factor influencing positivity effects in attentional processes. Research with younger adults has found that under 2-back conditions, the mean amplitude of the P3 component evoked by negative distractors did not differ significantly from that evoked by neutral distractors. However, under 0-back conditions, the mean amplitude of the P3 component evoked by negative distractors was significantly smaller than that evoked by neutral distractors (Zhang et al., 2016), suggesting that negative distractors may affect attentional processing more than working memory. Future research could leverage the high temporal resolution of ERPs technology to more precisely quantify and evaluate the differential effects of task-relevant or task-irrelevant emotional stimuli on brain activity during the encoding, maintenance, and retrieval stages of working memory. This would further examine the characteristics of emotional processing at different stages of older adults' working memory and deepen our understanding of the internal mechanisms underlying positivity effects in older adults' working memory.

Second, how do emotional materials influence the mechanisms underlying positivity effects in older adults' working memory? Debates persist regarding the mechanisms of positivity effects, specifically whether they stem from older adults' increased attention to positive information or reduced attention to negative information (Addis et al., 2010; Kalenzaga et al., 2016; Scheibe & Carstensen, 2010). Existing research has found that when task-relevant stimuli in working memory tasks are emotional scene pictures and emotional words, older adults show enhanced memory for positive stimuli (Bermudez & Souza, 2017; Majerus & D' Argembeau, 2011; Mammarella et al., 2013). However, when task-relevant stimuli are emotional faces, positivity effects manifest as older adults' reduced memory for negative stimuli (Mok et al., 2019; Sava et al., 2017; Svärd et al., 2014). These results can be interpreted in two ways. On one hand, positivity effects in working memory reflect both older adults' advantage in processing positive information and their avoidance of or reduced ability to process negative information. On the other hand, these findings also suggest that different emotional materials may influence the encoding and retrieval processes of emotional information representations. In research on the interaction between emotion and cognition, emotional scene pictures, emotional faces, and emotional words are commonly used stimulus materials. Researchers believe that the internal encoding processes differ across these emotional materials. Unlike the rapid processing of emotional pictures and faces, emotional words are abstract symbols with more complex and refined encoding processes. Participants need to re-represent words, a process influenced by multiple factors including individual motivation, purpose, and cultural background (Schacht & Sommer, 2009; Yuan et al., 2019). Additionally, because emotional scene pictures contain rich contextual information, their emotional meaning is relatively clear. In contrast, the processing of emotional faces is more susceptible to environmental factors, and individuals' processing of emotional faces varies depending on the scene in which the face appears (Walla & Panksepp, 2013). Belham et al. (2017) conducted two experiments using a visuospatial working memory paradigm with emotional scene pictures and emotional faces as experimental materials. The study found that when distractors were emotional faces, both older and younger adults showed a positivity bias. However, when distractors were emotional scene pictures, no emotional bias was observed, suggesting that emotional bias in working memory is influenced by stimulus material type. However, few studies have directly examined the impact of differences in emotional materials on older adults' working memory performance. Future research could consider using the same experimental paradigm to investigate older adults' working memory processing characteristics under conditions of emotional scene pictures, faces, and words separately. This would explore how differences in emotional stimulus materials influence positivity effects and help resolve debates regarding the mechanisms underlying positivity effects.

Third, what are the neural mechanisms through which the task relevance of emotional valence influences positivity effects in working memory? Currently, only three brain imaging studies have examined age differences in the neural mechanisms underlying emotional stimulus processing in working memory. These studies suggest that older adults' ability to process emotional stimuli may be related to functional changes in the dorsal executive system (including the middle frontal gyrus, parietal cortex, etc.) and the ventral emotional system (including the left inferior frontal gyrus, amygdala, etc.) with age. Both the middle frontal gyrus in the dorsal executive system and the inferior frontal gyrus in the ventral emotional system are closely related to the process of inhibiting emotionally irrelevant stimuli. Specifically, under negative irrelevant stimulus conditions, older adults' activation in the middle frontal gyrus was lower than under neutral irrelevant stimulus conditions (Oren et al., 2017). Under positive irrelevant stimulus conditions, older adults' activation in the left inferior frontal gyrus was lower than that of younger adults (Ziaei et al., 2018). Previous research with younger adults has examined functional differences between the middle frontal gyrus and inferior frontal gyrus in inhibiting emotionally irrelevant stimuli. Using a delayed matching-to-sample task requiring participants to ignore distracting emotional or neutral stimuli presented during the maintenance phase, researchers found that the middle frontal gyrus is involved in encoding and maintaining task-relevant stimuli, whereas the inferior frontal gyrus is involved in inhibiting representations of distracting emotional stimuli during the maintenance phase (Dolcos & McCarthy, 2006). Iordan and Dolcos (2017) further explored the role of emotional valence and found that the inferior frontal gyrus is involved in inhibiting interference from positive distractors. Since research on the neural mechanisms of positivity effects in older adults' working memory is still in its infancy, how the functions of the inferior frontal gyrus and middle frontal gyrus change with age during emotional stimulus processing requires further investigation. On the other hand, previous research has found enhanced functional connectivity between the inferior frontal gyrus and amygdala under emotional irrelevant stimulus conditions compared with neutral irrelevant stimulus conditions. The amygdala is an important node in the ventral emotional system, responsible for monitoring emotional stimuli and transmitting signals to the inferior frontal gyrus for information integration (Iordan et al., 2013). This result suggests that the process of inhibiting irrelevant emotional stimuli may involve coordinated activity between the inferior frontal gyrus and amygdala. Whether this coordinated activity pattern changes with age is a question worth exploring. Future research needs to further reveal the neural mechanisms through which older adults process task-relevant and task-irrelevant emotional information, providing brain functional-level evidence for the mechanisms through which emotional valence and task relevance influence positivity effects in working memory, and further clarifying the internal neural mechanisms underlying positivity effects in working memory.

Finally, despite the presence of positivity effects, older adults' working memory capacity still shows an overall age-related decline. How to improve older adults' working memory function is a hot research topic in cognitive psychology and cognitive neuroscience. Future research could consider using emotional information as experimental stimuli based on the characteristics of positivity effects in older adults' working memory and further examine its intervention effects. Working memory training using neutral materials has provided important evidence for behavioral and neural plasticity in older adulthood (Rhodes & Katz, 2017; Vermeij et al., 2017; Huo et al., 2018), although most studies have found that such improvements are limited to the training task or near-transfer tasks (Guye & von Bastian, 2017; Teixeira-Santos et al., 2019; Zinke et al., 2012). Given that older adults' ability to process emotional information is relatively preserved, whether emotional working memory training can better improve and promote older adults' cognitive functions compared with non-emotional neutral materials warrants further discussion. Studies with younger adults have found that emotional working memory training can improve performance on emotional Stroop tasks (Schweizer et al., 2011) and enhance emotion regulation ability (Schweizer et al., 2013). Beyond healthy populations, Iacoviello et al. (2014) found that emotional working memory training can significantly reduce depressive symptoms in patients with major depressive disorder, with trained patients also showing reduced processing bias toward negative stimuli. This suggests the potential application value of emotional working memory training in improving negative emotional experiences. Therefore, future research could consider applying emotional working memory training to older adult populations, examining its value and effectiveness in improving cognitive function and emotional experience, and optimizing existing cognitive training protocols and measurement indicators to effectively promote and achieve healthy and positive aging.

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Table 1 Studies with Emotional Valence as a Task-Relevant Attribute in Working Memory

Study	Age (Young vs. Old)	Sample Size (Young vs. Old)	Task Type	Material Type	Valence	Within-Group Results (Accuracy)	Between-Group Results (Accuracy)
Bermudez & Souza, 2017	26.17 vs. 70.96	24 vs. 24	Delayed matching-to-sample	Pictures	Positive/Neutral/Negative	YA: Positive=Neutral=Negative OA: Positive, Neutral > Negative; Positive=Neutral	Positive/Neutral/Negative: OA<YA
Hartley et al., 2015 Study1	19.45 vs. 72.93	31 vs. 31	Delayed matching-to-sample	Faces	Happy/Sad/Angry/Fearful/Surprised/Disgusted	-	Happy: OA=YA; Sad/Angry/Fearful/Surprised/Disgusted: OA<YA
Hartley et al., 2015 Study3	20.38 vs. 75.41	24 vs. 24	Delayed matching-to-sample	Faces	Emotional/Non-emotional	-	Emotional, Non-emotional: OA=YA

Study	Age (Young vs. Old)	Sample Size (Young vs. Old)	Task Type	Material Type	Valence	Within-Group Results (Accuracy)	Between-Group Results (Accuracy)
Majerus & D' Argembeau, 2011 Study2	24~30 vs. 60~84	15 vs. 15	Delayed matching-to-sample	Words	Positive/Neutral/Negative	YA/OA: Positive>Negative, Neutral; Negative=Neutral	Positive/Neutral/Negative: OA<YA
Majerus & D' Argembeau, 2011 Study3	24~30 vs. 60~84	15 vs. 15	Delayed matching-to-sample	Words	Positive/Neutral/Negative	YA: Positive>Neutral; Negative>Neutral OA: Positive>Neutral; Negative=Neutral	-
Mammarella et al., 2013	24.97 vs. 64.70	35 vs. 37	Operation span task	Words	Positive/Neutral/Negative	YA: Negative>Positive, Neutral; OA: Negative>Positive, Neutral; Positive>Neutral	-
Mikels et al., 2005	22.35 vs. 72.50	20 vs. 20	Affective maintenance task	Pictures	Positive/Negative	Positive=Negative	Positive: OA=YA; Negative: OA=YA
Mok et al., 2019	23.42 vs. 69.25	54 vs. 51	Short-term memory task	Faces	Happy/Fearful	OA, YA: Happy>Fearful	Happy, Fearful: OA<YA

Study	Age (Young vs. Old)	Sample Size (Young vs. Old)	Task Type	Material Type	Valence	Within-Group Results (Accuracy)	Between-Group Results (Accuracy)
Sava et al., 2017 Study1	19.84 vs. 74.33 vs. 78.82 (AD)	21 vs. 25 vs. 17 (AD)	Delayed matching-to-sample	Faces	Happy/Neutral/Sad	YA: Happy=Neutral=Sad OA: Happy>Neutral, Sad; Neutral=Sad AD: Happy>Neutral, Sad; Neutral=Sad	Happy: OA, AD<YA; OA=AD Neutral, Sad: OA, AD<YA; OA=AD
Sava et al., 2017 Study2	22.4 vs. 80.81 vs. 84.22 (AD)	21 vs. 21 vs. 18 (AD)	Delayed matching-to-sample	Faces	Happy/Neutral/Angry	YA: Happy=Neutral=Angry OA: Happy, Neutral>Angry; Neutral=Angry AD: Happy>Neutral, Angry; Neutral=Angry	Happy: AD<YA; OA=YA Neutral, Angry: OA, AD<YA; OA=AD
Svärd et al., 2014	25.20 vs. 70.50	40 vs. 35	Short-term memory task	Faces	Happy/Angry	OA, YA: Happy>Angry	Happy, Angry: OA<YA

Note: YA = Younger adults; OA = Older adults; AD = Alzheimer' s disease patients; - = Not reported in results

Table 2 Studies with Emotional Valence as a Task-Irrelevant Attribute in Working Memory

Study	Age (Young vs. Old)	Sample Size (Young vs. Old)	Task Type	Material Type	Valence	Task Requirements	Within-Group Results (Accuracy)	Between-Group Results (Accuracy)
Belham et al., 2017 Study1	21.38 vs. 71.10	56 vs. 39	Delayed recognition task	Pictures	Positive/Neutral/Negative	Remember spatial location of stimuli; ignore emotional valence	YA: Positive=Neutral=Negative OA: Positive=Neutral=Negative	Positive/Neutral/Negative: OA<YA
Belham et al., 2017 Study2	21.31 vs. 69.92	26 vs. 25	Delayed recognition task	Faces	Happy/Neutral/Angry	Remember spatial location of stimuli; ignore emotional valence	YA: Angry>Happy; Happy=Neutral; Angry=Neutral OA: Angry>Happy; Happy=Neutral; Angry=Neutral	Happy/Neutral/Angry: OA<YA

Study	Age (Young vs. Old)	Sample Size (Young vs. Old)	Task Type	Material Type	Valence	Task Requirements	Within-Group Results (Accuracy)	Between-Group Results (Accuracy)
Berger et al., 2018	25.03 vs. 68.60	31 vs. 31	2-back task	Faces	Neutral/Angry	Compare emotional valence of current stimulus with stimulus from two trials back; ignore n-1 and n-3 stimuli	YA: Angry=Neutral OA: Angry=Neutral	Angry, Neutral: OA<YA
Borg et al., 2011	27.07 vs. 78.35 vs. 80.92 (AD)	14 vs. 14 vs. 14 (AD)	Short-term memory task	Pictures	Neutral/Negative	Remember spatial location of stimuli; ignore emotional valence	YA: Negative=Neutral OA: Negative<Neutral AD: Negative=Neutral	Negative: OA, AD<YA; OA=AD Neutral: OA, AD<YA; OA=AD

Study	Age (Young vs. Old)	Sample Size (Young vs. Old)	Task Type	Material Type	Valence	Task Requirements	Within-Group Results (Accuracy)	Between-Group Results (Accuracy)
Hartley et al., 2015 Study2	20.38 vs. 75.41	24 vs. 24	Delayed matching-to-sample	Faces	Emotional	Remember facial identity; ignore emotional valence	-	Emotional: OA<YA
Hartley et al., 2015 Study3	20.38 vs. 75.41	24 vs. 24	Delayed matching-to-sample	Faces	Emotional/Non-emotional	Remember facial identity; ignore emotional valence	-	Emotional/Non-emotional: OA<YA
Truong & Yang, 2014	19.69 vs. 73.25	36 vs. 36	Delayed matching-to-sample	Words	Positive/Neutral/Negative	Remember designated emotional target stimuli; ignore designated emotional distractor stimuli	YA: Positive=Neutral=Negative; OA: Negative<Positive, Neutral; Positive=Neutral	Positive, Neutral: OA=YA; Negative: OA<YA

Note: YA = Younger adults; OA = Older adults; AD = Alzheimer' s disease patients; - = Not reported in results

Note: Figure translations are in progress. See original paper for figures.

Source: ChinaXiv —Machine translation. Verify with original.